The Effect of Fluorescent Light Flicker and Lamp Type on the Health, Productivity and Satisfaction of Data Entry Personnel: An Interventional Study

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Abstract

Fluorescent lighting has been highlighted as a significant factor in eyestrain, headache, lethargy and other asthenopic (eye related) complaints by office personnel. These three symptoms rate amongst the most highly reported complaints attributed to the office environment.

An interventional study was conducted in three data entry offices to assess the effect of fluorescent light flicker and modulation depth on the incidence and severity of common workplace symptoms, productivity and satisfaction with the work environment.

Each of the three offices had three lighting regimes installed for a four week period in a crossover design with an initial four week baseline period. The three lighting treatments were selected to represent commonly available lighting conditions and included triphosphor fluorescent tubes with high frequency electronic ballasts and low frequency magnetic ballasts and halophosphate fluorescent tubes with low frequency magnetic ballasts.

The study provided evidence to suggest that eyestrain and lethargy symptoms were considered to be more severe in the low frequency halophosphate lighting treatment. There was also a higher incidence of lethargy symptoms in the low frequency halophosphate lighting treatment. In addition, significant relationships were present between perceived decreased productivity (due to the work environment) and increased symptom severity in the low frequency halophosphate lighting treatment. The low frequency and high frequency triphosphor lighting treatments did not differ significantly. No significant relationships were shown between actual or perceived productivity and lighting treatments.

There was no evidence to suggest that participants were able to perceive flicker from any of the lighting treatment installations on a consistent basis. When participants perceived flicker it was not considered to be disturbing or annoying.

The actual productivity of participants was related to eyestrain and lethargy symptoms in one of the offices studied. The effect size was small to medium, explaining between 2-5% of the variability of the data. Actual productivity was not related to any other measures. Office personnel perceived that their productivity (due to the work environment) and work satisfaction was strongly affected by the eyestrain, headache and lethargy symptoms experienced.

These results did not show that flicker frequency or modulation depth affected the severity of eyestrain, lethargy and headache symptoms, the satisfaction of the occupants or their perceived or actual productivity. These findings support previous research that has suggested that differences in task performance may be limited to difficult visual tasks with minimal cognitive or motor components. Further, these results suggest that the effect of low frequency flicker on asthenopic symptoms may also be small and easily overwhelmed by other workplace factors. The breadth of this study was ambitious and featured limitations (such as small sample sizes) that may have impacted on the results found in some analyses. This study may not have been sensitive enough to detect small differences in the health, productivity and satisfaction of office personnel due to fluorescent light flicker.

The pattern of responses examined alongside research in this field suggested that differences in the spectral distribution of the tubes may be a culpable factor. A small colour component in the work task and an equally small luminance difference between lighting treatments may have contributed to this finding. However, given that there is limited support for this outcome in the literature, and the previous findings in research examining fluorescent light flicker, these results should be considered as exploratory.

Taken together, the research findings present a compelling argument for additional field research. This study provides a foundation that will enable future studies to further quantify the relationships between health, productivity and qualitative aspects of lighting in the work environment.

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Introduction

The internal office environment can have a significant effect upon the health, productivity and satisfaction of office personnel. Numerous research studies have shown that aspects of the indoor environment including indoor air quality, lighting, acoustics and thermal conditions can influence how people feel and behave in the work environment.

Lighting is one factor that many office personnel feel is a significant contributor to health symptoms in the workplace. Since the development of fluorescent lighting, people working under its illumination have complained about eyestrain, headache, eye fatigue, and other asthenopic complaints that they attribute to the light source. The flicker from fluorescent tubes has been identified as one of the culpable factors by subjective comments from subjects working under such lighting.

This interventional field study examined lighting related health symptoms, productivity and satisfaction of office personnel exposed to three lighting treatments with differing flicker frequency and luminous variation (modulation depth) in their work environment.

The study extended previous reported research studies by measuring objective task performance, physical sensations (eyestrain, headache and lethargy) and perception of the workplace under actual office environment conditions. The relationship between these variables is not well understood in the field of building health and there are limited studies in the lighting arena that have attempted to understand the relationship between these factors. In addition to monitoring the lighting conditions within the subject buildings, other environmental factors that may have contributed to the symptoms, productivity or satisfaction of the office personnel were monitored, and these were examined to determine their contribution to participants' responses.

A medical examination of approximately one third of the staff in each of the three offices was undertaken at the conclusion of the study to isolate factors that may have predisposed the office personnel to lighting related symptoms. The extent to which non-

work related factors contributed to symptoms experienced during the work shift was also explored.

The lighting technologies utilised in the study also have implications for energy usage in buildings. Lighting is a major consumer of energy in commercial buildings, contributing to up to 30% of the energy consumption of the building. The electronic ballasts and triphosphor fluorescent tubes utilised in this study are energy efficient in comparison to conventional magnetic ballasts and halophosphate fluorescent tubes, presenting up to a 25% saving in energy consumption. Thus the study also had the potential to support the promotion of energy efficient and environmentally friendly lighting solutions for modern office buildings.

The thesis is set out as follows: the specific aims and hypotheses are stated, followed by a review of the literature (Chapter One). The experimental methodology is then outlined in Chapter Two, followed by the results and discussion pertaining to these specific sections in Chapter Three. Two further chapters outline the environmental monitoring that was undertaken in the host offices and a medical study that was undertaken at the conclusion of the main study. The general discussion and final conclusions describe the primary findings of the study in relation to the research aims and hypotheses and previous research in this field. Study limitations and alternative explanations for the findings are outlined. The contribution that this study makes to the literature and directions for future research is discussed. A glossary is then included followed by the appendices. Finally, the references used in the thesis and a selected bibliography concludes this body of work.

Specific Aims

1. To determine whether it is possible to reduce the incidence and severity of eyestrain, headaches and lethargy experienced by office personnel by altering the flicker frequency and modulation depth of commercially available fluorescent lighting.

2. To determine whether differing flicker frequency or modulation depth influence the actual productivity of office personnel, the perceived effect of the work environment on their productivity, or their satisfaction with the work environment.

3. To examine the relationship between symptoms experienced in the workplace, actual productivity, the perceived effect of the work environment on productivity and satisfaction with the work environment.

4. To examine the role of personal characteristics, external and environmental factors in relation to symptoms experienced by office personnel.

5. To determine whether or not energy efficient lighting technologies affect the health of office personnel.

Research Hypotheses

1. That increased flicker frequency and reduced modulation depth of fluorescent lighting will decrease the incidence and severity of eyestrain, headache and lethargy symptoms reported by office personnel; will increase perceived and actual productivity; and will increase satisfaction with the work environment.

2. That symptom incidence and severity is related to perceived and actual productivity and satisfaction with the work environment.

3. That physiological characteristics such as visual aberrations, migraine and high blood pressure influence the incidence and severity of lighting related symptoms.

1 Background

Introduction

Since the first development of incandescent lighting, 'artificial' light sources have provided us with the ability to control the lighting in our environment without reliance on the sun. Fluorescent lighting is the lamp of choice for office buildings because of its good colour properties, long life and low energy consumption. The development of fluorescent lamps, luminaires and control gear has undergone continuous improvement, with many technological advances, and in a modern high quality office, fluorescent lighting provides good visual conditions for a range of office work.

Despite this, fluorescent lighting is not a popular light source, and occupants frequently attribute health symptoms that they experience in the workplace to fluorescent lighting. Research continues on a number of avenues to better understand the role of lighting in health, performance and satisfaction with the work environment.

The flicker from fluorescent lamps has been highlighted as a contributing factor to dislike of the lighting and health symptoms experienced by office personnel (Brundrett, 1974; Veitch & McColl, 1995). This review outlines studies of symptoms that are experienced in office buildings that can be attributed to the work environment. It describes symptoms that are attributed to lighting, and our current understanding of the effect of lighting on health, performance and satisfaction with the work environment. Fluorescent light flicker is defined in relation to lamps and control gear. Physiological responses and health symptoms attributed to flicker are also discussed. The state of research in this field is outlined and future research directions are recommended.

The Relationship between Buildings and the Health of Occupants

The internal office environment has been shown to have a significant effect upon the health of office personnel (Hall et al., 1991). It is common for occupants to attribute a wide range of symptoms that they experience in the workplace to aspects of the work environment. When these symptoms typically reduce or disappear after the occupant

has left the building, or when they are not experienced on days away from work, they may be attributed to work related factors (World Health Organisation, 1984).

If symptoms can be attributed to a causal factor in the workplace then the problem is classified as building related illness (BRI). Building related illness is typically identified by a unique set of symptoms that have been confirmed by clinical signs or laboratory findings and is generally limited to air borne contaminants or pollutants such as Legionnaires Disease or formaldehyde.

Sick Building Syndrome (SBS) describes health symptoms that are experienced in the work environment; improving or disappearing outside of work hours and for which no one specific causal factor can be identified. A building in which a high proportion of occupants (more than 30%) experience typical SBS symptoms can be described as a sick building (World Health Organisation, 1984). A wide range of symptoms have been characterised as SBS symptoms. Sensory irritation of eyes, nose and throat, and symptoms affecting the central nervous system, including headache, lethargy and fatigue, are common to all, with skin symptoms also commonly attributed (Wilson et al., 1987; Godish, 1994).

Environmental conditions in office spaces may contribute to the health of occupants and their satisfaction with the office environment. Factors that have been shown to contribute to Sick Building Syndrome include:

- Indoor air quality – inadequate fresh air, poor circulation, contaminants from building materials, microbials, exterior air;
- Thermal conditions – temperature, humidity and air circulation;
- Lighting – glare, flicker, inadequate illumination, poor distribution;
- Acoustics – vibration, noise;
- Electromagnetic fields.

Studies examining the prevalence of health symptoms in buildings, typically limit symptoms that are due to external factors by excluding symptoms that do not disappear or reduce outside of work hours, or that are not better on days away from

work (Skov et al., 1989). In addition, studies have validated symptoms experienced in the workplace by medical examination (Franck, 1986; Burge et al., 1990; Kjaergaard, 1992; Unger, 1992; Kjaergaard et al., 1993).

A variety of personal characteristics have been shown to contribute to SBS prevalence rates. These include age, gender, atopic history, job stress, job satisfaction and satisfaction with the work environment (Hedge, 1988; Skov et al., 1989; Hedge, 1990; Godish, 1994).

Symptoms experienced in the workplace may not be severe and when experienced infrequently do not necessarily constitute a major health concern, however they are not without further consequence. The physical work environment has a significant impact upon the behaviour and attitudes of employees and thus plays an important role in the satisfaction and commitment of staff and turnover rates (Carlopia & Gardner, 1992). Employee's who are uncomfortable in their workplace, are likely to have lower productivity, reduced job satisfaction, and may choose to leave their place of employment on this basis.

The Relationship between Buildings and Productivity

A number of studies have shown that occupants feel that the work environment affects their productivity in the workplace[1]. In an office survey of 4373 workers in 46 UK office buildings, Raw et al. (1990) found that 44% of respondents' felt that environmental work conditions negatively affected their productivity by 10-20%. Hall et al. (1991) reported that 51.4% of office workers felt that building related symptoms reduced their productivity sometimes, often or always. Of these, 35% reported that symptoms caused them to leave work or stay at home, sometimes or often.

Although workers have stated that the work environment impacted on their productivity, quantitative or actual differences in productivity due to environmental conditions or health symptoms have proven difficult to measure. Zyla-Wisensale &

[1] Perceived productivity.

Stolwijk (1990) reported that while productivity per person did not fluctuate to a great extent over a six month period, that daily output varied considerably in their study of 228 data entry operators. Lorsch & Abdou (1994) in their review of studies on productivity found that while some researchers doubt the validity of measured productivity, others claim a change of between 2.8-9.5% in productivity due to changes in the work environment. They concluded that a work environment that decreased worker complaints, and reduced absenteeism must indirectly affect the overall performance of the organisation. However, Goldman (1994) suggested that detriments in performance due to worker conditions are inconsistent, difficult to measure, and may be the result of other factors such as employee dissatisfaction.

The primary difficulty in measuring productivity in the work environment, is that office workers are typically expected to complete multiple tasks, many of which cannot easily be measured. In laboratory research, task performance can be clearly defined with clear increments of difficulty and arranged so that productivity can be determined. In addition, laboratory research is able to focus on individual variables and minimise the effects of others to decrease the variability of the results. In field research, this is not usually possible.

Therefore, much of this research has taken place in laboratories and has clearly demonstrated the effect that environmental conditions can have on performance. A substantial body of this research has examined the effect of lighting on visual and task performance (see Section 1.1: Lighting in the Workplace).

1.1 Lighting in the Workplace

Lighting plays an essential role in the ability of the occupants to carry out their work task. Lighting installations must provide conditions that enable the work environment and work task to be clearly visible and maximise task performance without impediment. In addition, lighting is required to fulfil a number of additional and less easily quantified goals. These requirements are not solely based upon the ability of the person to complete the work task, but also on the ability of the lit environment to

provide an appropriate work atmosphere including mood, atmosphere, visual comfort, aesthetic judgement and social communication (Veitch & Newsham, 1998).

There is broad agreement amongst the lighting community that illuminance, luminance, luminance distribution and uniformity, glare control, flicker rate and spectral power distribution are the important dimensions of the luminous environment (Veitch, 2000).

This review initially addresses our overall understanding of the role of lighting in the workplace, specifically examining the effect of lighting on health, satisfaction and productivity[2]. It then examines the role of fluorescent lighting flicker in detail.

Fluorescent Lighting and the Sick Building Syndrome

Fluorescent lighting has been suggested as a culpable factor in the Sick Building Syndrome (Boyce, 1981; Hedge, 1991; Raw, 1992). SBS symptoms that have been associated with lighting include eyestrain, headache, lethargy, and other asthenopic complaints (Wilkins et al., 1989; Lindner and Kropf, 1993). These three symptoms rate amongst the most highly reported SBS symptoms. In a British Harris poll, eyestrain topped the list of health complaints among office personnel (Hedge, 1991). The same paper reported that in a survey of 3,155 personnel, Hedge found complaints of tired eyes were the most common workplace related symptom affecting almost two thirds of all personnel. Wilson et al. (1987) found that three of the five most commonly reported SBS symptoms were lethargy (57%), eye irritation (46%), and headache (43%). In addition, visual discomfort has been associated with migraine attacks, gastrointestinal problems and aches and pains associated with poor posture (Rea, 2000).

Office workers also attribute symptoms to fluorescent lighting, and many prefer daylight or lighting systems that emulate daylight. Robertson et al. (1989) assessed subjective opinions about the lighting in two office buildings, and found that over

[2] Appendix K reviews quantitative (illuminance, luminance and glare) and qualitative (CRI, CCT, scotopic/photopic ratios, full spectrum lighting) aspects of lighting in further detail.

40% of the office workers strongly disliked the fluorescent lighting, and overall found the lighting to be less comfortable than daylight. Lindner & Kropf (1993) found that on average subjects perceived that 40% to 60% of headache and lethargy complaints were attributed to the lighting in their review of studies on asthenopic symptoms. However in their study of 3030 employees (cited in the same paper), only 5.8% of employees attributed their asthenopic complaints to the fluorescent lighting, these mostly aged between 20 and 30, with the majority of older age groups experiencing general vision complaints. Brundrett (1974) found that over 20% of subjects attributed eyestrain and headaches to the lighting, but that overall the subjects were satisfied with the lighting. Heerwagen (1990) also observed that office workers were satisfied with the lighting, but noted that subjects preferred daylight for visual and general health.

Aspects of lighting that have been associated with visual discomfort (dissatisfaction with the lighting and effects on health) include inadequate illuminance, uneven luminance distribution, flicker, glare and veiling reflections (Rea, 2000).

Fluorescent Lighting and Productivity (visual and task performance)

The vast majority of research examining lighting and productivity has been laboratory research that has evaluated visual or task performance. Very few studies have examined the effects of lighting on productivity directly. Of these, the one study that has attracted renown worldwide is the Hawthorne study, in which it was found that regardless of whether illuminance levels were increased or decreased, occupants' productivity increased with each intervention (Urwick & Brech, 1965). This research underpins the importance of ensuring adequate statistical design, but unfortunately contributes little to our understanding of the effects of lighting on performance.

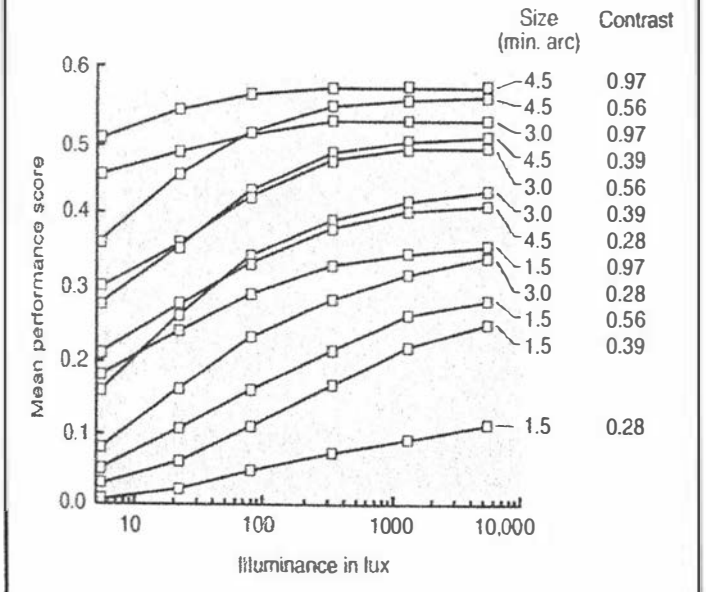
Adequate task visibility is the primary visual requirement in the work environment and thus is a primary determinant in the effect of lighting on task performance and productivity. Historically, this aspect of lighting has been the main focus in legislative requirements and has received extensive research attention in order to establish the conditions under which task visibility is maximised.

The visibility of objects is determined by a number of factors, the most critical being luminance, illuminance, contrast and size. Colour differences in the visual targets may also be important in task visibility and enable targets to be distinguished regardless of luminance differences (Rea, 2000).

The relationship between illuminance, task contrast and size is well understood. Increases in illuminance have been shown to increase visual performance, and can partially compensate for small size and low contrast. Higher illuminance is required as task complexity or difficulty is increased.

The visual performance model initially developed by Weston (1945)[3], quantifies the relationship between illuminance, luminance contrast and visual size on suprathreshold visual performance (Figure 1).

Figure 1. Mean performance scores for Weston's Landolt ring charts of different visual size and luminance contrast, plotted against illuminance (Rea, 2000)



[3] Cited from Rea (2000).

This model has been extensively reviewed, and other models that have been developed show similar trends (Smith & Rea, 1979; Rea & Ouellette, 1988; Clear & Berman, 1990; Bailey, Clear & Berman, 1993)[4]. These models show that visual performance follows a plateau and escarpment form, in which for a wide range of visual tasks above threshold levels, visual performance changes little with changes in visual conditions.

Research has shown that the relative visual performance (RVP) model developed by Rea & Oullette (1991)[5], concurs with a data entry task performance (DETP) model developed by Eklund et al. (2000), quantifying the relationship between illuminance, luminance contrast and visual size for achromatic tasks with negligible non visual components.

These models are important in defining the relationship between these key variables, but have limited ability to predict task performance in the work environment where tasks typically have significant non-visual components. In addition, these models are developed under laboratory conditions with short-term tests, using highly motivated participants under 'good' lighting conditions, which may differ considerably from the work environment.

This is illustrated by Smith & Rea (1987) who found that handwriting quality and illuminance level was more influential than cheque visibility in a cheque verification performance task. Eyestrain or postural changes can create visual and muscular fatigue, which can also be detrimental to visual or task performance (Rea et al., 1985). Inappropriate lighting conditions, including glare and flicker have been shown to affect fatigue, visual discomfort and visual performance (Boyce & Rea, 2001). Dissatisfaction with environmental conditions can lead to decreased motivation and subsequently productivity.

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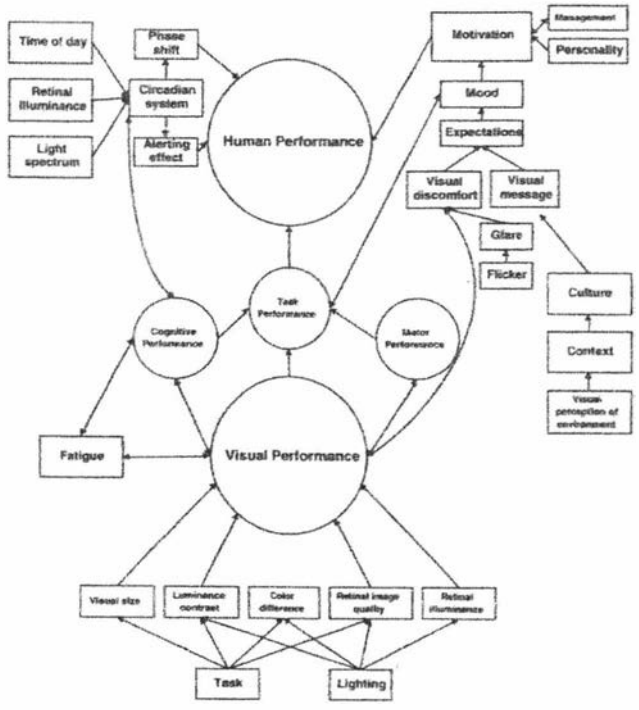
[4] Cited from Boyce (1996).

[5] Cited from Eklund et al. (2000).

Boyce (1996) examined the role of visual performance models and illuminance selection and concluded that while visual performance models were useful in ensuring that lighting conditions met the visual requirements for a particular task, many other factors were also important. In particular, while visual performance could be maintained in a wide range of operating conditions, these visual conditions may not be comfortable and hence may not be acceptable to users. '*Only lighting that does not limit visual performance, does not cause visual discomfort, and meets peoples' expectations will be acceptable to users*' (Boyce, 1996).

The three routes via which lighting can affect human performance include visibility, circadian photobiology and the psychological 'message' delivered by the lighting Boyce & Rea, (2001). These are encapsulated in a conceptual framework that illustrates the complexity of the relationships between these factors (Figure 2).

Figure 2. A conceptual framework setting out the three routes whereby lighting conditions can influence human performance. The arrows in the diagram indicate the direction of effect (Boyce & Rea, 2001).



While a detailed review of this document is outside of the scope of this document, Table 1 & Table 2 outline the current state of research since the previous review (Boyce et al., 1989) and indicate areas in which more research is necessary to optimise productivity and enhance the health and well-being of office personnel.

Table 1. Lighting and human performance matrix – direct effects (Boyce & Rea, 2001)

1989 Category	Progress since 1989
Visual performance	Two quantitative models of visual performance have been developed. One has been independently validated. These models cover different sizes and luminance contrasts of the target and different illuminances. They do not consider colour difference or blur.
Task performance	Quantitative models predicting the effect of lighting on the performance of specific tasks have been developed but no general model exists.
Colour vision	For achromatic, near-threshold tasks, scotopically-enriched light spectra reduce pupil size and improve task performance. What happens for realistic suprathreshold tasks remains to be determined. No progress has been made in quantifying the effect of lighting on the performance of chromatic tasks.
Visual search	No progress.
Age and individual differences	Guidelines for lighting based on known changes in ocular physiology with age have been developed and shown to lead to better performance of tasks of everyday living.
Fatigue	Prolonged work in inappropriate lighting conditions can cause fatigue. The effect this has on task performance depends on the nature of the task and the freedom the worker has to modify how the task is done.

Table 2. Lighting and human performance matrix – indirect effects (Boyce & Rea, 2001).

1989 Category	**Progress since 1989**
Discomfort	Lighting conditions that cause discomfort and alter the stimulus the task presents to the visual system will change visual performance. Lighting conditions that simply cause discomfort without affecting the stimulus presented by the task, may or may not affect task performance.
Light as an attention stimulus	Lighting can be used to attract attention, but no progress has been made on quantifying the conditions necessary.
Light and arousal	Light exposure can increase arousal, particularly at night, when exposure to light suppresses the hormone melatonin.
Light and	Lighting can influence mood, but so can many other factors. Changes in mood have

mood	been shown to affect task performance.
Lighting's influence on behaviour	Lighting can influence behaviour, either directly by attracting attention or providing necessary visual conditions, or by sending a message as to what is the appropriate behaviour.
Lighting and (hormone) biology	Understanding of the circadian photobiology system has grown greatly but much remains to be determined, such as the spectral sensitivity of the system. Exposure to light at night can have a short-term arousing effect and a longer-term phase-shifting effect. To ensure a phase-shifting effect, control of light exposure over 24 hours is necessary. Exposure to light at night can influence performance of some tasks, but why some tasks are sensitive and others are not remains to be determined.

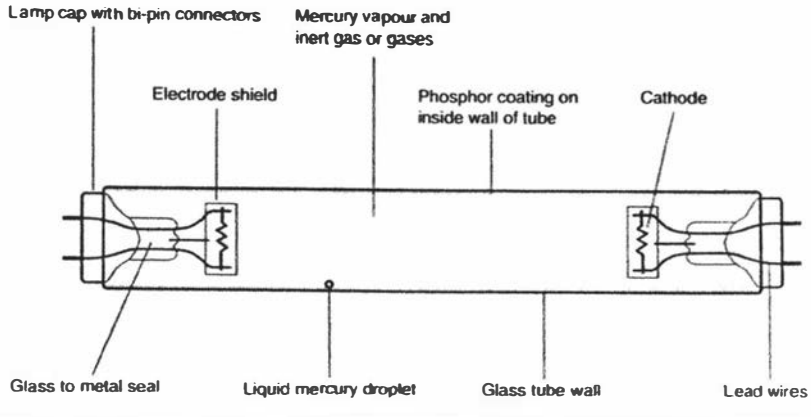
1.2 The Role of Lighting Flicker in the Health, Satisfaction and Productivity of Occupants

All electric lights experience luminous variation under normal operation. These include all or some of the following four mechanisms:

Flicker frequency (lamp discharge frequency);
Modulation (luminous variation);
Uneven firing of the electrodes at either end of the lamp;
Chromatic modulation (chromatic variation).

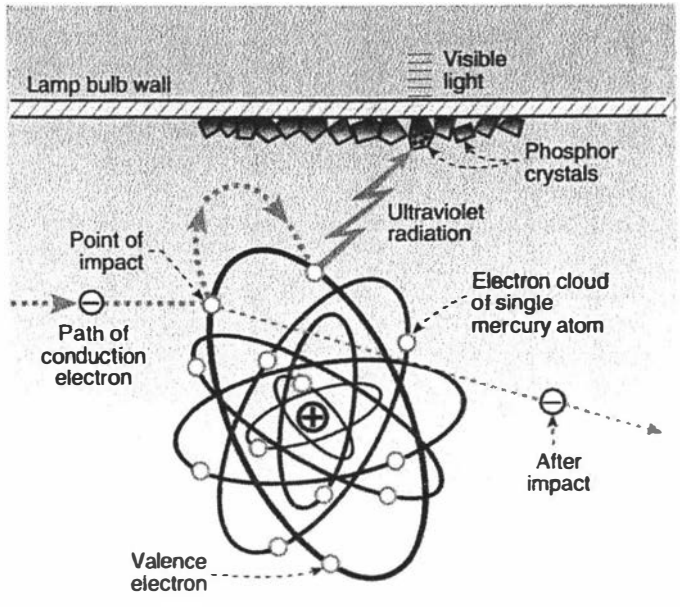
Filament lamps (incandescent filament and tungsten halogen) generate visible light via incandescence of the lamp filament by heating action. Filament lamps experience luminous variation (change in light output) due to changes in current supply.

Figure 3. Construction of a fluorescent lamp (Coaton & Marsden, 1997).



Discharge lamps include low-pressure sources (fluorescent lamps and low pressure sodium) and high-pressure sources (metal halide, high pressure sodium and mercury lamps). In these lamps an electrical discharge is created between the electrodes within the lamp (Figure 3). In fluorescent and some other discharge lamps, phosphors lining the inside of the fluorescent lamps convert the ultraviolet radiation emitted by the lamp discharge into visible light, with the blend of phosphors determining the spectral emission of the lamp (Figure 4). Other discharge lamps emit light in the visible spectrum without the need for phosphors. In addition, the half-life of the phosphors lining the lamp determines the colour of the light emitted between each discharge (chromatic modulation).

Figure 4. Magnified cross section of a fluorescent lamp, schematically showing progressive steps in the luminescent process, which finally result in the release of visible radiation (Rea, 2000).



Flicker Frequency

The frequency at which discharge lamps operate is regulated by the power supply to the lamp or by ballast operation. In discharge lamps with magnetic or wire wound ballast's (low frequency operation), the lamps discharge is synchronous with the power supply, and at twice the frequency. In most European countries, Australia and

New Zealand, the power is supplied at a frequency of 50 Hz. In North America, it is 60 Hz. Thus, the lamp flickers at a frequency of either 100 or 120 Hz (cycles per second). This flicker is imperceptible to the majority of office personnel, but the eye and visual system respond to the flicker (Berman et al. 1991).

When an electronic ballast (high frequency operation) controls the lamp, the discharge frequency is increased to between 20 kHz – 100 kHz[6]. The eye and visual system do not respond to this flicker (Eysel & Burandt, 1984).

Modulation (luminous variation)

The light emitted from both filament and discharge lamps undergoes luminous variation or modulation. The modulation or modulation depth of the luminance can be described by the following equation:

$$C = \frac{(L_{max} - L_{min})}{(L_{max} + L_{min})}$$

Where

C = modulation depth

L_{max} = maximum luminance (cd/m^2)

L_{min} = minimum luminance (cd/m^2)

In filament lamps, the modulation is due to changes in the current supply, resulting in a modulation depth of between 2 and 22% (Andersonn et al., 1994). In discharge lamps the amount of modulation is dependent upon the selection of phosphors utilised in the lamps. Lamps without a phosphor lining have modulation depths of between 83-100%, whereas in lamps with phosphor linings the modulation varies between 19-98% dependent upon the phosphors selected (Figure 5). The variation in modulation is dependent upon the persistence of the phosphors, which have a limited half-life, resulting in changes in the light emitted from the lamp between each discharge.

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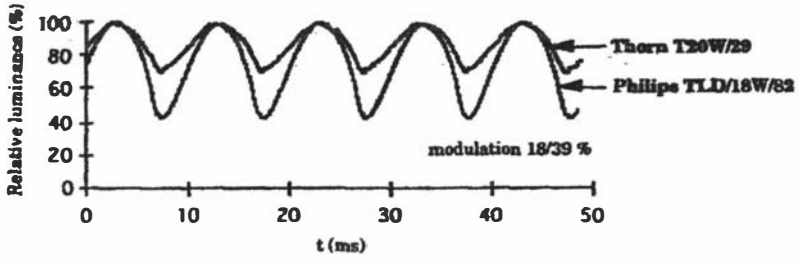
[6] Lamps controlled by electronic ballast's still may have a small (residual) 100 or 120 Hz component (Wilkins & Clark, 1990).

Fluorescent lamps utilise a range of differing phosphors from either the halophosphate or triphosphor families. The phosphor selection is dependent upon the colour properties, life and efficacy requirements for the lamp. Halophosphate lamps typically are lined with a blend of several phosphors each emitting in broad bands across the visible spectrum (Figure 6).

Figure 5. Time-dependent relative luminance from a single colour fluorescent lamp (ThornT20W/29) with a modulation of 18% and relative luminance from a full-colour fluorescent lamp (Philips TLD/18W/82) with a modulation of 39% (Andersonn et al. 1994).



Triphosphor fluorescent lamps are lined with three narrow band, rare earth phosphors with short, middle and long emission peaks that correspond to the spectral sensitivity of the short, middle and long wavelength cones in the eye (Figure 7 & Figure 8). These phosphors result in lamps with much higher efficacies, but are more expensive. Therefore triphosphor lamps may have a thin halophosphate coating allowing a reduction in the amount of rare earth phosphors used.

Figure 6. Spectral distribution of a halophosphate fluorescent lamp (Rea, 2000).

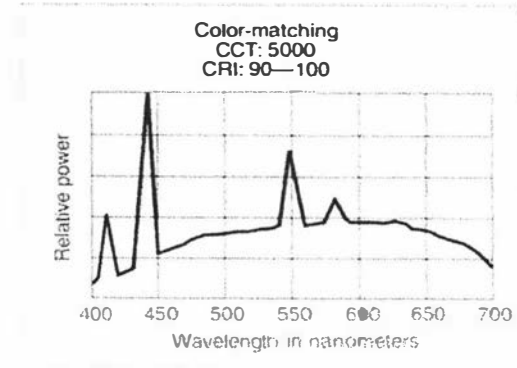
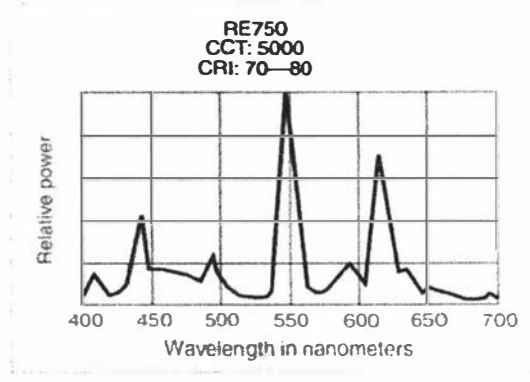
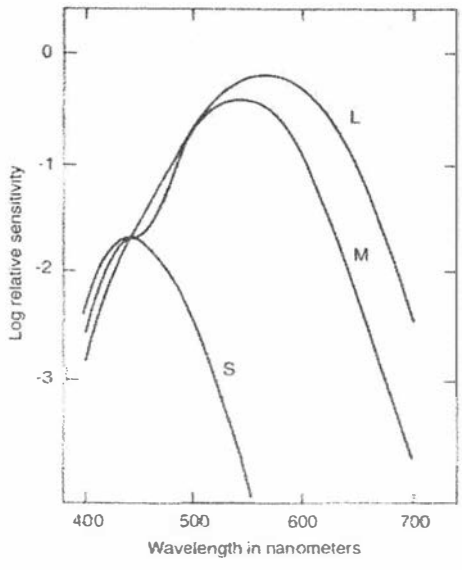


Figure 7. Spectral distribution of a triphosphor fluorescent lamp (Rea, 2000).



Wilkins & Clark (1990) measured the modulation depth of four lamp varieties including: halophosphate, triphosphor, multiband deluxe[7] lamps and a selection of lamps with high colour rendering indices[8]. Table 3 and Figure 9 compare these four lamp types in terms of their modulation depth, colour rendering and efficacy (Wilkins & Clark, 1990; Andersonn et al., 1994).

Figure 8. The relative spectral sensitivity curves of the three cone photoreceptors: long (L), middle (M) and short (S) (Rea, 2000).



The greater the modulation depth, the more perceptible the flicker, thus lamps utilising long persistence phosphors have smaller modulation depths and less visible flicker than that of lamps with short persistent phosphors which have a greater modulation depth (Collins & Hopkinson, 1954; Lindner & Kropf, 1993).

Chromatic Modulation (chromatic variation)

Each phosphor has an associated colour, and differences in emission result in changes in the colour of light emitted over time. This is shown in Figure 9. This chromatic shift may also influence flicker perceptibility. Green (1969) found that blue cones were significantly less sensitive to flickering light, in comparison to red or green

[7] Multiband deluxe lamps are lined with a blend of triphosphor and halophosphate phosphors.

[8] High CRI lamps can be lined with halophosphate phosphors only, or a blend of triphosphor and halophosphates. In Figure 9, the lamps contain halophosphate phosphors only.

cones. However, when blue flicker was combined with red and green flicker it was as perceptible as other colours, and the blue cone response was as fast as other cones when measured through the luminance pathways (Stockman et al., 1993). This is an area in which research is continuing to attempt to gain a better understanding of visual response to flicker through the magnocellular and parvocellular mechanisms.

Table 3. Modulation depths for fluorescent lamps and control gear (Andersonn et al., 1994).

Fluorescent Lamp Description	**Control Gear**	**Colour Rendering Index (CRI)**	**Modulation Depth (%)**
Halophosphate	Low Frequency ballast (50 Hz)	50-80	19-22
Triphosphor	Low Frequency ballast (50 Hz)	85	38-39
Polyphosphor[9]	Low Frequency ballast (50 Hz)	90-100	30-42
Triphosphor	High Frequency electronic ballast	85	0.9

Uneven firing of the electrodes at either end of discharge lamps

In new discharge lamps, the anode and cathode of the lamp fire simultaneously. However as the lamp ages, differential decay can cause uneven firing between the electrodes to occur, resulting in a 50 or 60 Hz flicker that is visible across the length of the fluorescent lamp. A planned lamp replacement programme can alleviate this flicker. Manufacturing defects may also cause uneven firing of the lamp electrodes. This flicker is visible to a large proportion of the population, and is likely to be the flicker source that occupants are dissatisfied with in the majority of cases (Collins & Hopkinson, 1954).

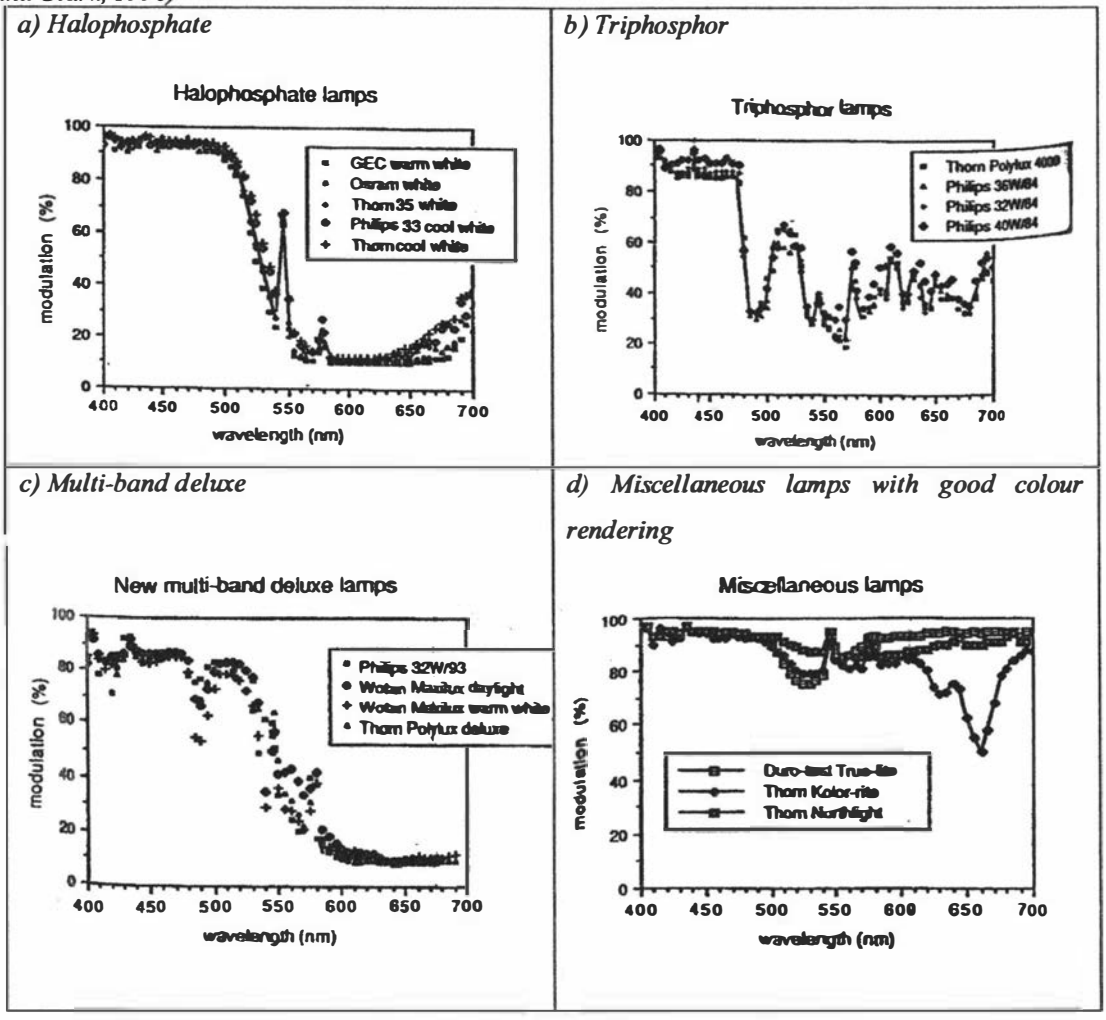
Perception of fluorescent lamp flicker

The eye is able to perceive variation in luminance over a wide range of visual conditions, with the perceptibility of temporal changes (flicker) dependent upon a number of factors, including the sensitivity of the visual system, the properties of the flicker and the field of view (Collins & Hopkinson, 1954; Lindner and Kropf, 1993).

[9] As per Multiband deluxe.

The physical properties of the fluorescent light source that have been shown to affect the perception of flicker include: luminance (Figure 10), modulation, waveform, chromatic distribution, and the size and position of the light source view (Collins & Hopkinson, 1954; Berman et al., 1991; Seiple & Holopigian, 1996).

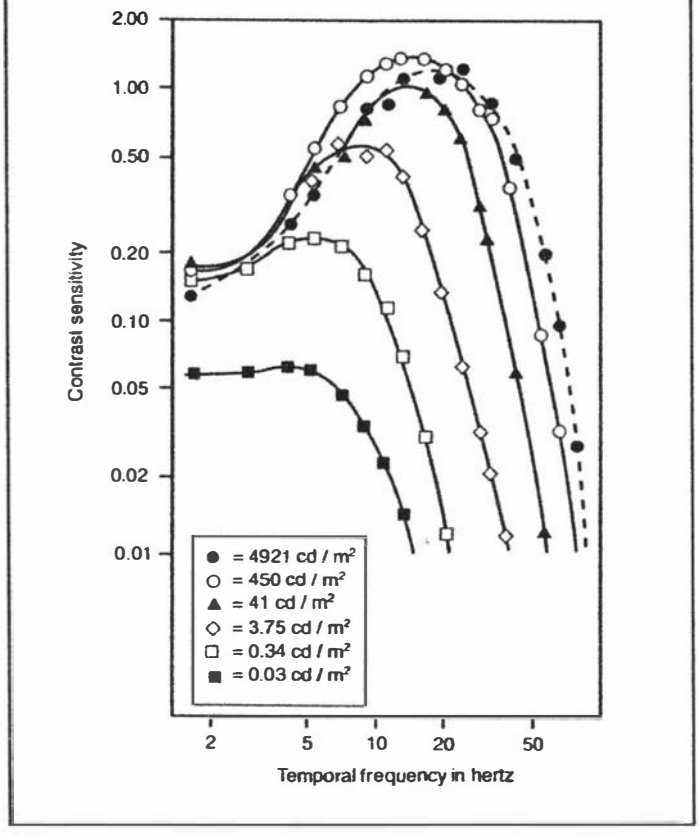
Figure 9. Modulation from differing lamp types as a function of wavelength: a) Halophosphate, b) Triphosphor, c) Multi-band deluxe and d) Miscellaneous lamps with good colour rendering (Wilkins and Clark, 1990)



The Critical Fusion Frequency (Critical Flicker Frequency) or CFF has been widely used to assess flicker perceptibility. The CFF is reached when the flicker is no longer perceptible as intermittent, and appears as a steady light. The CFF peaks at approximately 60 Hz with an upper limit of 80 Hz (Rea, 2000). However, the CFF may not be the best measure of the perceptibility of flicker, as background flicker can be seen at frequencies of over 100 Hz by some people (Collins & Hopkinson, 1954; Dakin et al., 1994).

The age, gender, pupil size, fatigue, and psychological state of the subject will also influence the perception of flicker and the Critical Fusion Frequency level, with females and those aged between 20 and 30 the most sensitive to modulating light sources (Collins & Hopkinson, 1954; Rey & Rey, 1963; Brundrett, 1974; Lindner & Kropf, 1993; Yim & Mayer, 1994).

Figure 10. Temporal modulation transfer (contrast sensitivity) function for different adaptation luminance's for a 68° field of view (Rea, 2000).



Collins & Hopkinson (1954) examined differences in the perceptibility of flicker when waveform (modulation depth, waveform regularity) and viewing conditions (illuminance levels, size of the field of illuminance) were varied. Participants were asked to rank the flicker sensation as: just perceptible; just obvious; just uncomfortable; and just intolerable; with mean frequencies of 70, 65, 61 and 56 hertz recorded for each category. The minimum and maximum frequencies at which flicker was 'just perceptible' were 56 and 120 Hz respectively. They observed that the larger the area of illumination, and the higher the luminance, the more readily the flicker was perceived. Greater modulation and waveform irregularity also increased the perception of flicker. The majority of the subjects were unable to see flicker under

normal office conditions. The study concluded that `well engineered installations' were unlikely to cause visible flicker, but commented that high luminance, irregular waveforms, high modulation and any 50 Hz component introduced may increase the visibility of the flicker to perceptible levels.

Dakin et al. (1994) assessed the visual sensitivity with which a target moving across a flickering background could be detected and compared this to the CFF of participants. Ninety six participants took part in the study, and of these, six participants previously complained of adverse reactions (asthenopic symptoms) under fluorescent lighting. The results showed that the CFF values varied from 40 to 100 Hz with a mean value of 66 Hz. However, background flickering effects were observed at more than 115 Hz for some participants. Those participants who had previously self-identified as sensitive to flicker had a higher average CFF of 91 Hz.

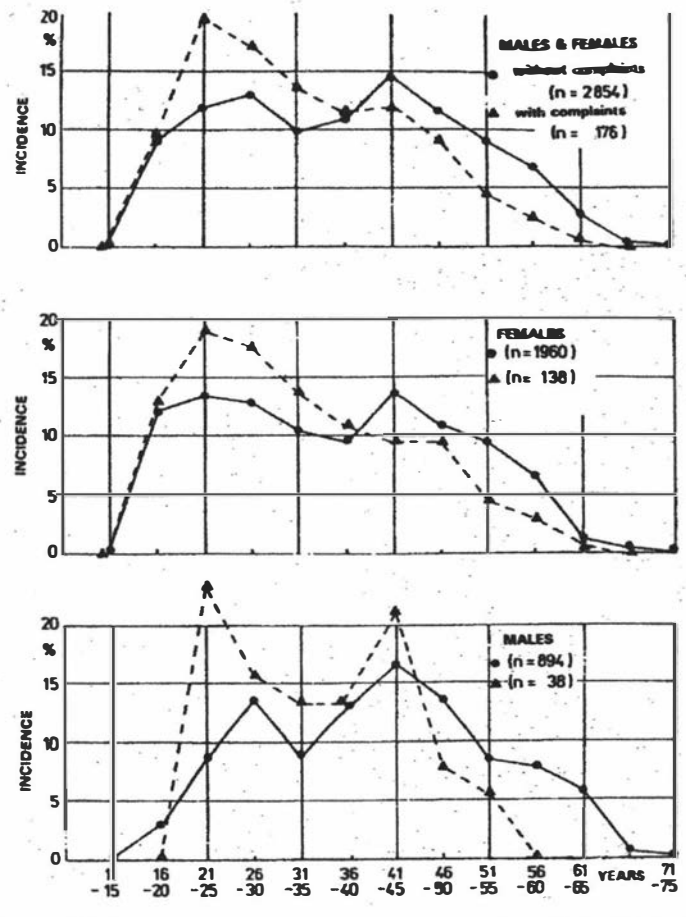
Taken together, these two studies suggest that although the CFF is typically below 100 Hz, some occupants will be able to perceive a 100 Hz flicker from the fluorescent lighting in office situations, and that these occupants are more likely to experience asthenopic symptoms. In addition, if a 50 Hz modulation is present, either due to malfunctioning lamps or poor maintenance, a significant portion of the occupants are likely to perceive the flicker.

It is the perception of flicker from fluorescent lamps in workplaces that has attracted the majority of complaints about fluorescent lighting. Brundrett (1974) noted that if subjects perceived flicker they were less satisfied with the lighting. He distributed a questionnaire to over 600 people working in modern offices in the UK, which asked for an appraisal of their satisfaction with office lighting. Flicker was perceived by 24% of all surveyed, with 10% still seeing flicker while looking at their work. Over 25% of the subjects attributed eyestrain to the lighting, with just under 20% and 5% respectively attributing headaches and fatigue to the lighting. There was a significant relationship between perception of flicker and headaches or eyestrain, and flicker perception was associated with unsatisfactory ratings of the lighting. The proportion of staff detecting flicker was age sensitive, with the proportion of participants detecting flicker in each age group declining rapidly when occupants were aged over 30 years.

This research study suggested that approximately one quarter of office workers were able to perceive flicker. This figure is much higher than the research literature suggests for perception of a 100 Hz flicker. It is probable that the majority of occupants saw a 50 Hz harmonic from aged or malfunctioning lamps.

The type of fluorescent lamps used in the offices, the maintenance regime, the size of the offices and a number of other factors previously discussed may also have been influential. These variables were not reported in the study.

Figure 11. Age distribution of subjects with and without complaints under FLI (Lindner & Kropf, 1993).



Taken together, research suggests that flicker will be perceived most frequently by women aged between 20 and 30 in open plan offices with high luminance levels (large field of view and lighting visible in peripheral vision) where the lighting system is not adequately maintained. Lindner & Kropf (1993) reported that the highest proportion of those who attributed asthenopic (vision related) complaints to

fluorescent lighting were females aged between 20 and 30 years (Figure 11). Research has shown a higher incidence of Sick Building Syndrome symptoms amongst females and those aged between 20 and 40 (Burge et al., 1987; Skov et al., 1989). This suggests that fluorescent light flicker may be a contributing factor to the Sick Building Syndrome.

Physiological Responses to Flicker

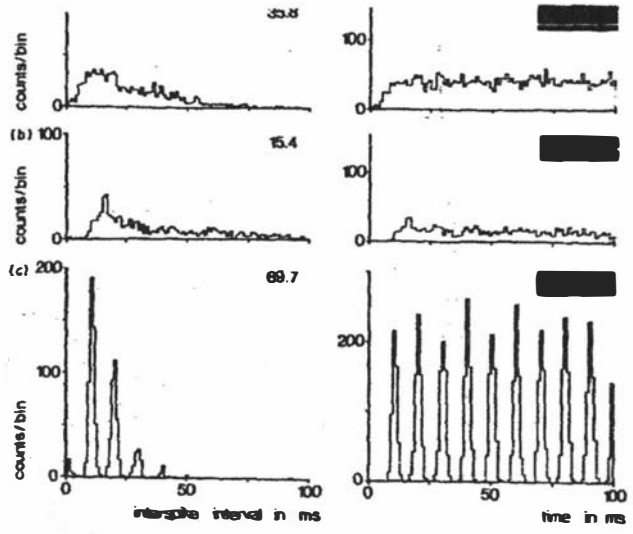
It has been shown that components of the visual system continue to respond synchronously to modulating light above the perceptual CFF. Kerlinger (1968) initially suggested that the visual system may process information that is not received by the cognitive process and this has been supported by subsequent research. Brundrett (1974) measured brain activity (EEG response) synchronous with the modulating light at frequencies of up to 70 Hz.

Eysel & Burandt (1984) showed that intermittent fluorescent light evoked a synchronous response in feline visual neurons at up to 120 Hz, (well above the cat CFF of 45 Hz). They observed that the nerve firing rate was significantly different under fluorescent light as compared to incandescent or daylight. The nerves fired at almost twice that of incandescent and natural light, and showed strong phase locking of responses to the luminous modulation (Figure 12).

Berman et al. (1991) measured the time-averaged electroretinogram (ERG) responses under VDT (Visual Display Terminal), fluorescent lighting and intense stimuli from a slide projector. ERG responses were obtained at 76 Hz, 145 Hz and 162 Hz for the VDT, fluorescent lighting and slide projector respectively. The modulation rate of the VDT was not given, but the fluorescent lamp and slide project modulation was 100%. The fluorescent lamp modulation was unusually high for commercially available fluorescent lamps.

Greenhouse et al. (1993) examined the relationship between VDT and fluorescent illumination to determine if a reduction in temporal contrast sensitivity occurred as a result of a low frequency beat or modulation between the two flickering sources. The study found no evidence to suggest that changes in contrast sensitivity occurred.

Figure 12. Interval distributions (interval histograms) and auto-correlation histograms of neurons responding to (a) daylight, (b) incandescent lamp light, and (c) fluorescent lamp light. (a) On-centre neuron stimulated with daylight of 150 cd/m², (b) On-centre neuron stimulated with incandescent lamps light (150 cd/m², m=0.14), and (c) same on-centre neuron responding to fluorescent lamp lighting of equal mean luminance (150 cd/m², m=0.53). Please note the different depth of modulation (m). The waveforms of 10 msec periods of the luminance time functions are shown with different amplifications for the different light sources as insets in the auto-correlograms (Eysel & Burandt, 1984).



Flickering light influences the accuracy of rapid eye movements (saccades) in visual tasks. West and Boyce (1968) examined eye saccades under a low frequency flicker (3 hertz). They found that the saccade rate increased significantly when the information regarding the position of the fixation target was intermittent. However, the saccades did not differ significantly between steady and intermittent flicker for a steady target. Wilkins (1986) detected significant differences in the visual response of the eyes to high frequency and low frequency lighting. Participants read a page of conventionally printed text under fluorescent lamps controlled by low frequency and high frequency control gear and were required to fixate upon one of two target letters. The treatments included two levels of illumination (not stated) and two pairs of targets closely and more widely separated. The saccades were slightly larger under low frequency lighting as opposed to high frequency lighting, and more small corrective saccades were registered. The result was significantly different for widely spaced targets, but for closely spaced targets the increase was not significantly different.

Illuminance differences were not significant. Similar results were found in an experiment in which participants read text on a CRT (Cathode Ray Tube) monitor with a frame frequency of 50 Hz and 100 Hz. Mourant et al. (1981) observed differences in eye saccades when viewing a stationary target under steady versus modulating light.

Kennedy & Murray (1991) furthered this research using two groups, one of experienced typists who reported high levels of asthenopic symptoms, the other students with no typing experience. The subjects carried out a reading task under three conditions of illumination (50 Hz, 100 Hz, and steady illumination). Both groups had less accurate saccades in the 50 Hz and 100 Hz conditions, than under steady illumination. The light was produced by rotating discs that created a 100% modulation (no persistence) as opposed to fluorescent lighting, which has a modulation of between 17% to 90%, thus the effects may have been more pronounced in this study. The authors suggested that the results explained flicker induced visual fatigue.

Fluorescent lighting has also been shown to increase anxiety, symptomatic responses, and physiological responses of those who suffer from Agoraphobia. Agoraphobics have been shown to experience heightened anxiety, higher levels of frontlet muscle activity, discomfort and accelerated heart rates in spaces lit by fluorescent lighting (Watts & Wilkins, 1989; Hazell & Wilkins, 1990). Hazell & Wilkins (1990) found that there was no significant difference in symptom response between high frequency and low frequency fluorescent lighting in the agoraphobic group, but the control group reported significantly more symptoms under the low frequency fluorescent lighting. Nine of the 24 agoraphobics could detect differences between the high and low frequency fluorescent lighting conditions.

Fluorescent Light Flicker effects on Health, Satisfaction, Mood and Performance

It is hypothesised that the previously discussed unconscious neurological and physiological mechanisms, are the source of asthenopic complaints reported by

subjects working under fluorescent lighting with low frequency control gear (Veitch & McColl, 1995).

Research by Lindner & Kropf (1993), suggests that those people who regularly experience asthenopic complaints are sensitive to light modulation. In a thorough optical examination of 10 'normal' subjects and 10 'complaint' subjects, the researchers noted that those people who suffered from asthenopia had a number of shared traits that included:

(i) Heterophobia (short sightedness);
(ii) Diminished stereoscopic vision (near sightedness);
(iii) Increased peripheral flicker sensitivity;
(iv) Elevated subjective light sensitivity;
(v) Longer optical response power;
(vi) Higher number of photic (sympathetic) driving neurons.

The above traits suggest an increased susceptibility to intermittent light. Wilkins (1979)[10], suggested that the binocular mechanism (heterophobia and diminished stereoscopic vision) is adversely affected by extensive flicker fields such as are found in typical open plan offices[11]. Flicker sensitivity has been found to increase with higher illuminance, and larger areas of illumination (Collins & Hopkinson, 1954), hence those people with increased peripheral flicker sensitivity are more likely to perceive flicker in open plan offices. Lindner & Kropf (1993) did not examine the history of lighting related health problems. These items were included in a study by Veitch & McColl (1995) that characterised the history of migraine, reading difficulty, anxiety, ocular pathology, eyestrain, headaches and epilepsy of each subject. No relationship was found between sensitivity to flicker and light related health problems. However the experimental tasks only lasted approximately 15 minutes. These items should be included in future epidemiological studies.

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[10] Cited from Lindner & Kropf (1993).

[11] In open plan offices the lighting may be connected over one to three phases. If all of the fluorescent lighting is on a single phase, then the flicker frequency is 100 or 120 hertz. Where the lighting is connected over two or three phases, the flicker frequency is correspondingly increased.

Research into the visual performance and visual comfort of office personnel and research subjects has indicated that changing the flicker frequency and modulation of fluorescent lighting may reduce the incidence of asthenopic complaints in commercial buildings and improve task performance.

An interventional field study conducted by Wilkins et al., (1989), showed that changing the fluorescent lamps from low frequency to high frequency halved the incidence of headaches and eyestrain. The study took place in a government legal office of 300 employees involved primarily in close visual work. The participants in the study (124[12]) were asked to fill out a weekly questionnaire for one year, in which they recorded the severity of their headaches and eyestrain on a daily basis using S=severe, M=mild and 0=none. The experiment was double crossover (Figure 13), with changes to the lighting taking place after eight months. A questionnaire submitted at the end of the time frame confirmed that the subjects were not aware of the changes to the office space. Existing luminaires were changed to one of three experimental variables.

1 - Magnetic ballast (50 Hz) with switch start - Low Frequency Operation

2 - Magnetic ballast (50 Hz) with electronic start - Low Frequency Operation

3 - Electronic ballast (32 kHz) - High Frequency Operation

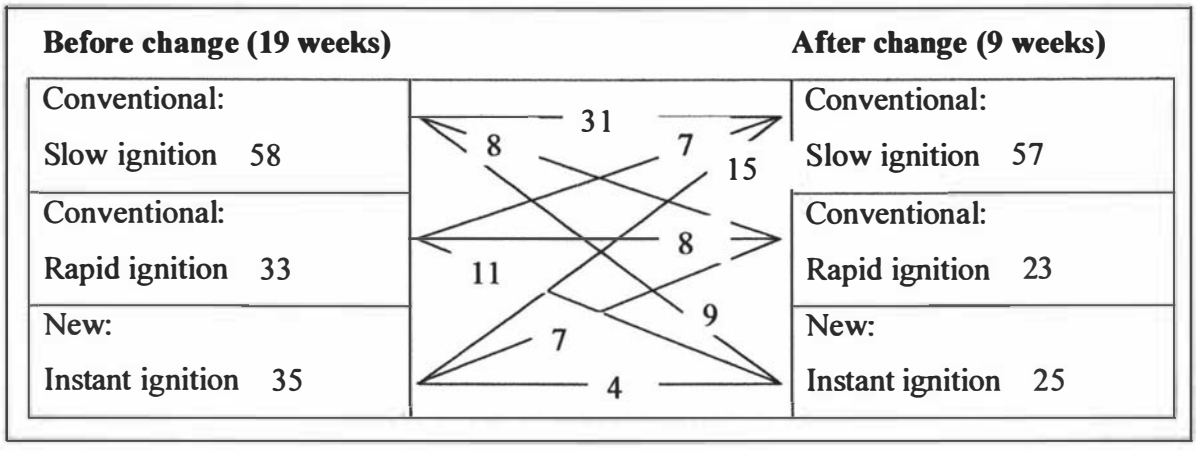
Condition 2 (electronic start), was included as a placebo with the only difference being the change in ignition time. The low frequency lighting had modulation rates of between 43% and 50%. The high frequency lighting had a modulation of less than 7%.

The analysis grouped severe and mild symptoms and included the 19 weeks before the changeover and the 9 weeks after the changeover. Data was available from forty two participants who were exposed to both the new (high frequency operation) and the conventional (low frequency operation) lighting. The mean weekly incidence of headaches varied between 0.23-0.51 for the conventional lighting (variables 1 and 2), and 0.06-0.31 in the electronic ballast condition. The mean weekly incidence of

[12] 178 participants initially agreed to complete the questionnaire with 45 participants (25%) lost during the study period.

eyestrain was 0.10-0.36 and 0.01-0.13 respectively for the conventional and electronic ballast conditions. Occupants left the high frequency lighting on for 30% longer on average.

Figure 13. Schematic representation of the design of the study, showing the number of subjects in each condition at each period, and the number who changed from one condition to another (Wilkins et al., 1989)



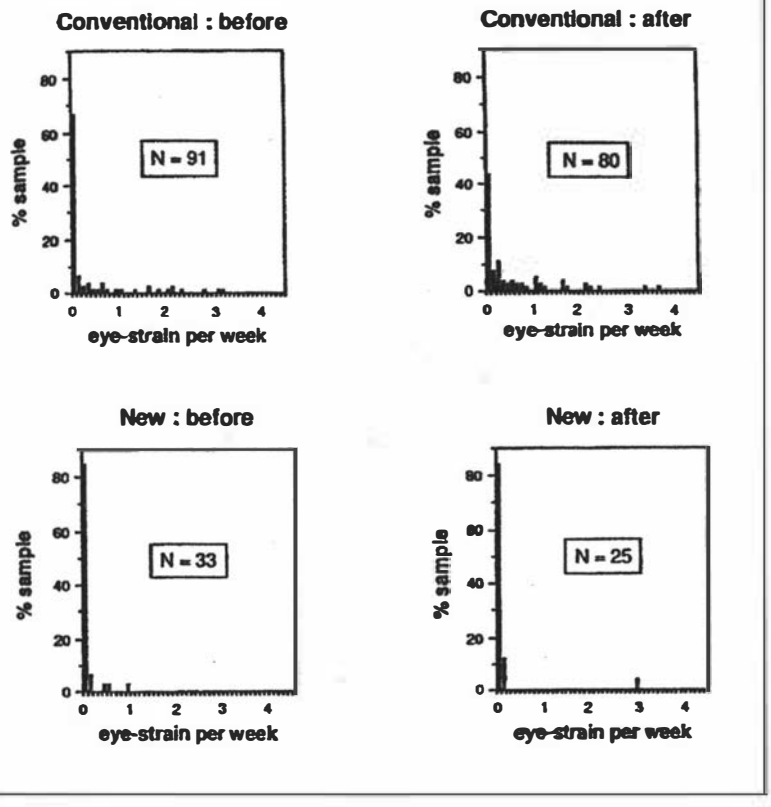
There was no relationship between the modulation of the existing lamps and symptom response. However as the existing lamp types (cool white and white), had a modulation of 43-47% and 49-50% respectively, this small difference in modulation would be most unlikely to find an effect. There was a 5% difference in illuminance between lighting treatments, as the high frequency ballast's had a lower light output in relation to the low frequency lighting treatment. There is no evidence in the literature to suggest that this small difference would influence symptoms.

The questionnaire responses indicated that many people reported few symptoms, with a few reporting many (Figure 14). Future research may benefit from questionnaire items that examine the history of lighting related health complaints to determine predisposing factors that may influence symptoms.

Rey & Rey (1963) found a significant difference in the visual performance and fatigue of five students under high frequency and low frequency fluorescent lighting. They compared the effects of the two lighting conditions in the performance of a visual task (Bourbon test), and three fatigue tests (fusion flicker frequency, motor reaction time, and rhythmical irregularity). The visual performance scores, and two of the three

fatigue tests were significantly different. Despite flaws in the research methodology, when taken alongside other research in this area, it contributes to work in this field. Rey & Rey (1963) also reviewed a number of early studies, which showed small and often inconsistent effects.

Figure 14. Histograms of the weekly incidence of episodes of eyestrain and headache among subjects exposed to new and conventional lighting, before and after the changeover from one form of lighting to the other (Wilkins et al., 1989).



A study by Veitch & McColl (1995) showed increased visual performance under high frequency as compared to low frequency lighting, and suggested that further research was required on the health effects due to modulation. Veitch & McColl (1995) observed the visual performance, comfort and health of 48 students under three differing fluorescent lamps: full spectrum fluorescent light (FS), cool white fluorescent light (CW), and filtered cool white fluorescent light[13] (FCW); and differing flicker rates - low frequency (120 Hz), and high frequency (20 - 60 kHz). The visual performance task consisted of a Vision and Lighting Diagnostic Kit

[13]The filter is marketed as a low cost alternative to full spectrum lamps, which is applied to a cool white lamp and produces a SPD similar to that of a FS lamp and daylight.

(VaLID) using a Landolt ring task of 12 rows with varying size and luminance contrast (six row pairs numbered A-L). Visual comfort was self-reported at the conclusion of a reading task (5 pt type on matte white paper). The health status questionnaire examined the history of lighting related complaints including migraine, eyestrain and anxiety. The experimental office was windowless, and dimmable magnetic and electronic ballast's maintained a constant illuminance level.

They found that the subject's performance was significantly better under high frequency light for one of the six row pairs (G/H) tested in the visual performance test (VaLID). The G/H row pair had a contrast of 0.21 and explained 26% of the variance in the visual performance scores for the two rows. The two rows with lower contrasts did not show significant effects, possibly due to the large variation in responses for these rows. There was no significant difference between the lamp types although the full spectrum light (which had the highest chromatic modulation) had the lowest visual performance score. The authors suggest that this difference may be significant with a larger sample size.

Visual comfort was lower under the low frequency lighting treatment but was not significantly different to other lighting treatments. The authors suggested that with longer exposure times, the effect of flicker on visual performance might be reflected in the assessment of the satisfaction with the lighting. No effect was shown for lamp type.

The study showed that there was a large difference in visual performance for one of the contrast stimuli tested, but taken as a whole the effect was small. Most work tasks in modern offices have greater contrasts and visual tasks that are substantially easier than the row that showed a significant effect in this study. The lamp type, history of lighting related health conditions and visual comfort did not differ significantly. Some analyses approached significance, suggesting that small effects may be present and that these areas warrant further research attention.

Veitch & Newsham (1998a) examined the effect of lighting conditions on the task performance, mood, comfort, health and aesthetic judgements of 292 office workers. The participants worked for a day under one of nine lighting treatments that examined

the relationship between lighting quality (as assessed by lighting designers) and lighting energy efficiency (lighting power density). The variables included electronic and magnetic ballasts, direct/indirect lighting, semi-specular louvres and prismatic lensed troffers. The lamps had a colour temperature of 3500 K and a colour rendering index of 80 or over.

The verbal intellectual performance (creative writing), psychophysical performance (target detection and reaction time), perception of difficulty of vision test and visual performance task differed significantly with ballast type. All measures were improved under the electronic ballast lighting treatments with the exception of the vision test, which was perceived to be more difficult under the electronic ballast condition. The visual performance test (VaLID) was performed under constant conditions in a separate space at the beginning and end of the day. Therefore this test did not examine the effect of differing ballast type on task performance directly, rather, it examined the carry-over effect of the lighting treatment on vision (visual fatigue). The results were similar to the previous research of Veitch & McColl (1995) and showed a significant difference in visual performance on one row pair E/F (contrast 0.31). None of the other rows differed significantly. The psychophysical performance test was completed on a computer, therefore an interaction between ballast type and screen flicker may have been present. The study found that the following measures did not differ significantly with respect to ballast type: proof reading, computerised typing task, social behaviour, environmental satisfaction, mood, health or aesthetic impression.

Each lighting treatment varied in luminance distribution, and the treatments utilising electronic ballasts had lower luminance overall, which may have influenced the results. Overall, the study lends support to increased task performance under electronic ballasts as compared to conventional ballasts and suggests that ballast type may influence visual fatigue. However, the research did not report changes in health symptoms. A within subjects study would be more sensitive to this measure. There was no difference between ballast type in the two clerical tasks that were more typical of office work. This suggests that in these tasks, cognitive and motor components may have been more influential than the visual component.

Increased levels of visual fatigue, subjective discomfort and perceived task difficulty were present in a visual search task with a flickering versus a steady text (Harwood & Foley, 1987). In a similar study Mourant et al. (1981) found that participants had higher levels of visual fatigue when the text flickered intermittently.

Nelson et al. (1996)[14], examined the effects of flicker frequency, SPD, ambient temperature and humidity on task performance for a spatial relations task, psychomotor tracking task and a reading comprehension task. There were no significant differences between flicker frequency for any of the three tasks.

Bartenbach & Witting (1996) assessed the effect of low and high frequency flicker conditions on the task performance, satisfaction and perception of office workers. They found that the participants made significantly less errors, had faster reaction speed and completed the work task more rapidly in the high frequency lighting treatment. In addition, the participants recorded less fatigue under the high frequency lighting treatment. The paper did not provide detailed information on the study methods or statistical analyses.

Modulation effects on Health, Satisfaction, Mood and Performance

There is some evidence to suggest that reducing the modulation of the fluorescent lighting without changes to flicker frequency may reduce symptoms experienced by office personnel.

Modulation depth has been shown to influence the perception of flicker as discussed previously (Collins & Hopkinson, 1954). Neary & Wilkins (1989) examined the visual effects of short and long persistence phosphors utilised on a VDU. They found that in the short persistence treatment, perceptual phenomena (ghosting of the image) were present and this significantly increased corrective visual saccades. The visual phenomena were not present for the long persistence phosphor treatment.

[14] Cited from Veitch (2000).

Changing the modulation of fluorescent lighting, as well as increasing the fresh air circulation, decreased eye irritation in a commercial office building. The modulation of the fluorescent lighting was changed from full spectrum (modulation of approximately 90%) to halophosphate (modulation of approximately 20%), in a study of 23 office workers on one floor of a commercial air-conditioned building (Sterling & Sterling, 1983). This also changed other spectral qualities (colour temperature, colour rendering). The authors hypothesised that ultraviolet radiation (UV) from the full spectrum lamps was reacting with the air causing photochemical smog resulting in eye irritation. A significant decrease in eye irritation was noted when fresh air circulation was increased and fluorescent lamps were changed. Changing the lamps alone resulted in a slight but not significant decrease in eye irritation. No difference in performance was noted for any conditions.

Tinted glasses developed by Wilkins & Wilkinson (1991) that minimised the spectral emission of wavelengths with a high chromatic modulation were found to relieve visual discomfort and assist with reading under all kinds of lighting in preliminary studies on subjects with visual difficulties. Lenses with similar transmission properties are widely available commercially, however several studies have suggested that these lenses are a placebo effect and that significant results may be due to other visual difficulties such as peripheral brightness sensitivity (Spafford et al., 1995). Rurther research is continuing in this area.

Fluorescent Light Flicker and Energy Efficiency

In a typical contemporary commercial building, artificial lighting is one of the larger energy consumers, accounting for approximately 30 - 40% of the energy consumption (Massey University, 1992). There is considerable scope for significant reductions of energy. The operation of artificial light largely coincides with peak electricity tariffs and new technology for energy efficient office lighting has shown that energy savings of up to 40% are achievable (Centre for Advanced Engineering, 1996).

In many commercial buildings, energy efficient triphosphor fluorescent lamps have superseded halophosphate lamps. These lamps have increased light output, minimal

depreciation, a greater lifespan and better colour rendering than halophosphate lamps that are currently used for lighting general office spaces.

Electronic ballasts offer significant energy savings over magnetic ballasts, reducing energy consumption by up to 30%, increasing the life of fluorescent lamps and offering flicker free operation. Magnetic or low frequency ballasts are available as either regular or low loss. The low loss ballasts do not offer the additional benefits of electronic ballasts, but have significantly lower energy consumption.

A less apparent cost of inefficient artificial lighting is the generated waste heat and subsequent demand for chilling in an air-conditioned building. Energy efficient lighting that utilises appropriate lamps, control gear and luminaires require fewer lamps and less heat is produced.

These benefits are already ensuring a steady uptake of triphosphor lamps and increased use of electronic ballasts in commercial buildings, regardless of any potential benefits to occupants within the office spaces. Further research is required to determine if energy efficient triphosphor lamps and electronic ballast's will impact upon the productivity of office workers, and thus it's economic feasibility and attractiveness to the consumer.

1.3 Summary

Fluorescent light flicker has been highlighted as a potential contributor to asthenopic symptoms experienced in the workplace and has been shown to affect visual performance, fatigue and satisfaction with the lighting (Brundrett, 1974; Wilkins et al.,1989). A large number of factors influence the perceptibility of the flicker including:

- Ballast type
- Lamp characteristics
- Lamp age
- Office configuration
- Occupant characteristics

However, research suggests that provided lamps are well maintained, only a small proportion of occupants are likely to be able to perceive lamp flicker (Collins & Hopkinson, 1954). This is an important area for future investigation. There is a lack of field studies that evaluate the relationship between flicker perception, lamp maintenance, health symptoms and environmental satisfaction, particularly with modern installations.

In addition to the perception of visible flicker, lamps operating with low frequency ballast's have been shown to influence the physiological responses of the eye and neurological pathways. Visual neurons respond to flickering light at frequencies well above those present in lamps operated with low frequency control gear, firing synchronously in response to the luminous modulation. This subconscious response has been shown to result in less accurate processing of visual information. Several studies have found that flicker frequency can influence visual fatigue, subjective discomfort, post task visual performance, headaches and eyestrain, although this has not been demonstrated in all research. It is theorised that it is these unconscious mechanisms that cause the asthenopic symptoms reported by subjects working under fluorescent lighting (Wilkins, 1991)[15].

There is evidence to suggest that some physiological conditions can increase sensitivity to flicker, resulting in more asthenopic symptoms in susceptible populations. The only significant field study (Wilkins et al., 1989) found that headache and eyestrain symptoms were more than halved under high frequency lighting when compared to low frequency lighting. In the study, the occupants carried out a work task at supra-threshold levels. Only a small proportion of the participants experienced headache and eyestrain symptoms. These participants may have been more sensitive to fluorescent light flicker, however the study did not cite the proportion of the participants who could detect flicker or participant demographics.

Future studies should monitor other aspects of the building and occupants' perceptions in order to determine the extent to which lighting contributed to

[15] Cited from Veitch & McColl (1995).

symptoms in relation to other environmental parameters. In addition, these studies would benefit from collecting the history of vision related health problems and detailed demographic information from participants in order to evaluate predisposing factors that may influence symptoms.

Increasing flicker frequency has been shown to improve task performance on some measures (visual performance, verbal intellectual, psychophysical and reaction speed). These studies had significant visual components. Veitch (2000) suggested that '*the effect of flicker is limited to visual processing only, and does not influence other cognitive processes (arousal and stress)*'. This is reflected in studies that have shown flow-on effects including decreased visual comfort and asthenopic symptoms.

The influence that chromatic modulation has on perceptibility, asthenopic symptoms and visual performance is not clear. Although the persistence of the phosphors influences the modulation depth, this difference has not been shown to significantly affect symptoms in office populations, although it may be influential in some groups.

Taken together, the research strongly suggests that the flicker from low frequency fluorescent lighting may influence the health symptoms, performance and satisfaction of office personnel. Imperceptible flicker may influence visual processing, leading to increased visual fatigue and decreased task performance. In addition, susceptible populations may be able to perceive flicker from lighting installations using low frequency ballasts. These personnel may experience a higher incidence of visual discomfort in comparison to other office staff.

Laboratory research has yielded a valuable understanding of the role of fluorescent light flicker in relation to visual performance tasks. However it is not without the limitations of a laboratory experiment (Kerlinger, 1968; Boyce, 1981; Goldman, 1994). The isolation of the setting, the desire to perform at one's best, the short time period, and small population group are all factors that suggest that further research in a field setting is required.

Specifically, the interventional field study completed by Wilkins et al. (1989) should be repeated to validate the effect that changing flicker frequency had on symptoms

experienced by office personnel. This study could be extended to include modulation depth as a lighting treatment and the questionnaire should include the participants satisfaction with lighting conditions, including detection of flicker in the office environment.

In addition, laboratory research has shown that flicker frequency affects visual performance, and further research in a field setting is necessary to determine if there is a flow on effect on actual productivity in the work place.

Taken together, the literature strongly suggests that one obvious research direction for further exploring the effect of fluorescent light flicker on office personnel is via further field research. The interventional study by Wilkins et al. (1989) suggests a valuable starting point in developing an appropriate methodology.

2 *Experimental Methodology*

2.1 Choice of Experimental Study

The range of research examined in the literature review suggested that an interventional study would contribute to the body of research in this field.

Previous laboratory studies have identified that flickering light can disrupt the visual process, influencing neural firing and saccadic eye movements at frequencies well above the CFF (Critical Flicker Fusion) and that flickering light can be detrimental to performance. Laboratory research is typically used to isolate one factor and determine causality. It has high internal validity, and is most commonly utilised early in the research process. The external validity of laboratory research is low, as these studies encourage participants to focus on one aspect of the workplace, are usually only for a relatively short time period, and often utilise subjects that are not representative of the population of interest. Participants can be highly motivated and may strive to give the 'appropriate' response. This is not representative of the workplace, where office workers are exposed to a plethora of environmental conditions over a long time period, with each ranked differently in terms of their relative importance and magnitude of effect. Therefore, while laboratory studies are critical at the early stages of establishing causality, interventional or epidemiological studies are essential in establishing the relative importance of the variables to workplace health and productivity.

Epidemiological field studies are commonly used in health research to give a snapshot of a population and the trends within that particular group, typically requiring large sample sizes. Epidemiological studies enable the prevalence of a particular symptom in the chosen population to be identified, but have limited ability to show cause and effect when they are not used in conjunction with another experimental method such as physical sampling.

The body of research examined in the literature review, suggests that fluorescent light flicker may affect the health, performance and satisfaction of office personnel in the

workplace. Other research has suggested that modulation may also be an important factor.

This research proposed that an interventional study that examined the health, performance and satisfaction of office personnel exposed to differing lighting flicker treatments would make a valuable contribution to the previous research in this field.

An interventional study has the following advantages:

- High external validity – participants are exposed to a wide range of environmental factors in the workplace and the experimental treatment is just one of many factors in the work environment. Therefore the relative importance of the treatment is able to be distinguished and the extent of its contribution to workplace symptoms when other 'background noise' is included;
- Long-term exposures to treatment - participants are exposed to the treatment conditions for an extended period. Adaptation is able to occur, and treatment effects can be measured longitudinally, giving a consistent pattern of cause and effect;
- Actual workplace productivity can be measured – the ongoing productivity of the office personnel can be monitored and compared to the treatments of interest, perceived productivity and workplace symptoms;
- Research uptake – The research results are valid for office spaces. Therefore results can be disseminated to the general public with rapid uptake of results.

The disadvantages of this type of study include:

- Poor internal validity – effects that are due to the treatment can be diluted or masked by the plethora of other factors in the workplace.
- It can be difficult to distinguish treatment effects because of the variation introduced by other factors;
- Interventional studies can be very expensive as changes must be made to a large number of units;
- These studies typically take a long time period and require a significant number of participants who must participate for the entire duration of the study. Thus it can

be difficult to select an appropriate host office and study population to meet these criteria.

2.2 *Selection of Lighting Treatments*

To maximise the external validity of the study, control gear and lamp combinations were selected to include the following criteria:

- Commonly utilised in commercial office buildings in New Zealand;
- Maximum variation in flicker frequency and modulation between lighting treatments;
- Energy efficient control gear and lamps;
- Control gear and lamps used in previous research.

Control Gear

Research that has assessed effects due to flicker frequency has compared high frequency electronic ballasts with low frequency magnetic or magnetic ballasts. Both types of control gear are commonly used in New Zealand and international office buildings and therefore were utilised in this study.

Modulation Depth

Previous studies (Wilkins & Clark, 1990; Andersonn et al., 1994) had identified a range of modulation depths for particular phosphor combinations commonly used in fluorescent lamps (Table 4 & Figure 15). Therefore, fluorescent lamps and control gear were assessed to ensure comparability to these studies. Fluorescent lamps were fitted inside standard twin lamp recessed troffers. One troffer was wired with low frequency ballasts (low loss magnetic ballast[16]), the other with high frequency ballasts (electronic ballast). Four randomly selected fluorescent lamps from each type were tested, a matched pair being used in the troffer at the same time.

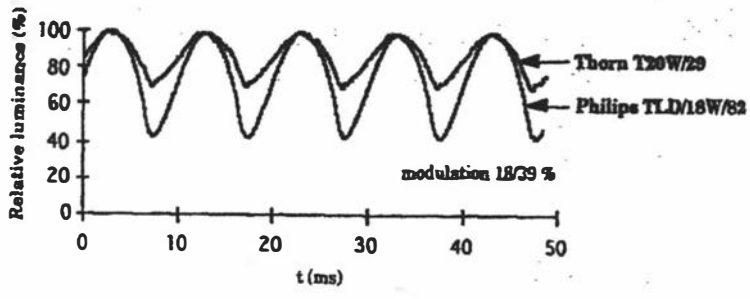
[16] Low loss ballasts are an energy efficient magnetic or choke ballast.

Table 4. Modulation depths for fluorescent lamps and control gear (Andersonn et al., 1994).

Fluorescent Lamp Description	**Control Gear**	**Colour Rendering Index (CRI)**	**Modulation Depth (%)**
Halophosphate	Low Frequency ballast (50 Hz)	50-80	19-22
Triphosphor	Low Frequency ballast (50 Hz)	85	38-39
Polyphosphor	Low Frequency ballast (50 Hz)	90-100	30-42
Triphosphor	High Frequency electronic ballast	85	0.9

A Hagner photometer[17] was used to measure the luminance of each separate lamp in the luminaire, which was then displayed on a digital oscilloscope (Figure 16) and the modulation depth measured. The Hagner photometer was selected because of its high correspondence with V_λ (the relative spectral luminous efficiency of the human eye in the photopic range[18]) and its rapid response time. The testing was carried out in an internal room without windows or other light sources.

Figure 15. Time-dependent relative luminance from a single colour fluorescent lamp (Thorn T20W/29) with a modulation of 18% and relative luminance from a full-colour fluorescent lamp (Philips TLD/18W/82) with a modulation of 39%. Because of the different mixing of phosphors in the two types of lamps the light was modulated differently. The frequency of the supply voltage was 50 Hz which gave discharges in the lamps every half-period and light with a frequency of 100 Hz (Andersonn et al., 1994).



The photometer's light sensitive area was directed towards the centre of the fluorescent lamp being tested, equidistant from either end of lamp. Light from the

[17] For complete specifications see Appendix H.

[18] Luminance of greater than 10 cd/m^2.

second lamp in the recessed fitting was screened from the lamp being tested. The photometer was set at its highest measuring range (40 μs).

The modulation depth was calculated as:

$$\left(\frac{L_{max} - L_{min}}{L_{max} + L_{min}}\right) \times 100\%$$

Where:

L_{max} = maximum luminance (cd/m^2)

L_{min} = minimum luminance (cd/m^2)

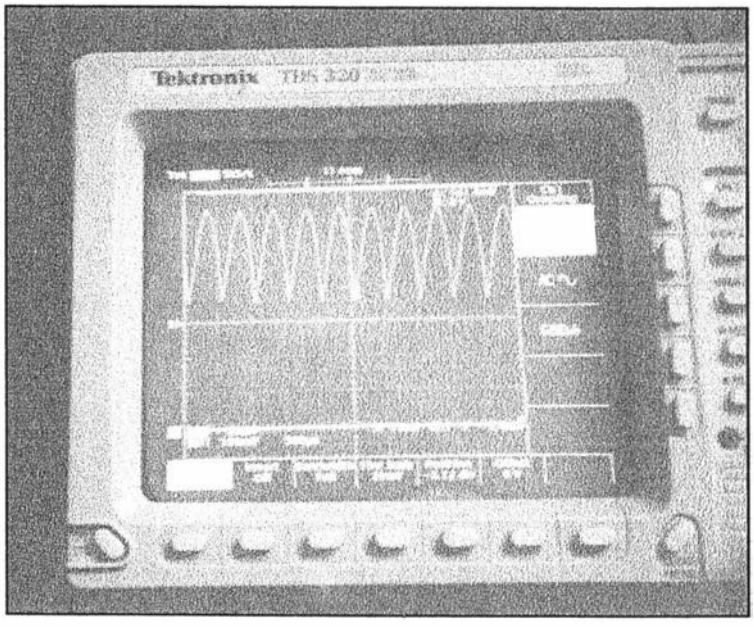


Figure 16. Luminance output from the fluorescent lamp controlled by the low frequency ballast displayed on the digital oscilloscope.

The results are shown in Table 5. They concurred with that of other researchers. The greatest difference in modulation depth occurred between the warm white halophosphate lamp (19%) and the warm white (39%) or cool white triphosphor fluorescent lamp (40%). Therefore this contrast is the most suitable for the treatment conditions comparing modulation depth. The warm white and cool white triphosphor lamps used with high frequency control gear had modulation depths of 3% and 1% respectively, which also concurred with that found by other researchers.

Halophosphate fluorescent lamps are commonly used within New Zealand and internationally, but are being superseded by triphosphor fluorescent lamps, which in comparison have a higher colour rendering index, longer life, less depreciation and higher lamp efficacies. At this point in time, these two lamp types are the most

commonly utilised in New Zealand office buildings and thus fit the criteria stated previously.

Therefore, warm white halophosphate and warm white triphosphor lamps were chosen as the modulation depth contrast. These lamps were matched for correlated colour temperature (CCT) to minimise the possibility that subjects were able to detect changes between lighting treatments. However, it was not possible to match the colour rendering index (CRI) using commercially available fluorescent lamps. Research that has examined the colour properties of lamps has suggested that coloured scenes are perceived more clearly with lamps with a higher CRI, that less illuminance is required to give equivalent perceived clarity and that spaces utilising lamps with a high CRI are preferred. However, there was no evidence provided by the literature to suggest that the lamp CRI would influence health or productivity. In light of the importance of selecting lamps with the greatest contrast in modulation depth and matching colour temperature, the difference in the lamp colour rendering index was accepted.

Balancing Luminance between Treatments

The difference in luminous efficacy between the selected lamps resulted in a 15% increase in luminous flux (light output) between the halophosphate and triphosphor fluorescent lamps. This would have resulted in differences in the illuminance and luminance within the office spaces between the treatment conditions.

Spaces that are perceived as brighter can significantly affect satisfaction and mood, and increased illuminance has been shown to influence visual performance (Boyce, 1973; Baron et al., 1992; Knez, 1995), although these effects were not associated with illuminance differences of this small order. There was no evidence provided by the literature suggesting that a difference as small as 15% could affect health, performance or satisfaction. Indeed, this level of variation was smaller than that which already existed between workstations in each of the three offices. It was suggested that staff might detect a difference in brightness in the spaces, possibly resulting in increased positive effect (personal communication P. Boyce, M. Donn and J. Veitch 1997). However, in discussion with these parties it was concluded that the

baseline period should proceed without modifying the lamps, and participant responses would be monitored.

Table 5. Modulation Depth for fluorescent lamps and control gear tested

Product Description	Lamp Type	Control Gear	Correlated Colour Temperature (CCT)[19]	Luminous Flux (Lumen)	Colour Rendering Index (CRI)	Modulation Depth (%)
Sylvania LUXLINEPlus F36W/830	Triphosphor	Low Frequency (50 Hz)	Warmwhite De Luxe (3000 CCT)	3350	85	39
Sylvania LUXLINEPlus F36W/840	Triphosphor	Low Frequency (50 Hz)	Coolwhite De Luxe (4000 CCT)	3350	85	40
Sylvania Standard F36W/133-ST	Halophosphate	Low Frequency (50 Hz)	Coolwhite (4300 CCT)	2850	58	27
Sylvania Standard F36W/129-ST	Halophosphate	Low Frequency (50 Hz)	Warm white (3000 CCT)	2850	51	19
Sylvania LUXLINEPlus F36W/830	Triphosphor	High Frequency (20 kHz)	Warmwhite De Luxe (3000 CCT)	3350	85	3
Sylvania LUXLINEPlus F36W/840	Triphosphor	High Frequency (20 kHz)	Coolwhite De Luxe (4000 CCT)	3350	85	1

A number of personnel in all three offices commented upon the increase in brightness with the new lighting in the space, raising concern that the difference in brightness between the treatment conditions would be noticed and possibly influence participant responses. Therefore, a number of methods of reducing the perceived brightness of the fluorescent lamps by balancing the luminance between the triphosphor and the halophosphate fluorescent lamps were considered. These included removing fluorescent lamps selectively from the luminaire, placing a plastic sheath over the

[19] CCT, Lm and CRI from manufacturers data.

triphosphor fluorescent lamps or on top of the diffuser, or placing black tape at the ends of, or along the back of, the fluorescent lamp.

The selective removal of fluorescent lamps from the luminaire, while the most simplistic method, would result in unacceptable variation in the light output from the luminaires and thus was rejected.

The plastic sheath or cover had the advantage of ensuring that the luminance distribution from the diffuser was not altered. However, the plastic must absorb light equally across the entire visible spectrum and must not degrade or alter its absorption properties either from the ultraviolet light or heat generated by the fluorescent lamp. This method was rejected because there was a relatively short time frame in which to instigate the changes. Initial enquiries suggested that it would be difficult to guarantee the availability of sufficient quantities of a gel with appropriate properties in the time available.

The use of black tape placed at the back of the lamp where it was not visible to the office occupants was selected as an expedient and low cost method of reducing the luminance from the fluorescent lamps. This method could be undertaken and assessed readily with the equipment and laboratory space available and instigated within the time frame available. While a small change to the luminous distribution from the luminaires may have occurred, this was expected to be small as prismatic diffusers were used over the luminaires in all host offices.

Therefore a series of tests were conducted to determine if it was possible to reduce the luminance from the fluorescent lamps by covering the non-visible (rear) part of the lamps (back) with a thin black tape. Two sets of triphosphor warm white fluorescent lamps and halophosphate warm white fluorescent lamps were tested separately in a two lamp recessed troffer complete with a prismatic diffuser and low frequency control gear. Twelve locations were positioned at even intervals on the diffuser, and the luminance was measured at each point at a distance of approximately 3 metres perpendicular to the troffer. From these tests, it was estimated that a width of approximately 10mm along the entire length of the lamp would give the desired reduction in luminance. All triphosphor lamps were subsequently treated in this

manner, and were installed in the luminaires with the tape located at the rear of the lamp where it was not visible.

In addition, the fluorescent lamps utilised in the host offices were expected to depreciate slightly, with some loss in light output over the course of the study. If the lamps are new, this depreciation is more rapid and the lamps may undergo small colour shifts. This depreciation is more marked with halophosphate as compared to triphosphor fluorescent lamps. Ideally, the lamps should be burned in before the beginning of the study, but facilities were not available. In this study, the lamps were utilised for 700 hours, so the actual depreciation was expected to be minimal during this time. The risk of a colour shift in a small proportion of the fluorescent lamps was accepted.

2.3 Selection of Host Offices

The appropriate selection of host offices in which to conduct the research study was a fundamental part of the study. To ensure that results could be transferred to the wider commercial office environment, the offices needed to be in a typical commercial building and in order to monitor productivity, the work task had to be repeatable and measurable. Offices utilising Visual Display Units were excluded, as the flicker from the monitors was a confounding variable. To maximise exposure to the lighting treatments, the contribution of daylight had to be limited.

Data entry offices were identified as the most suitable spaces, meeting the following criteria:

- Commercial office environment;
- Exacting visual task requiring high levels of visual accuracy;
- Evening or twilight shift, therefore minimal daylight contribution during the winter months;
- Static task, therefore little departure from experimental condition;
- Measurable and repetitive work task;
- Minimal use of Visual Display Units (VDU).

The choice of data entry personnel gave the following limitations:

- Higher attrition rate than other working environments (a high proportion of part time or casual staff);
- Atypical work task and hours of work;
- A 'biased' sample (non-random selection of subjects).

Given the good match between the desired criteria and this office environment, the limitations were considered acceptable.

Four cheque data entry offices were located in Wellington, New Zealand, as potential host offices, with all four offices carrying out similar operations on the same equipment. However, one of these was excluded because of small staff numbers and unsuitable office layout. More detailed information on the data entry offices is given in Section 2.6 (Description of Office Spaces).

2.4 Selection of Study Design and Statistical Analysis

Lighting Treatment Contrasts

The contrasts of interest in this study were:

Low frequency control gear (50 Hz magnetic ballast)	vs	High frequency control gear (30 kHz electronic ballast)
Low modulation depth (19%) (Halophosphate fluorescent lamp)	vs	High modulation depth (39%) (Triphosphor fluorescent lamp)

Thus the following three lighting treatments and baseline lighting were selected (Table 6 and Figure 17):

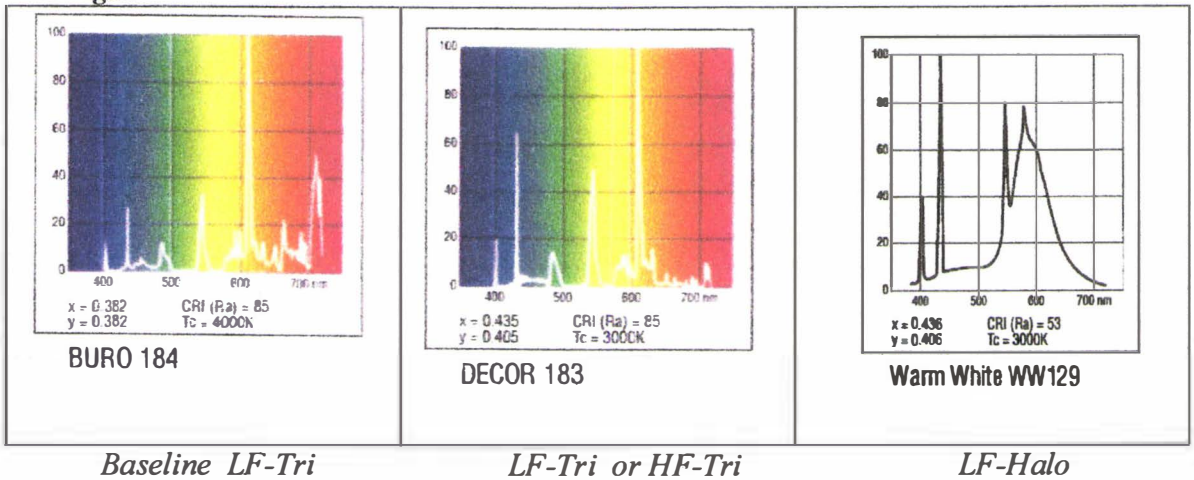
- Low frequency halophosphate fluorescent lamp (LF-Halo);
- Low frequency triphosphor fluorescent lamp (LF-Tri);
- High frequency triphosphor fluorescent lamp (HF-Tri);
- Baseline lighting - Low frequency triphosphor fluorescent lamp (Baseline).

The baseline period utilised triphosphor lamps with low frequency control gear and a cool colour temperature (4000 CCT). These lamps were in other respects similar to the triphosphor condition.

Table 6. Lighting Treatments and Baseline

	Control Gear	Lamp Type	Correlated Colour Temperature	Luminous Flux (Lumen)	Colour Rendering Index	Modulation (%)
Treatment One	High Freq (HF)	Triphosphor (Tri)	Warm white (3000° K)	3350	85	3
Treatment Two	Low Freq (LF)	Halophosphate (Halo)	Warm white (3000° K)	2850	51	19
Treatment Three	Low Freq (LF)	Triphosphor (Tri)	Warm white (3000° K)	3350	85	39
Baseline	Low Freq (LF)	Triphosphor (Tri)	Cool white (4000° K)	3350	85	40

Figure 17. Spectral distribution of the three fluorescent lamps used in the study. Buro184 (Baseline), Décor 183 (LF-Tri and HF-Tri), Warm White WW129 (LF-Halo), from Sylvania Lamp Catalogue.



Crossover Design

A crossover design with three treatments was selected as the most appropriate experimental design. The availability of three offices and three lighting treatments lent itself to a crossover design (Table 7), with a configuration that would enable

detection of any carryover effects. In addition, this design limited the duration of the study[20] and permitted smaller sample sizes from each office.

Table 7. Crossover experimental design (with baseline shown)

	Baseline weeks 1-4	Trial One weeks 5-8	Trial Two weeks 9-12	Trial Three weeks 13-16	Baseline weeks 17-18
Office One	Baseline	HF-Tri	LF-Tri	LF-Halo	Baseline
Office Two	Baseline	LF-Halo	HF-Tri	LF-Tri	Baseline
Office Three	Baseline	LF-Tri	LF-Halo	HF-Tri	Baseline

A crossover design is a form of repeated measures design, where more than one observation is collected from each participant. A repeated measures design minimises the variability between observations, as variation between several individuals is usually much greater than variation between several observations on one individual. It also allows experiments with a smaller number of participants, with several observations typically collected on each participant over time. A Latin square arrangement of factors (treatments) and sequences (offices) enables any differences due to order (trials) to be protected against by balancing the order in which each factor is presented (Ott, 1993).

A crossover design enabled the study to be conducted without the need for a separate control group. This was important as random allocation of participants to offices was not possible, and the offices could not be divided to provide a control group. This design also minimised the need to control factors such as proximity to windows and air conditioning outlets, as the treatments were compared within, not between office spaces, thus any variability that this introduced was minimised in the analysis.

A baseline period was included at the beginning and conclusion of the experimental section of the study, and consisted of a common lighting regime (low frequency triphosphor fluorescent lamps), installed in all three offices. The baseline period familiarised participants with the procedures they would follow during the trial,

[20] To minimise attrition rates and enable the study to be completed within the winter months.

accustomed staff to changes in the lighting, and as much as possible ensured that all three offices had equitable lighting conditions before entering the experimental period. The baseline period also made it possible to quantify inherent differences in symptom reporting within offices, and by collecting data at the conclusion of the study, it was possible to determine if response fatigue occurred during the study.

The most significant disadvantage of crossover designs is the possibility of contamination or a carryover effect imposed on an experimental period by the experimental period immediately preceding it. In this study, the carryover effect may result from physiological effects from the previous lighting treatment, or perceptual differences between the lighting treatments (where the previous lighting treatment affects the response of the participants to the new lighting treatment).

Carryover effects can be detected and avoided by including a washout period immediately following each treatment. The washout period may be a time period where the subjects are not exposed to any treatment by returning to the initial baseline period. Alternatively, if it is difficult or impractical to return to a baseline period, a washout period can be imposed by removing a sufficient initial period of any new treatment from the analysis. In this study, it would have been impractical for the participating offices to revert to the baseline lighting regime between each treatment period and it would have increased the length and cost of the study. For these reasons, it was concluded that it was more appropriate to exclude an initial period of data from the collected information.

A repeated measures analysis was incorporated to detect differences between average weekly responses enabling any carryover effects to be detected. In order to estimate carryover effects accurately using a repeated measures analysis, data/responses were needed from several participants on a continuous basis. In other words, a number of participants must provide usable responses on a daily basis throughout the treatment/trial period. However, the majority of participants in the host offices did not work every shift, therefore it was not possible to obtain daily data throughout the study period. In the absence of this data, the analysis considered the 'weekly average responses' utilising data from participants for each week of the trial period. This

approach provided an estimate of the carryover effects, but was not as accurate as using daily data.

Statistical Models

The primary analysis was undertaken using ANOVA to determine if the lighting treatments differed with respect to headache, lethargy and eyestrain symptoms. This model corresponds to the crossover design employed within the 3x3 Latin square framework (excluding the baseline period). Separate analyses were undertaken on the monthly average and the weekly average reported symptom severity.

Secondary analysis considered the effects of the lighting treatments on actual productivity, perceived productivity and satisfaction with aspects of the workplace. In addition, the relationship between these measures and symptom severity was examined. As the collected data did not correspond to the main planned statistical design, the data was examined using differing statistical procedures. Detailed information on all proposed analyses is provided in Sections 2.8-2.10.

Monthly Average Analysis

In these analyses, the responses from each participant were averaged over the four weeks in each trial period. The source of variation (of interest) and the degrees of freedom (Df) associated with the primary analysis of the experiment (say, for average monthly symptom severity experienced by office personnel) were as follows[21]:

Table 8. Skeleton ANOVA table for Crossover Design (monthly average symptom severity)

Source of Variation		Df	
Between participants	Offices	2	3 offices
	Error 1	3(n-1)	'error' for testing office differences (n participants)
Within participants	Trials	2	3 trials
	Treat	2	3 lighting treatments
	Treat*Trial	2	interaction

[21] Power Analysis report, Appendix F (Ganesh, 1996).

	Error 2	6(n-1)	'error' for trials, treatments and interaction
Total		9n-1	Overall variation

The general linear model for this design is:

$Y_{ijkl} = \mu + office_k + \varepsilon_{lk} + treatment_i + trial_j + (treatment*trial)_{ij} + \varepsilon_{ijkl}$

μ = overall mean

$office_k$ = the fixed main effect for k^{th} office

ε_{lk} = random error for office effects or the random effect of the l^{th} operator in k^{th} office $\sim N(0,\sigma_1^2)$

$treatment_i$ = the fixed main effect for i^{th} treatment

$trial_j$ = the fixed main effect for j^{th} trial

$(trial*treatment)_{ij}$ = the interaction effects between treatments and trials[22]

ε_{ijkl} = random error for main effects of treatments and trials related and their interaction effects $\sim N(0,\sigma_2^2)$

Here,

ε_{kl} = operator(office)

ε_{ijkl} = operator*treatment + operator*trial + operator*treatment*trial

Weekly Average Analysis

In these analyses, the responses from each participant were averaged over the days of each week within each trial period. The source of variation (of interest) and the degrees of freedom associated with the repeated measures analysis of the experiment (average weekly symptom severity experienced by office personnel) were[23]:

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[22] The treatment*trial interaction has only two degrees of freedom rather than four, the missing two degrees of freedom are in the sum of squares due to sequences (offices).

[23] Power Analysis report, Appendix F (Ganesh, 1996).

Table 9. Skeleton ANOVA table for Crossover Design (weekly average symptom severity)

Source of Variation		Df	
Between participants	Offices	2	3 offices
	Error 1	3(n-1)	'error' for testing office differences (n subjects)
Within participants	Trials	2	3 trials
	Treat	2	3 lighting treatments
	Treat*Trial	2	interaction
	Error 2	6(n-1)	'error' for trials, treatments and interaction effects
Repeated measures	Weeks	3	4 weeks
	Weeks*Trial	6	interaction effects
	Weeks*Treat	6	interaction effects
	Weeks*Trial* Treatment	12	interaction effects
	Error 3	27n-15	'error' for testing weeks and interaction effects
Total		36n-1	Overall variation

The general linear model for this design is:

$$Y_{ijklm} = \mu + office_k + \varepsilon_{lk} + treatment_i + trial_j + (treatment*trial)_{ij} + \varepsilon_{ijkl} + week_m + (week*treatment)_{im} + (week*trial)_{jm} + (week*treatment*trial)_{ijm} + \varepsilon_{ijklm}$$

μ = overall mean

$office_k$ = the fixed main effect for k^{th} office

ε_{lk} = random error for office effects or the random effect of the l^{th} operator in k^{th} office $\sim N(0,\sigma_1^2)$

$treatment_i$ = the fixed main effect for i^{th} treatment

$trial_j$ = the fixed main effect for j^{th} trial

$(treatment*trial)_{ij}$ the interaction effects between treatments and trials

ε_{ijkl} = random error for main effects of treatments and trials related and their interaction effects $\sim N(0,\sigma_2^2)$

$week_m$ the fixed effect for m^{th} week

$(week* treatment)_{im}$ = the interaction effects between weeks and treatments

$(week*trial)_{jm}$ = the interaction effects between weeks and trials

$(weeks*trial*treatment)_{ijm}$ = the interaction effects between weeks, trials and treatments

ε_{ijklm} = the overall random error for main effect of weeks and its interactions with treatments and trials ~ $N(0,\sigma_3^2)$

Here,

ε_{kl} = operator(office)

ε_{ijkl} = operator*treatment + operator*trial + operator*treatment*trial

ε_{ijklm} = overall residual

2.5 Experimental Measures

The response variables of interest included:

- Lighting related health symptoms experienced by office personnel;
- Actual productivity;
- Satisfaction with the office environment;
- The perceived effect of the work environment on productivity;
- Perception of flicker;
- Demographic characteristics that may influence health symptoms.

These measures were collected via a self-reported questionnaire. In addition, a subsequent medical study (Chapter Five: Medical Study) collected information on physiological characteristics or external factors such as other jobs, which may influence symptoms experienced by the participants.

Questionnaire Design

Participant responses were collected via a self-reported questionnaire (Appendix C). Self-reported questionnaires, with filter questions for non-occupational symptoms, are commonly utilised in Building Health studies, and have been validated with medical examinations (Burge et al., 1990; Burge et al., 1991).

The questionnaire was comprised of three sections: demographic information, health symptoms and perception of the office environment.

Section One was a standard questionnaire that collected demographic characteristics and solicited information on factors that may have influenced symptom incidence or severity. Information collected included: age, gender, time employed as a data entry operator, predisposing medical conditions such as high blood pressure, diabetes and migraines and visual history including use of spectacles or contact lenses, presence of cataracts or eye infections. This questionnaire was collected once at the beginning of the study.

Section Two collected lighting related health symptoms via a short frequent questionnaire completed after each work shift. The questionnaire was based upon the methodology used in Wilkins et al. (1989). In their study the incidence of headache and eyestrain in office workers was collected over a one year period with symptoms classified by participants as none, mild or severe. In this study, the data was collected on a seven point Likert scale to enable small differences in perceived severity to be detected (1=no symptoms and 7=very severe symptoms). This method enabled the participants to classify their symptoms more precisely, but gave sufficient flexibility for symptoms to be grouped and analysed in a number of ways. A similar scale was trialed in the pilot study and indicated that this level of sensitivity was meaningful to participants. Participants were asked to identify whether or not they experienced lighting related symptoms (headache, eyestrain, lethargy) and how severe they considered the symptom. Participants were given no guidance as how to rank symptoms. As the study was within subjects, between subject differences in perceived severity were not important. Variability between offices was detected in the analysis by examining the relationship between responses during the baseline period.

The second part of this section categorised symptoms as either work related (symptoms that were experienced in the work environment and reduced or

disappeared after leaving the workplace) or non-work related[24] (symptoms that were experienced in the work environment, but did not reduce after leaving the workplace). This methodology enabled non-work related symptoms to be filtered from the questionnaire and is widely used in Sick Building Syndrome research questionnaires to isolate work related symptoms (Robertson et al. 1989; Skov et al. 1989; Godish, 1994).

Section Three of the questionnaire was used to assess the participant's perception of the work environment. The questionnaire did not focus exclusively on lighting, but had lighting related questions embedded in the questionnaire, in order to minimise participants' focussing primarily upon the lighting conditions in the office. Participants were briefed that the study evaluated office environment conditions, and that lighting was the primary variable of interest, but they were not told what specific aspects of the office environment were being evaluated and/or changed throughout the study period.

Participants were asked to identify the degree of satisfaction or dissatisfaction they experienced with aspects of the work environment (lighting, air circulation, temperature), overall satisfaction with the work environment and job satisfaction at the end of the working week on a seven point Likert scale (-3 = very dissatisfied, 0= indifferent and 3 = very satisfied). In addition, an open-ended question asked participants to outline specific aspects of the work environment that were liked or disliked.

Participants were also asked to indicate if they felt that the work environment had increased or decreased their productivity on a seven point Likert scale (–3 = significantly decreased productivity, 0=no impact on productivity and 3=significantly increased productivity). Finally, they were asked whether or not they had detected flicker. This section was also completed on a weekly basis.

[24] Non-work related symptoms may be attributable to other factors such as influenza, colds or lack of sleep.

Productivity

The host offices were selected in part because they carried out a work task in which productivity could be measured. The number of cheques entered by the staff was continuously data logged. Office management collated this productivity data on a regular basis in two of the three offices. The actual productivity of office personnel in Office Three was not measured at the request of office management. The productivity data collected by office management in Offices One and Two was used to measure changes in actual productivity throughout the study.

2.6 Description of Office Spaces

The three host offices were typical commercial offices in multi-storey commercial buildings centrally located in Wellington, New Zealand. All three offices had the following characteristics:

- Open plan;
- Fully air conditioned;
- White ceiling, white or lightly coloured walls, medium dark carpet;
- External windows with blinds or light coloured curtains.

Table 10. Lighting conditions in the three host offices prior to experiment.

Existing Office Lighting Conditions	**Office One**	**Office Two**	**Office Three**
Luminaires	Recessed three lamp	Recessed four lamp	Recessed three lamp
Diffusers	Prismatic	Prismatic	Prismatic
Fluorescent lamps	Cool white triphosphor and halophosphate	Cool white halophosphate	Cool white triphosphor
Control gear	Low frequency ballasts	Low frequency ballasts	Low frequency ballasts
Horizontal workplane illuminance[25]	430-650 lux	370-565 lux inside rm 700 lux outside rm	470 lux
Ceiling height	2.6m	2.7m	2.6m
Wall colour	white	white	light blue or white
Ceiling colour	white	white	White
Floor colour	medium gray	medium blue	medium gray

[25] Average value.

The lighting conditions in each of the three offices were very representative of New Zealand commercial office buildings (Table 10).

Detailed information including floor plans, illuminance, luminance, reflectance and Yxy Tristimulus values are given in Chapter Four (Environmental Monitoring) and Appendices A, B, G and I.

Before the research study began all luminaires and diffusers were cleaned and components replaced where necessary. Electrical circuits in the experimental offices were checked and altered to ensure that all lighting circuits were operating on the same phase.

The study was undertaken between early May and mid September, with the trial period occurring during the winter months of June, July and August. During this time, sunset occurred between 5:03pm and 5:51pm (Lamont, 1998), thus there was minimal daylight contribution[26].

The illumination levels in the three offices were measured and 'Calculux' lighting design program was used to determine that the illuminance levels in the three offices would be acceptable during the lighting study (meet the appropriate workplace standards). In addition, the modelling of the spaces was used to ensure that the desktop illuminance levels in all three offices were as comparable as possible during the experimental treatment period.

In Office One the three existing triphosphor or halophosphate fluorescent lamps were replaced with three new cool white triphosphor fluorescent lamps during the baseline period. In Office Two the four existing halophosphate fluorescent lamps in the inside room were replaced with four new cool white triphosphor fluorescent lamps. The luminaires in the outside room were reduced to three new cool white triphosphor lamps, as the illuminance levels in this office were significantly higher than those in the interior office. The existing unframed diffusers were replaced with new, framed diffusers to facilitate ease of removal and replacement throughout the study.

[26] The majority of staff began work at 5:30pm.

Subsequently, the luminaires in the inside room also had the fourth fluorescent lamp removed during the baseline period at the request of the office management. This was because a number of staff had commented that the fluorescent lighting in that space was too bright.

In Office Three, the two existing triphosphor fluorescent lamps were replaced with three new cool white triphosphor fluorescent lamps, to ensure that acceptable illuminance levels were maintained throughout the study.

Work Tasks

The function of the data entry centres was to process cheque transactions by manually entering the hand written amount on the cheque as digital text that was subsequently electronically processed. The tasks that were conducted by the office staff included[27]:

- Machining - Processing of cheques by manually entering the hand written amount on the cheque;
- Pre-sort - Manual pre-sorting and encoding of the cheques;
- Online - Bulk processing of machined cheques into categories;
- Reject - Manual resort of rejected cheques;
- Typing - Related keyboard work utilising Visual Display Units.

The task of interest was machining, as this was the process where the productivity could be recorded. Machining was the primary task for the majority of personnel.

Daily cheque and credit card transactions were processed during the twilight shift, the transaction material arriving by courier for processing throughout the course of the evening. The majority of the staff in the three offices began work at approximately 5:30pm and continued until the material had been processed at approximately 10:00pm. The remainder of the staff began earlier, some completing a full eight hour day, others leaving earlier in the shift. The workload varied with the volume of cheques received, peaking on Monday evenings as the weekend transactions were

[27] This includes the range of activities carried out in the office space. The data from participants was selectively screened depending on the range of activities carried out in any one shift.

processed and immediately following the twentieth of the month. In these periods a greater number of staff were employed and the work-shift was extended until the task was completed. Staff worked between two and five shifts per week of between four and eight hours.

Packages of cheques were delivered to each desk by a staff member as and when required and these were then placed into a depression in the desk to be processed. The data entry operator entered the numerical amount of the cheque using a keyboard to the right of the cheques, their left hand transferring the cheque to another location in the desk (See Appendix A: Office Photos). The cheques were then transferred and collected via a mechanised system and delivered to the Online Machine for further processing. The cheques were processed from a number of banks throughout New Zealand, with approximately one-third coloured in light blue or green, and the remainder light grey or white (See Appendix G: Environmental Monitoring Data and International Standards). The number of cheques processed per hour varied between approximately 500 to 1500. Staff would break intermittently as new bundles of cheques were delivered, loaded into the machine or collected, and if the machine jammed.

Office One

Office One employed approximately 60 staff with the majority of these working a twilight shift, from 5.30pm - 10:00pm. Office personnel carried out differing tasks depending upon their competence, preference and/or necessity.

The majority of personnel were machinists with some of these beginning the evening shift as pre-sorters. Typing staff were a separate group of personnel, with a different supervisor, and were not exposed to the treatment conditions. At the beginning of the experimental period, an additional eighteen staff were employed and the office was reorganised to fit additional workstations. The office floor was divided into three sections, that each carried out differing tasks:

Area One: Experimental Lighting Conditions - Machining and Online only (40 workstations);

Area Two: Existing Lighting - Pre-sort and Rejects only (20 workstations);
Area Three: Existing Lighting - Typing (8 workstations).

The questionnaire classified staff according to the work tasks carried out during their shift. Staff who indicated machining and did not tick any other categories were considered to be exposed to the treatment condition. All other responses were excluded from the analysis.

Productivity

Office One recorded the individual output of the machining staff in order to monitor the productivity of the office personnel. The number of cheques for each time period on the machine was recorded and could be used to give an hourly average. The total daily volume of cheques entered in the office was also recorded. The productivity of the staff was not monitored continuously, rather staff were encouraged to record their productivity for at least one hour of every shift. Office staff would break intermittently as new cheques were delivered or loaded into the machines. An individual staff member led the workers through a series of exercises every hour, for approximately 3-5 minutes, which were designed to reduce or prevent repetitive strain injury (RSI) or occupational overuse syndrome (OOS).

Office Two

Office Two employed approximately 35 staff, the majority of whom worked a twilight shift from 5.30pm and 10:00pm. Office personnel carried out the tasks discussed above with the majority doing machining during the twilight shift. The office was divided into two open plan rooms, connected by a glazed partition. Both rooms had the experimental lighting installed. The analysis included all questionnaire responses.

Productivity

Office Two recorded the individual output of the machining staff in order to monitor the productivity of the office personnel. The number of cheques for each time period on the machine was recorded and calculated to give an hourly average. Office staff

would break intermittently as new cheques were delivered or loaded into the machines. The total daily volume of cheques entered was also recorded. All staff that indicated on the questionnaire that they were machining during the work shift were included in the analysis.

Office Three

Office Three employed approximately 35 staff. Half of these staff worked an afternoon shift from 2:00 to 10:00, the remainder a twilight shift from 5:30pm to 10:00pm. Office personnel worked in one of three offices and rotated through the differing work tasks on an hourly basis, with RSI breaks between tasks. All three offices had the experimental lighting conditions installed. A small number of typists worked in a separate room that did not have the experimental lighting installed.

The questionnaire classified staff according to the rooms that they worked in. All staff working in the rooms with the experimental lighting installed had their data included in the primary analysis.

Productivity

Office Three did not measure the productivity of individuals. The total daily volume of cheques entered was recorded.

2.7 Participation in Study

To ensure adequate statistical power, the number of staff available to participate, the validity of their responses, and probable attrition from study was estimated. Previous research suggested that any effect that existed was likely to be small, thus attracting participants and ensuring that they remained involved in the study and participated fully was critical. Interventional studies that run for long periods of time, with little compensation to the participants are particularly vulnerable to high attrition rates

and/or response fatigue[28]. In addition, the crossover design of this research meant that the study would be more robust if it was balanced, with each office having an equal number of participants that all completed each treatment period. This is extremely difficult to achieve in interventional studies, but ensuring that the greatest possible number of staff participate in each office and remain in the study, increases the ability of the study to detect any effect that is present.

A power study was conducted utilising data from the pilot study and a previous study by Wilkins et al. (1989), to predict the number of subjects necessary in each treatment period to give a β risk of 0.9, or a 90 % chance of detecting a difference if it exists (Appendices E and F). The power study concluded that a minimum of 20 subjects per office would be required to detect a significant difference of one mean eye symptom (on a nine point Likert scale) between any two treatment conditions using the monthly average symptom severity data. The analyses assumed that participants provided usable data in each treatment period. A minimum of 40 subjects would be required to give a similar level of sensitivity for the weekly average symptom severity data for use in the repeated measures analysis. If the differences between lighting treatments was as much as 2 (on a nine point Likert scale) only 10 subjects would be required for this analysis.

The estimated number of personnel was 60, 35 and 40 for Office One, Two and Three respectively and included all staff, some of whom would not be receiving the treatment condition. The number of personnel who would participate in the study, attrition due to participants dropping out of the study or leaving the workplace was calculated using the participation and attrition rates in the four week pilot study. The pilot study had a 95% participation rate (18/19), with two participants subsequently withdrawing.

In addition, discussion with office management enabled estimates of the number of staff who would be exposed to the lighting treatment to be calculated and the probable proportion who would leave the workplace during the study period (Table 11). This

[28] Response fatigue occurs when participants become bored or fatigued with the study and give inaccurate responses or do not complete questionnaires fully.

gave assurance that the number of participants providing usable data for the monthly average symptom severity analyses would be adequate, if the difference between lighting treatments was as large as one, and if participants provided usable data in each treatment period. If the difference between lighting treatments was as large as two, then the repeated measures analyses would also provide accurate estimates of treatment effects.

Table 11. *Estimated participation rates in main study (including attrition)*

Offices	No. of staff	No. participating (90%)	No. of participants lost through attrition		No. of participants who complete the study
			Left workplace	Non-study completion	
Office One[29]	60	54	5	5	40 (66%)
Office Two	35	32	5	5	22 (62%)
Office Three	40	36	5	5	26 (65%)

Ethical Code of Conduct

The pilot, main and medical study methodology was examined and approved by the Massey University Human Ethics Committee (MUHEC) who are accredited to the New Zealand Health Research Council (HRC) and the New Zealand Lotteries Health (LH) organisations[30].

Recruitment and Retention of Participants

A brief presentation was given in each of the three offices introducing the Massey University staff members involved in the administration of the project, the purpose of the study, what participation in the study involved and the ethical code under which the study was conducted. This information is summarised in the Information Sheet and Consent Form (Appendix C).

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[29] Office One employed eighteen new staff and was undergoing restructuring at the beginning of the experimental period. Therefore it was assumed that the number of staff participating and leaving the workplace would be higher.

[30] The MUHEC act on behalf of the HRC and LH committees to approve studies conducted by Massey University staff members or students.

The occupants were informed in the information sheet that it was a study of workplace environmental conditions, and that changes to the office were to take place, but were not told when these changes would occur or what the changes would be. The researchers and the office supervisors were aware of when the lighting changes were to take place, but did not know what lighting treatment was being installed (double blind). The changes to the lighting treatments took place during weekends outside of work hours.

Study participants were asked to complete a questionnaire outside of work hours on a daily basis for an eighteen week period. By way of compensation for the time and effort involved, when research staff visited the office to take illuminance measurements and check the monitoring equipment, they brought muffins, which were distributed to all office staff regardless of whether they were research participants. In addition, completed questionnaires would be entered into a draw for a small prize (movie ticket) in each office. However, by the conclusion of the first experimental period, additional funding was available and it was possible to compensate participants more appropriately for the time spent in completing the questionnaire. In the first instance staff that had regularly completed the questionnaire throughout the first period of the study (eight weeks) were offered a choice of a movie ticket, box of chocolates or $5 Scratch Kiwi (lottery ticket) as compensation for the time spent completing the questionnaire over that period. From that point onwards for each weekly questionnaire completed, participants were offered a $1 Scratch Kiwi (lottery ticket).

The offices were visited on a two to three weekly basis by one researcher, who was occasionally accompanied by other research personnel when additional assistance was required. Initially the majority of visits were conducted on a Monday evening, the evening in which the majority of office personnel worked. However, as this was the busy night, supervisors expressed a preference for other evenings. Therefore the trips were made on a mix of evening shifts.

Actual productivity data was collected from office management and was used in the analyses if written permission was obtained from the participant.

2.8 *Proposed Analysis*

Data from the questionnaires were entered onto a spreadsheet, with output as ASCII files. The SAS system software was used for all the statistical analyses. The data set was initially screened to ensure that it had been entered correctly, that personnel who were not exposed to the treatment conditions were removed from the data and that unusual data points were deleted if necessary.

All analyses were assessed using a 5% level of significance ($\alpha = 0.05$). However, in line with the exploratory nature of this thesis, the discussion describes the extent to which evidence is provided to show that there is a difference between lighting treatments or a relationship between other variables. A p-value of less than 0.05 provides evidence that a relationship is present (strong evidence where $p<0.01$). While a p-value of over 0.05 is less conclusive, values of between 0.05 & 0.1 provide some evidence to suggest that significant differences or relationships may be present. Where this outcome is consistent with other findings, it is appropriate to discuss these results. *'There is no sharp border between significant and insignificant, only increasingly strong evidence as the p-value decreases'* (Moore & McCabe, 1993).

Participation in the Study

The number of participants choosing to take part in the study, attrition rates and the quality of the usable data available for the primary analysis is described. This data is discussed in relation to the power analysis that was conducted.

Characteristics of Participants in the Research Study

The demographic characteristics of the subjects taking place in the study are outlined. This section is largely descriptive. Chapter Five (Medical Study) examines the physiological and demographic characteristics of the participants in relation to the symptoms experienced in the workplace in further detail.

Monthly Average Symptom Severity

Introduction

The relationship between symptom severity and lighting treatments was explored by means of Analysis of Variance (ANOVA). In addition, the Duncan multiple range comparison test was carried out to further evaluate significant differences between treatments.

Data was screened in the following manner:

- Data that did not list a participant, office or week number were deleted;
- Participants who worked in spaces other than those that had the experimental lighting treatments installed had their data during that period excluded;
- Participants who were identified as managers, pregnant or sick for a prolonged duration of the study were excluded.

Daily responses from participants were examined individually and as a group to isolate outliers or unusual data points that may have been incorrectly entered or were inconsistent with other responses (scatter plots). Single data points were only removed where an entry was inconsistent with the rest of the data set.

Several sets of analyses were carried out on the baseline and treatment data sets. These included:

- Screening symptoms to exclude those that did not reduce at the conclusion of the work shift;
- Examining the effect of a washout period (the first week of each lighting treatment removed);
- Examining the effect of age, gender and office differences on the study outcomes;
- Examining only the responses in which symptoms were experienced.

These analyses were selected to determine if these factors influenced the study findings and were in line with the exploratory nature of this study. The selected analyses were based upon previous research findings (as discussed in the Literature Review).

The following sections outline the data sets tested. Each data set was tested independently, as screening the data sets reduced the number of data points available for the analyses and hence the accuracy of estimates of treatment effects. Testing combinations of these factors would have been desirable, for example treating baseline, age and gender together as covariates, but this screening would reduce the size of the data set to non-usable levels.

Baseline Data:

The data from the baseline period was initially examined to determine if there were significant differences between the participants in the three offices. If the three offices differed, then the treatment effects should be adjusted for these to remove any bias in the data. The data was tested with a one week and a three week washout period. Although a one week washout period should be adequate to enable any carry over effect to abate, the three week washout period examined the data when the majority of participants had been recruited and were familiar with the study questionnaire. The data set with the one week washout period was larger as not all participants completed all four weeks of the questionnaire. The complete and screened (symptoms that did not disappear outside of working hours deleted) data sets were considered for each of the analyses.

In this study, the baseline data did not represent a perfectly level 'playing field' for several reasons:

- Although all three offices had the same lamps installed for the baseline period, and the lighting was balanced as much as possible across the three offices, there were still some differences in the illuminance levels and luminance distribution in the offices;
- A lamp was removed from a luminaire in Office Two during the baseline period at the request of office management;
- Additional workstations were added to Office One during the baseline period, as staff numbers were increased.

The following data sets were tested using ANOVA:

1. **BW4 Baseline data, week four only (three week washout);**
2. **BSW4 Baseline screened data[31], week four only;**
3. **BW2-4 Baseline data, weeks 2-4 (one week washout);**
4. **BSW2-4 Baseline screened data, weeks 2-4.**

Treatment Data:

The following data sets were considered for the lighting treatment analyses.

1. **C Complete data set.**

   The complete data set included all four weeks of data within each trial period, and therefore had the largest number of participants and data points.

   This data set did not include a washout period. Estimates of the size of the carryover effect, if present, were not possible to estimate accurately and therefore a one week washout was imposed for all other data sets.

2. **CW Complete data set with washout.**
3. **SW Screened data set with washout.**

   Data sets CW and SW included a one week washout period, enabling participants to adjust to the new lighting treatment and allowing any carryover effect from the previous lighting treatment to abate.

4. **CW-CVB Complete data set with washout – covariate baseline**
5. **SW-CVB Screened data set with washout – covariate baseline**

   As previously outlined, differences between the participants in the three offices may introduce a bias to the data that may lead to inaccurate estimates of treatment effects (Ott, 1993). In these analyses, the baseline data and thus the treatments were adjusted for any pre-existing differences between offices. The baseline data used in these analyses were data set BW2-4 and BSW2-4, the average symptom severity data from weeks two, three and four of the baseline period.

[31] Symptoms that remained after leaving the work environment were excluded.

6. **CW-CVA** **Complete data set with washout – covariate age**
7. **CW-CVG** **Complete data set with washout – covariate gender**

In these analyses age and gender were treated as covariates. Research literature has shown that the age and gender of participants may influence the incidence and severity of symptoms experienced (Skov et al., 1989; Hedge, 1990). Therefore this information was treated as a covariate in the data to determine the effect, if any, of these factors.

8. **C-S** **Complete data set - symptoms only**
9. **CW-S** **Complete data set with washout - symptoms only**
10. **SW-S** **Screened data set with washout – symptoms only**

These analyses only included participant responses when symptoms were experienced. Therefore this data focused upon differences in symptom severity, not incidence.

This data set considered those participants who may have been more sensitive to environmental conditions in the workplace.

Weekly Average Symptom Severity

A repeated measures analysis using the weekly average responses was undertaken to obtain an estimate of carryover effects. This data was not used to provide estimates of treatment effects due to insufficient data points.

In this study, the majority of participants did not work every shift throughout the week; therefore it was not possible to obtain daily data from the participants. In lieu of this data, the weekly average was calculated.

However, data was not available from all participants on a weekly basis and for some participants, data was not available in every treatment period[32]. Therefore the repeated measures analysis contained insufficient data points to provide accurate

[32] This data may have been unavailable because the participant did not complete the questionnaire, were not exposed to the lighting treatment or did not work these shifts.

estimates of carryover effects. Thus, while the results of the analyses are briefly reported and discussed, it has been assumed that a one week washout provides sufficient time to ensure that carryover effects abate.

Assumptions Underlying the Analysis of Variance

All data sets were checked to ensure that they satisfied the assumptions for the ANOVA.

Firstly, ANOVA assumes that the response variable is continuous. The symptom severity data collected in this study was ordinal, however it could be treated as continuous data as the responses were collected on a 7 point Likert scale that was subsequently averaged over a weekly or monthly period. The other main assumptions are:

Additivity

ANOVA requires treatment effects to be additive, as opposed to multiplicative. Profile plots were used to examine differences between treatments, as large differences suggest that a multiplicative model may be suitable and that transformation of the data set may be required.

Normality

ANOVA requires normally distributed data. Standardised residuals from fitted models were used to examine this assumption by generating the Shiparo-Wilks test statistic, skewness[33] and kurtosis[34] values, and by visually examining scatter plots and normal probability plots and histograms. The normality assumption is typically checked on the overall residuals from an ANOVA. As the residual data are not independent (the residuals within a treatment group will be correlated), the visual examination is a crude check for normality. Shiparo-Wilks formally tests the

[33] Compares the spread of deviations on either side of the mean.

[34] Compares the heaviness of the tails of a distribution.

normality of the data, however the actual error level and p-value will only be approximate (Weber & Skillings, 2000).

Homogeneity of Variances

ANOVA requires the data from each treatment to have equivalent variability. The homogeneity of the treatment data was visually examined by plotting standardised residuals (residual vs. predicted (fitted) values) and by generating the Levene's test statistic[35].

Independence

Finally, ANOVA requires independence of observations. This assumption cannot be tested, and is usually met by appropriate statistical design. In this study it was assumed that the participants were independent and did not collude in their questionnaire responses. The crossover design employed ensures statistical independence.

Extreme Data Points

In addition, the standardised residual data was examined for extreme or unusual data points. Within a treatment group, almost all residuals should lie within approximately three standard deviations (SD) of the mean (zero), with any observation outside this being a possible (potential) outlier. Observations more than approximately five standard deviations outside of the mean are probable outliers. Outliers can be extremely influential, and therefore the data was carefully examined to ensure that any outliers were not erroneous or atypical values.

Removing extreme values must be done with caution, as there is a danger of introducing bias to the data when data points are removed without justification. Extreme values were examined in relation to the rest of the data set, other responses from the individual and with reference to medical factors that may have been influential to determine if they were consistent with the rest of the data. Outliers

[35] Tests the homogeneity of variance between groups.

(greater than three standard deviations) were deleted from the data set and changes to the ANOVA results discussed.

Transformation of Data

Where the data did not meet the requisite assumptions, the relationship between treatment means and the standard deviation was examined for the raw data, the log and square root transformed data, to determine whether these standard transformations would lead to justification of the basic assumptions.

Multiple Comparison Tests

The F-Test generated by ANOVA does not indicate which of the treatment means are different, it only indicates whether there are significant differences among the means. Therefore Multiple Comparison Tests (MCP's) were used in conjunction with ANOVA to determine how the treatments differ, by performing pairwise treatment comparisons.

There are two types of MCP's. The first of these performs comparisons on all treatment pairs and thus are described as controlling the comparison wise (CW) error rate. The second type of MCP controls the experiment wise (EW) error rate by generating an overall error based upon the number of comparisons carried out. MCP's that control the CW error are less conservative and may inflate the Type I error rate (chance of detecting an effect when it does not exist). In comparison, MCP's that control the EW error are more conservative, but may inflate the Type II error rate (chance of not detecting a significant effect). As this study was exploratory, a MCP that controls the CW error rate was more appropriate. '*The other possibility is to use data snooping*[36] *comparisons as a basis for generating a hypothesis that must be confirmed in future testing. Here the data snooping comparisons serve an exploratory or hypothesis-generating, role...*' (Ott, 2000). In this study, Duncan's multiple range test was selected. Duncan's test controls the comparison wise error

[36] When comparisons are not selected a priori or when all comparisons are investigated then the Type I error is inflated and this practice is often called data snooping, particularly if CW error rates are used.

rate, but is not the least conservative of these tests. This test is also robust to unequal sample sizes provided the difference between sample sizes is not too large. *'If more power is desired and at the same time a higher error level than* α[37] *can be tolerated...then the Duncan procedure should suffice'* (Weber & Skillings, 2000)).

2.9 Actual Productivity

The management in Offices One and Two collected the actual productivity data from the participants. In both offices, the number of data units was recorded for a fixed time period and the hourly average was calculated from these totals. Office Three did not record the number of units entered and therefore this data was unavailable for analysis.

As data was only available from two of the three offices, and the study was designed to fit a crossover design, this section was exploratory in nature. Limited statistical analyses were carried out, with the data visually examined to assess if relationships were present, and the results discussed in light of the other data collected. The analysis considered the relationship between the actual productivity of the participants and lighting treatments; workplace symptoms; perceived productivity; and satisfaction with the work environment.

Several data sets were examined:

1. **The complete data set including the baseline (C+B).** This data set maximised the data points available for the analyses increasing the statistical power and minimising the risk of a Type II (β) error;
2. **The complete data set (C) & complete data set with washout (CW);**
3. **The symptoms only data set (CS).** This data set ignores symptom incidence (symptom severity = 1), as this was shown to differ from symptom severity in the lighting treatment analysis and included a large number of responses that may have been unduly influential in the regression analyses.

[37] In this study α (alpha) refers to an anticipated significance level of 0.05.

The data from each individual was examined to determine the variability within individual responses. Individual data points were examined, and inconsistent or unusual data points were excluded. Productivity counts between 500 and 1500 entries per hour were included in the analyses. Counts above and below these were assumed to be incorrectly entered, or influential, and were excluded. Participants who had been employed for less than six months or whose productivity count increased over the study period had their data excluded.

A T-test was conducted on the weekly average counts across the study to determine if the actual productivity data sets from Offices Two and Three could be combined for analyses. The data was then visually examined using scatter and box plots, in conjunction with linear regression.

2.10 Perception of the Work Environment, Symptoms and Lighting Treatments

Questionnaire data was also collected on the satisfaction that occupants had with air movement, temperature, lighting and overall satisfaction with the work environment. An additional question asked respondents to outline other aspects of the work environment that they liked or disliked. These results were initially examined graphically to explore the participants' perception of the office environment and differences between the three offices.

The analysis considered the relationship between perceptual measures (including satisfaction with office lighting, perceived productivity), symptom severity and lighting treatments, using a chi square test for independence. Correspondence analysis was used to interpret the data graphically.

Chi Square analysis utilises categorical data to test the relationship or association between two sets of variables, by testing the hypothesis that the two variables are independent (Moore and McCabe, 1993). The analysis compares the expected cell

counts (data distribution) on a contingency table with the actual cell counts. The extent of variation between the two values is used to determine if the two data sets are dependent or related.

In this analysis, the raw data was collected on a seven point Likert scale as either daily or weekly responses, with daily responses combined to give a weekly average. The data was then grouped into categories to enable statistical processing and interpretation of the graphical display (Table 12). The number of categories were based on the number of participant responses in each group. Categories with less than five responses were merged[38] to allow meaningful analysis to be carried out.

Correspondence analysis (CA) was then used to graphically interpret the data and determine where differences existed. CA is a weighted, component analysis, of a contingency table that enables the relationship between categories to be shown graphically (Greenacre, 1993). The initial statistical processing is similar to chi square analysis. Expected values are then normalised and lower dimensional solutions are generated in the same manner as Principle Component Analysis (PCA) (Manly, 1994). These dimensions are derived from the total inertia within the categories (similar to the total variation in PCA and proportional to the chi square statistic). The dimensions are then plotted, with the first principle axis accounting for most of the inertia, the second explaining the second largest proportion etc. These two dimensions typically explain the majority of the inertia and can be plotted as a two dimensional graph which relates the rows and columns as points in a single plot.

The initial analysis ignored treatment differences and was used to determine if the perceived effect of the work environment on productivity or satisfaction with lighting was associated with eyestrain, headache or lethargy symptoms experienced in the workplace. These analyses were carried out using both the complete and screened data sets and considered all responses (including the baseline and washout periods) to maximise the size of the data set. Further analysis examined the relationship between perceived productivity and satisfaction measures within each treatment period and office, utilising the complete data set. A one week washout period was excluded from

[38] Chi square analysis produces reliable results when there are at least five counts per cell.

the treatment data. Finally the relationship between perceived productivity and satisfaction with lighting, air circulation, temperature, job satisfaction and the overall work environment was explored.

Table 12. *Grouping questionnaire measures into categories for chi square analysis*

Response Variables		Grouping of categories						
Perceived Productivity	Questionnaire measure	sig. decreased productivity			no impact on productivity			sig. increased productivity
		-3	-2	-1	0	1	2	3
	Chi square grouping	decreased productivity			no impact on productivity	increased productivity		
Workplace Symptoms	Questionnaire measure	no symptoms						very severe symptoms
		1	2	3	4	5	6	7
	Chi square grouping	no symptoms	mild symptoms			severe symptoms		
		no symptoms	symptoms					
Satisfaction	Questionnaire measure	very dissatisfied			indifferent			very satisfied
		-3	-2	-1	0	1	2	3
	Chi square grouping	dissatisfied			indifferent	satisfied		

2.11 Environmental Monitoring

Aspects of the office environment including illuminance, luminance, reflectance, temperature, humidity and carbon dioxide levels, particulates and noise were monitored during the study period and compared to New Zealand and international standards (Chapter 4). Where parameters did not meet recommended levels, these were discussed in relation to the symptoms experienced by the occupants and effects on the data.

2.12 Medical Study

A number of participants (26) took part in a medical study (Chapter 5). This study examined the symptoms experienced by the participants in detail, and was used to

determine the extent to which workplace factors or physiological characteristics may explain symptomatic responses.

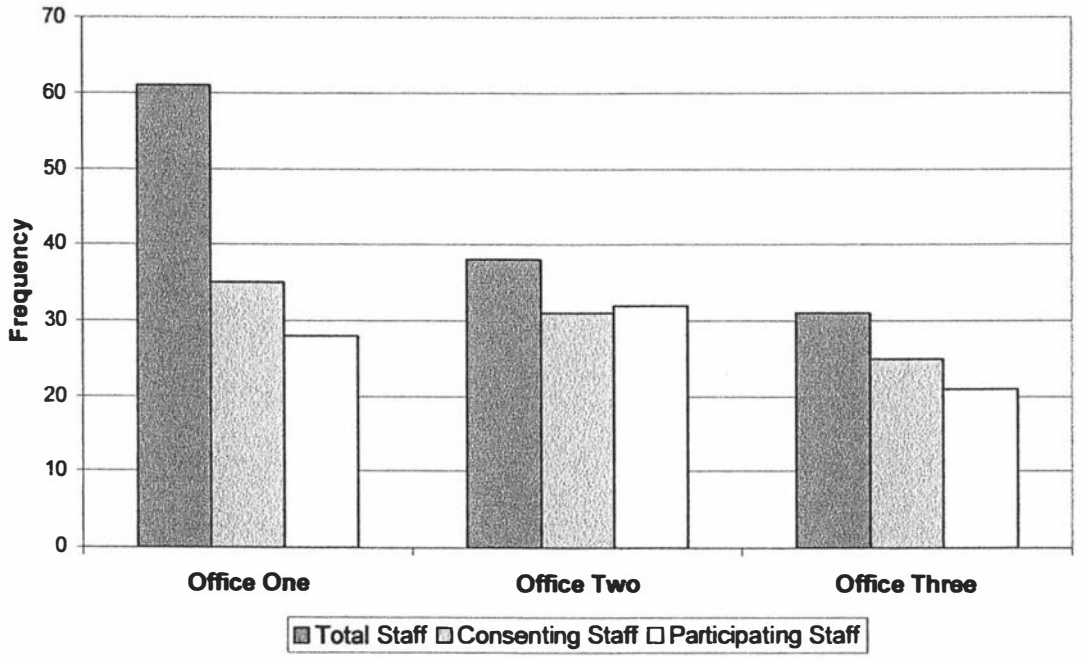
The medical examination was administered by an occupational health physician in conjunction with a detailed questionnaire, and was used to examine the nature of the symptoms experienced by office personnel; physiological characteristics that may have influenced symptoms; and aspects of the workplace that may have contributed to the symptoms. In addition, the medical study was used to identify individual characteristics that may have influenced susceptibility to the lighting system.

3 Results and Discussion

3.1 Participation in Study

The number of staff who agreed to participate in the study was comparable to those initially calculated in both Offices Two and Three with 80% of staff completing consent forms (Table 13). However, the participation rates in Office One were lower with only 57% of staff agreeing to participate. Office One had the greatest number of staff, but lower participation and higher attrition. Office Two had the highest overall participation and minimal attrition. Office Three had the smallest number of personnel.

Figure 18. Participation in Study



Section One of Table 13 shows the total staff in the offices at the time of the study, the number of staff agreeing to participate, and the number of staff from whom usable data was available after screening. This data is shown graphically in Figure 18. Data was excluded if participants were not exposed to the lighting treatments, were managers, unwell (for a prolonged period) or pregnant. The number of staff who

agreed to participate, but then subsequently did not complete the study, or left the work place throughout the study are also identified.

Table 13. *Participation in the study*

		Office One	Office Two	Office Three	Total
Section One					
Recruitment and Attrition	Total number of staff	61	38	31	130
	Completion of consent form	35	31	25	89
	Number of participants (after screening)	28	32	21	81
	Did not complete study	5	2	6	13
	Left workplace	4	0	1	5
Section Two					
Number of data points[39] included in primary analysis (monthly average symptom severity)	Baseline 1	17	21	20	58
	Trial 1	16	24	15	55
	Trial 2	20	24	17	61
	Trial 3	15	23	13	51
	Baseline 2[40]	11	16	10	47
Section Three					
Number of data points included in primary analysis with washout period included (monthly average symptom severity)	Baseline 1	14	19	18	51
	Trial 1	14	24	15	53
	Trial 2	16	22	16	54
	Trial 3	13	21	11	45
	Baseline 2	8	8	8	24
Section Four					
Number of participants completing all four weeks in each trial period	Trial 1	7	11	6	24
	Trial 2	4	14	7	25
	Trial 3	1	10	5	16

Section Two of Table 13 summarises the number of participants whose data was used in the primary analysis. In Office Two, where all participants were exposed to the lighting treatments, the majority of participants had usable data. However, in Offices One and Three, where not all participants were exposed to the lighting treatment during their work shifts, or when participants frequently worked in more than one

[39] Frequency of participants providing data in each trial period.

[40] Only two weeks of data was collected in Baseline Two.

space, between 20% and 40% of the data was excluded. Figure 19 summarises this data graphically.

Section Three of Table 13 shows the number of participants whose data was available with the washout period included. Section Four shows the number of participants who completed all four weeks in each trial period. It is clear that usable data was not available from all participants on a weekly or trial basis. This is particularly apparent in Trial Three of Office One, where only one participant completed all four weekly questionnaires. In all three offices, less than half of the participants provided usable data for all four weeks of each trial period.

Figure 19. Number of data points included in primary analysis (monthly average symptom severity).

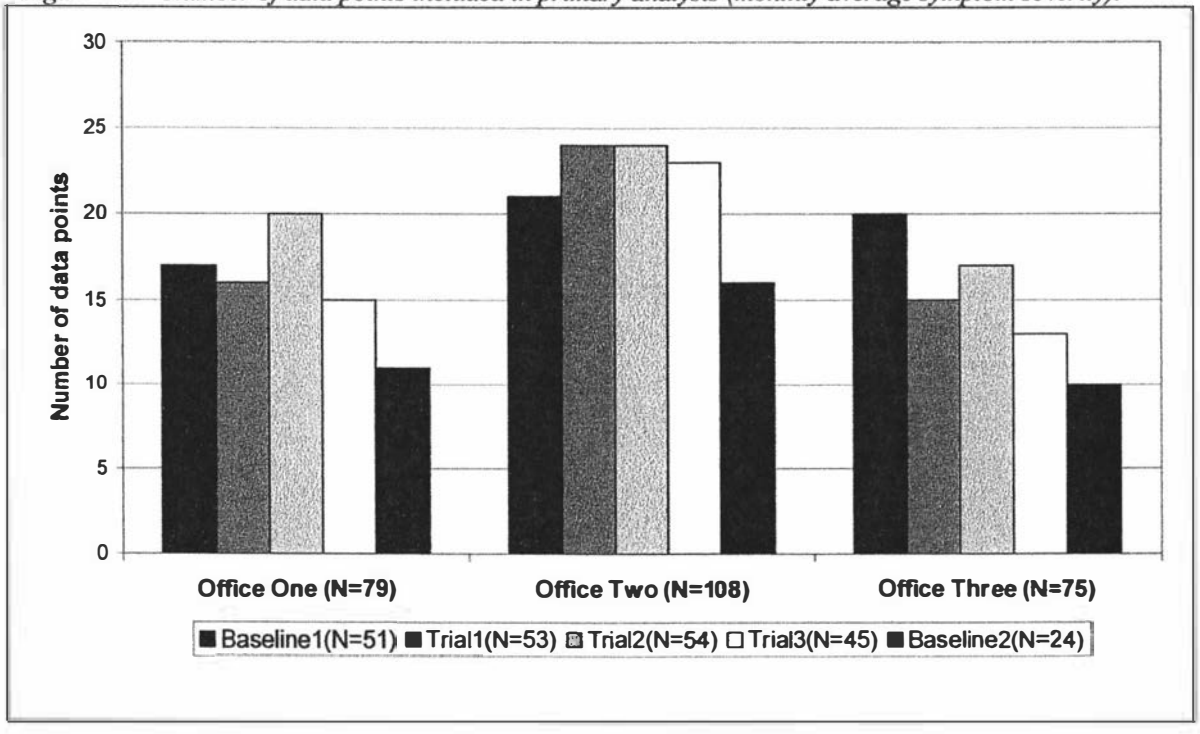


Table 14 shows the number of participants in each office who provided usable data for each trial period. In Offices Two and Three, the majority of participants contributed usable data to all three trial periods. These participants completed at least one questionnaire in each trial period, in a room with the experimental lighting treatment installed. This data was then used to calculate the monthly average eyestrain, headache and lethargy symptom severity. However in Office One, many of the participants only contributed data to one or two of the trial periods.

Table 14. Number of participants in each office who provided usable data in all three, two or only one lighting trial.

Number of trial periods	Office One	Office Two	Office Three
3	11	18	11
2	4	7	5
1	10	3	2

Discussion – Participation in Study

Participation in the study was slightly lower than anticipated, with the number of participants providing usable data in Offices One, Two and Three at 28, 32 and 21 respectively. Attrition rates were higher than expected in Office One. In addition, the majority of participants did not provide usable data for all weeks of each trial period, and many also did not provide usable data in each trial period.

There were substantial differences in participation rates and the amount of usable data in each of the three offices. Initial participation rates and quantity of usable data was much greater in Office Two in comparison to the other offices. All participants were exposed to the experimental lighting treatments in this office, and thus provided usable data for subsequent analyses. A high proportion of the staff in this office were either students or had recently been students, thus the office staff may have had a greater appreciation of the study aims and heightened willingness to participate[41] and the office supervisor was very supportive of the study.

Office One had low participation rates in relation to the other offices. The office restructuring taking place at the beginning of the study, the larger office population and the new staff additions are probable contributors to lower participation rates. Also, the room in which the experimental lighting was installed adjoined a larger room. A number of participants worked in this room at the beginning of their work shift, moving to the room with the experimental lighting treatment later in their shift. Data from these participants was not included in the analyses.

[41] The number of students in this office as described by the supervisor did not appear to be accurately reflected in the number of participants who identified themselves as students.

The consequences of lower participation rates, and reduced availability of usable data from weekly questionnaires and treatment periods were threefold. Firstly, the numbers of participants whose data was available for analyses was reduced, with subsequent reduction in the power of the analyses. Secondly, the crossover design of the study was compromised[42], as many participants did not provide data for all three lighting treatments. Thirdly, the weekly repeated measures analysis was not able to provide accurate measures of carryover or treatment effects.

Overall, the participation numbers fall marginally short of the required 20 subjects per office as concluded in the Power Analysis for the monthly average symptom data (Appendices E & F). Further, as the Power Analysis was based upon the assumption that participants provided usable data for all lighting treatments, the β risk was likely to have been higher than calculated. The calculated β risk was 0.09, (the power of the test being 0.91) if the difference in mean eye symptoms was as large as 1[43]. The results showed that the difference in mean symptoms was not that large (Section 3.4: Monthly Average Symptoms Analyses). Participants in the pilot study reported higher symptom severity with a greater variance than in the main study, therefore the number of participants required for the main study may have been less than was calculated from the pilot study responses[44]. However, given the lower than anticipated participation rate, the smaller difference in mean symptom severity and the limitations of the power study undertaken, it seems evident that the β risk is likely to be at least somewhat decreased. In statistical terms this increases the probability of accepting the null hypothesis and a significant effect is less likely to be found.

Forty participants were required to provide usable weekly data throughout the study in order to detect a similar sized effect for the repeated measures analysis. Given the

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[42] Both the ANOVA and the Duncan's MCP test consider unequal sample sizes, so although the unbalancedness of the data was not optimal, the analyses were selected to minimise any impact this might have on the outcomes.

[43] This was based on the estimates from the ten point Likert scale used in the pilot study, as opposed to the seven point Likert scale that was subsequently used in the interventional study.

[44] Eye symptoms. Pilot study: mean 2.30; std dev 1.48. Main study (complete data set): mean 1.48-1.86; std dev 0.63 – 1.11.

data available, these analyses would provide highly inaccurate estimates of treatment effects therefore treatment results are not reported. This analysis was undertaken to provide estimates of any carryover effect that may be present.

The results reported above suggest that the study may be more appropriately treated as exploratory, or as a large pilot study that contributes to the research findings in this field and highlights methodological approaches for further research.

3.2 *Characteristics of Participants in the Research Study*

This section of the results outlines demographic and health characteristics of participants that may have influenced lighting related symptoms.

Data was available from participants who completed Section A of the questionnaire. This included 70% of participants in Offices One and Two and 80% of participants in Office Three. Further information on the characteristics of the office personnel and effects that they may have on symptoms is discussed in Chapter Five (Medical Study).

Age and Gender of participants

Table 15. *Age and Gender of Participants*[45]

		Office One	Office Two	Office Three	Total
Age	< 20	1	2	0	3
	20-29	13	10	8	31
	30-39	4	7	3	14
	40+	1	4	3	8
	Total	19	23	14	56
Gender	Female	15	13	14	42
	Male	5	10	3	18
	Total	20	23	17	60

[45] Totals do not match between demographic characteristics as not all participants completed the questionnaire or specific sections of the questionnaire

The majority of participants were aged between 20 and 40 (Table 15) with the largest single grouping within the 20-29 year age group (55%). More than two thirds of the total office population were female (70%), with the greatest proportion of males in Office Two (43%).

Tobacco Smoking Habits/Status of Participants

More than half the participants had never smoked (53%), while a further third were current smokers. These proportions were similar in all three offices (Table 16).

Table 16. Tobacco smoking status of participants

	Office One	Office Two	Office Three	Total
Current smoker	6	5	8	19
Former smoker	5	4	0	9
Never smoked	9	14	9	32
Total	20	23	17	60

Visual Acuity

Table 17. Visual Acuity of Participants

		Office One	Office Two	Office Three	Total
Vision last tested	Never tested	3	5	4	12
	Tested more than two years ago	11	7	4	22
	Tested less than two years ago	6	11	9	26
	Total	20	23	17	60
Use of visual aids	Glasses worn	6	9	7	22
	Contact lenses worn	2	1	1	4
	Neither glasses or contact lenses worn	10	12	9	31
	Total	18	22	17	57
Visual impairment	Short sighted	8	9	4	21
	Far sighted	3	2	3	5
	Don't know	2	3	4	9
	Total	13	14	11	38

Almost half of the participants wore corrective glasses or contact lenses (46%) and of these more than two thirds were short sighted reflecting the age distribution of the participants and the high proportion of tertiary students (Table 17)[46]. Those who wore corrective lenses made up the majority of the participants whom had their vision tested within the previous two years (43%), with a further 37% tested more than two years ago.

Medical Conditions

Medical conditions that may have affected asthenopic symptoms were included in the questionnaire (Table 18). Participants listed conditions experienced within the last two years and if treatment was currently being administered. Eight of the participants had experienced eye infections in the last two years, however none of these were being treated, so it was assumed that these conditions were not experienced during the course of the research study. Fourteen of the participants, (almost 25%) self-identified as experiencing migraine.

Table 18. *Incidence of medical conditions that may influence vision related health symptoms*

	Office One	Office Two	Office Three	Total
Eye Infections	4	3	1	8
Cataracts	0	1	0	1
Glaucoma	0	0	0	0
Retinal Problems	2	0	0	2
Migraine	4	4 (+2*)	4	14
Diabetes	0	0	1*	1
Thyroid Problems	1*	0	0	1
High Blood Pressure	0	0	1 (+1*)	2
Depression	2	1	0	3

**The participant was being treated/receiving medication for this condition.*

[46] Participants aged between 20-29 and those who are involved in close work have a higher incidence of myopia (personal communication Dr R. Jacobs, Head of School of Optometry, Auckland University, 2003)

Almost half of the participants who experienced migraine and two participants who experienced depression or high blood pressure reported unusually severe symptoms[47], suggesting that these medical conditions may have influenced symptom incidence and severity.

Employment Demographics

Table 19. Employment Demographics

		Office One	Office Two	Office Three	Total
Number of years as a data entry operator	<1 year	8	3	4	15
	1 – 2	5	4	1	10
	2 – 3	3	7	2	12
	3 +	4	8	10	22
	Total	20	22	17	59
Other vocations or employment	Only paid employment	15	18	8	41
	Other full time employment	1	2	3	6
	Other part time employment	4	-	-	4
	Full time tertiary study	9	5	1	15
	Part time tertiary study	1	2	1	4
	Homemaker	2	1	2	5
	Homemaker with children	5	7	6	18
Hours of employment	1 – 9	3	-	-	3
	10 – 19	8	11	7	26
	20 – 29	5	4	1	10
	30 – 39	5	6	3	14
	40 +	2	-	2	4
	Total	23	21	13	57
Number of shifts per week	1 – 2	3	7	2	12
	2 – 3	6	2	6	14
	3 – 4	3	4	-	7
	4 – 5	11	8	5	24
	Total	23	21	13	57

[47] Symptoms that were identified as outliers in the ANOVA, or participants reporting unusually severe symptoms throughout the study.

The majority of participants (75%) had been employed as data entry operators for more than a year (Table 19). Offices Two and Three had a high proportion of long term staff, whereas the largest proportion of participants in Office One had been employed for less than one year.

In all three offices, data entry was the primary source of employment, although some participants had other full time or part time positions. Up to one third of participants were full time or part time students, with the majority of these in Office One or Two. An additional third of participants identified themselves as homemakers with children[48].

The majority of participants worked between two and five shifts per week and between 10-40 hours per week, with the largest proportion employed 10-19 hours per week.

Discussion

The data outlined in this section describes those participants who took part in the study and completed the demographic questionnaire. Not all participants completed this section; therefore it is possible that the spread of data is inaccurate. For example, the proportion of students in Office Two is lower than was expected based on discussions with office management.

The three offices did not appear to differ significantly with respect to age, smoking habits and visual acuity. Office Two had a higher proportion of male participants. The data did not suggest that any one of the three offices had a higher proportion of medical conditions that may have affected symptom incidence or severity.

Age and gender have been shown to be positively correlated to workplace symptoms, with women and those aged between 20 and 30 most likely to experience Sick Building Syndrome symptoms, to experience symptoms more frequently and feel that symptoms are more severe (Skov et al., 1989; Godish, 1994). As the demographics of

[48] Some of these participants were also students.

this study indicate a high proportion of personnel fit into this category, it is possible that as a group, the occupants experienced higher symptom incidence and severity than other groups of office workers. However, symptom incidence and severity was not shown to differ significantly with age and gender when these variables were treated as covariates in the ANOVA. In addition, the higher proportion of males in Office Two was not reflected in lower symptom severity in this office.

More than half of the participants had not had their eyesight tested for more than two years. When this data is examined in relation to the results of the Medical Study (Chapter Five) it suggests that for many, visual impairment may be a plausible contributor to eyestrain and headache symptoms. Almost one third of participants in the medical study were found to have visual difficulties and these were highlighted as a significant contributor to eyestrain and headache symptoms.

Almost half of the participants who self reported experiencing migraine were found to have unusually severe symptoms. In the Medical Study, the occupational physician found that muscular strain and high blood pressure were significant contributors to headaches (and migraine) experienced in the workplace.

Participants in Office Three appeared to be less transient than those in Offices One or Two with almost 60% of the participants employed for more than three years, a greater proportion of homemakers with children and few staff undertaking tertiary study. In contrast, Office One appears to have had a higher turnover of staff, with the highest proportion of participants employed for less than one year. This may be due to the office restructuring and the addition of new staff at the beginning of the study period. This office had the lowest participation rate, and reported the lowest symptom incidence and severity.

Many of the research participants had other vocations, including other part time work, tertiary study and childcare. These were identified as probable contributors to symptoms in the Medical Study.

Overall, the demographic age and gender grouping, a work environment in which they have limited control, and the additional vocations of this population, suggests that this group of participants, in comparison to other groups of office workers, may report higher levels of workplace symptoms. Shift work has also been shown to influence workers' physical and mental health and well being (Mellor, 1986). As a similar study is not available to compare these results, this is not known. However, at least some of the symptoms experienced by the office personnel may be attributed to medical conditions and in many cases these may be reduced by regular physical examinations. Repeating this study with other data entry populations and office worker populations would determine whether these results are equally applicable for these populations.

3.3 Symptom Severity and Lighting Treatments

Summary

The relationship between symptom severity and lighting treatments was explored by Analysis of Variance (ANOVA), with Duncan multiple range comparison test used to determine specific differences between treatments.

The data was initially screened and extraneous values excluded from the analysis. Each data set was examined to determine if the assumptions of ANOVA were met and influential responses were identified.

The initial analysis considered data from the baseline period in order to determine if significant differences existed between the occupants in the three offices. There was some evidence to suggest that this may be the case, and therefore, analyses that treated the baseline data as a covariate were undertaken.

ANOVA was then used to examine the average eyestrain, headache and lethargy symptoms experienced by the participants during each treatment period, in order to determine if differences between lighting treatments, trials and offices existed and any interactions between these variables.

The visual examination of the data set in combination with the statistical tests revealed that the ANOVA assumptions were not met with respect to normality and homogeneity in many of the data sets. The data sets were examined after removal of extreme values and standard transformations (square root and logarithm) were attempted, but these did not improve the data to any large extent. Other transformations, plus non-parametric analyses were considered, but when balanced against the other limitations of the data set, plus the complexity in interpretation, it was concluded that there would be little advantage or gain in statistical validity by conducting further complicated transformations. The violations of assumptions were not extreme and therefore the raw untransformed data was used for the analysis in this piece of work.

Primary analysis examined the symptoms experienced by the participants in relation to lighting treatments, trials and offices. A number of data sets were analysed that considered factors that may have influenced the experimental outcomes. These included: screening non work related symptoms, treating the baseline symptoms, age and gender data as covariates, including a washout period, and excluding responses in which the participants had no symptoms. Duncan's multiple comparison test was then used to determine where the significant differences lay. Finally, a repeated measures analysis was undertaken to determine if differences were present between weekly data sets, thus providing some evidence to support a carryover effect from the previous lighting treatment.

Baseline Data – Differences in Symptom Severity between Offices

The data from the baseline period was initially examined to determine if significant differences existed between the three offices. If the three offices differ then the main data set should be adjusted for these differences by treating the baseline data as a covariate. The baseline data did not represent a perfectly level 'playing field' as is discussed in Chapter Two (Experimental Methodology). However it will still be of use in determining if office differences are present.

The ANOVA was run on the following data sets and the residual data was examined to check that assumptions were met:

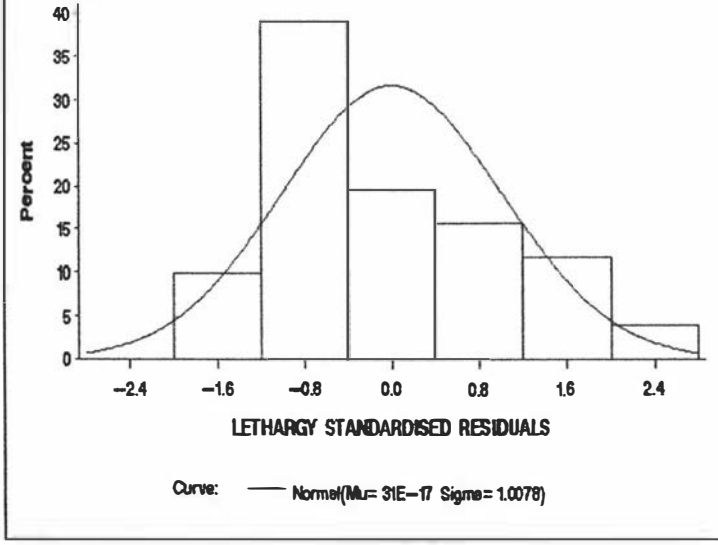
1. **BW4 Baseline data, week four only (three week washout);**
2. **BSW4 Baseline screened data, week four only;**
3. **BW2-4 Baseline data, weeks 2-4 (one week washout);**
4. **BSW2-4 Baseline screened data, weeks 2-4.**

Assumptions underlying the Analysis of Variance

The standardised residual data was used to check that the assumptions of normality and homogeneity of variance were met. The normality assumption was visually examined using normal probability plots and histograms. The Shiparo-Wilks test statistic (S-W), skewness and kurtosis values were also calculated.

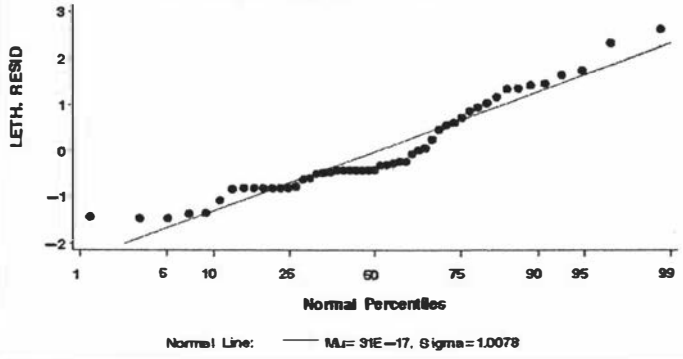
The normal probability plots and histograms revealed moderate non-normality. Typical examples of these graphs are shown in Figure 20 and Figure 21. Skew and kurtosis values for the data sets were within the acceptance range. However all data sets gave significant Shiparo-Wilks test statistic ($0.0001<p<0.002$), with data sets BW4 and BSW4 (three week washout period) showing greater non normality.

Figure 20. Standardised residual histogram plot of lethargy symptom severity with normal curve superimposed (Data set BW2-4).



The homogeneity of the treatment data set was visually examined using standardised residual plots and by Levene's test. The majority of tests gave statistically significant values for Levene's test ($0.0001<p<0.1$). It was clear from the standardised residual plots that Office Two had much greater variability than Offices One and Three in the majority of the data sets (Figure 22).

Figure 21. Standardised residual normal probability plot of baseline lethargy symptoms(Data set BW2-4)



Examination of the extreme data points revealed that only one data point was a probable outlier. This data point was from an occupant in Office Two, who only gave one response that was included in Data Sets BW4 and BSW4. The reported symptom was substantially higher than other responses. This data point was excluded from the final analyses.

The variance in the majority of data sets was substantial, in some cases greater than the mean value for the offices, suggesting that transformation of the raw data may be appropriate. A comparison of the standard error for the raw and transformed data sets showed that this value may be able to be reduced by a log transformation of the data. However, as results from the baseline analysis showed similar patterns to that of the main data set[49], transformations were not undertaken.

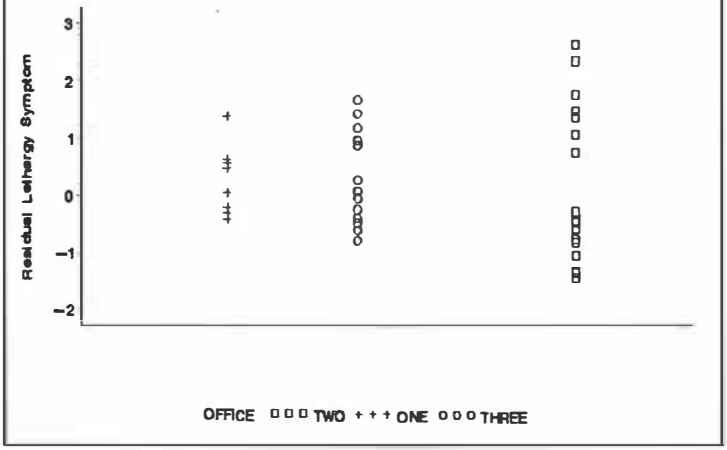
Office Differences – Eyestrain, Headache and Lethargy Symptoms

The results (Table 20) indicate that participants in Office Two reported higher average symptom severity than either Office One or Three. In Data Sets BW2-4 and BSW2-4, eyestrain, headache and lethargy symptoms were significantly more severe in Office

[49] The main data set was not transformed.

Two. For Data Set BW4 and BSW4 only eyestrain symptoms were significantly more severe.

Figure 22. Residual vs predicted lethargy symptom severity (Data set BW2-4)



Discussion: Baseline Lighting Treatment Data

The intention of this analysis was to determine if the symptoms experienced by participants varied between the offices, therefore no further analysis was carried out on the data. It was clear from the results thus far, that although the data sets did not meet all ANOVA assumptions, Office Two was sufficiently different in a number of the analyses to suggest that differences between offices may be influential. However, these results should be interpreted with some caution. As was discussed in the introduction, the baseline data was not produced in a homogenous environment, and this may have affected the level of symptoms reported by the participants. In addition, the baseline data does not meet all the ANOVA assumptions and not all analyses showed that office differences were present. While ANOVA is robust to small violations of normality and homogeneity, the other limitations of the data sets suggests caution. As previously discussed, data sets BW4 and BSW4 were collected when participants were probably adapted to the baseline conditions, but only a small number of data points were used in the analysis. This was reflected in the variance in the data sets.

Given the possible flaws in the baseline data it would be inappropriate to only consider analyses that treat the baseline period as a covariate. However, these

analyses should certainly be included in order to enable useful inferences to be made. Data sets BW2-4 and BSW2-4 were treated as covariates in analyses CW-CVB and SW-CVB respectively.

Table 20. *Results of ANOVA – Baseline data.*

Symptom	MSE value[50]	F Test	p-value	Treatment	N[51]	Mean	Duncan[52]
Data set BW4 – Complete data set: three-week washout							
Eyestrain symptoms	0.97	5.17	0.01	Off. 1	10	1.18	B
				Off. 2	15	2.30	A
				Off. 3	12	1.31	B
Headache[53] symptoms	0.90	2.21	0.13	Off. 1	10	1.49	A
				Off. 2	14	2.05	A
				Off. 3	12	1.30	A
Lethargy symptoms	1.22	1.5	0.23	Off. 1	10	1.44	A
				Off. 2	15	2.20	A
				Off. 3	12	2.03	A
Data set BSW4 - Screened data set: three week washout							
Eyestrain symptoms	0.96	5.57	0.01	Off. 1	10	1.18	B
				Off. 2	15	2.30	A
				Off. 3	11	1.21	B
Headache symptoms	1.32	2.12	0.14	Off. 1	10	1.44	A
				Off. 2	15	1.90	A
				Off. 3	11	1.33	A
Lethargy symptoms	0.98	1.01	0.38	Off. 1	10	1.43	A
				Off. 2	13	2.01	A
				Off. 3	11	1.70	A
Data set BW2-4 – Complete data set: one week washout							
Eyestrain symptoms	0.85	14.35	0.0001	Off. 1	14	1.22	B
				Off. 2	19	2.74	A
				Off. 3	18	1.40	B

[50] The MSE value is the Mean Squared Error value and is an estimate of the within-group variance (σ^2). Table 21 provides the standard deviations for each lighting treatment condition for the complete data set.

[51] The average monthly symptom severity provided by N participants exposed to this lighting treatment condition.

[52] Groups with the same letter are not significantly different.

[53] One outlier was removed.

Headache symptoms	0.84	5.12	0.01	Off. 1 Off. 2 Off. 3	14 19 18	1.67 2.35 1.42	B A B
Lethargy symptoms	1.38	4.43	0.02	Off. 1 Off. 2 Off. 3	14 19 18	1.45 2.64 1.90	B A A/B
Data set BSW2-4 - Screened data set: one week washout							
Eyestrain symptoms	0.80	15.63	0.0001	Off. 1 Off. 2 Off. 3	14 19 17	1.20 2.72 1.32	B A B
Headache symptoms	0.86	4.61	0.02	Off. 1 Off. 2 Off. 3	14 19 17	1.54 2.30 1.45	B A B
Lethargy symptoms	1.28	3.55	0.04	Off. 1 Off. 2 Off. 3	14 17 17	1.41 2.47 1.80	B A A/B

3.4 Monthly Average Symptoms Analysis

The following data sets (monthly average) were tested to determine if there were differences in the symptoms experienced by participants in the different lighting treatments, offices, trials or if any interaction was present.

The following data sets were considered.

1. **C** **Complete data set;**
2. **CW** **Complete data set with one week washout;**
3. **SW** **Screened[54] data set with one week washout;**
4. **CW-CVB Complete data set with washout – covariate baseline;**
5. **SW-CVB Screened data set with washout – covariate baseline;**
6. **CW-CVA Complete data set with washout – covariate age;**
7. **CW-CVG Complete data set with washout – covariate gender;**
8. **C-S** **Complete data set - symptoms only;**

[54] Responses from participants in which symptoms did not reduce or disappear at the end of the work shift were excluded.

9. **CW-S** **Complete data set with washout - symptoms only;**
10. **SW-S** **Screened data set with washout – symptoms only.**

Assumptions underlying the Analysis of Variance

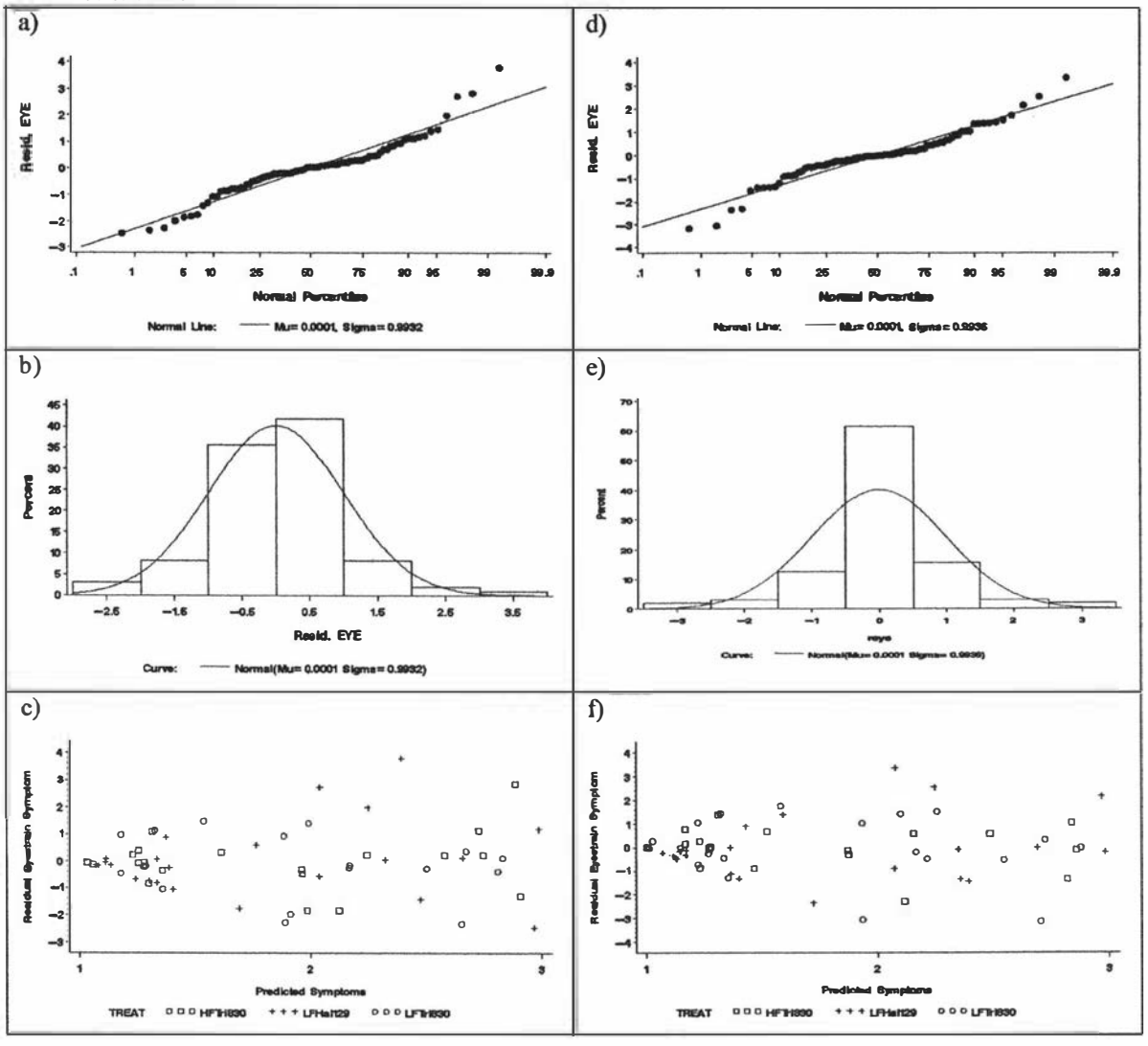
This section outlines the steps that were taken to check the assumptions of homogeneity of variance and normality for each of the data sets, including any differences that were present when possible or probable outliers were removed. As was the case with the baseline data, normality was checked by examining normal probability plots and histograms in conjunction with skew and kurtosis values and the Shiparo-Wilks test statistic. Homogeneity of variance was checked by examining standardised residual plots, alongside the Levene's test statistic.

Finally, the standard deviations for the raw and transformed (log, square root) data was calculated to give an indication of whether homogeneity of variance among treatments was able to be achieved by one of these standard transformations.

The eye symptom data was first examined to determine if the data met homogeneity of variance and normality assumptions (Figure 23). Normality probability graphs and histograms did not reveal marked deviation from normality and skew and kurtosis values were within acceptable parameters, however the Shiparo-Wilks test statistic was significant ($p<0.02$) giving some evidence of non-normality.

Standardised residual plots generated to examine the homogeneity of variance, showed a funnelling of the predicted data between 1 and 1.5, with the remainder of the data points well spread. This shows that those participants with an average monthly symptom severity of between 1 and 1.5 had less variance in their responses than those who reported above this value. A visual examination of the data did not suggest that this variation differed across lighting treatments, however Levene's test was significant ($0.02>p>0.01$). The data set was then rerun with all outliers removed. This improved the plots somewhat, and reduced the Shiparo-Wilks and Levene test statistics in most cases, however, the values remained significant ($p<0.05$) in the majority of data sets.

Figure 23. Standardised residual plots of eye symptom severity using data set SW:CVB (screened data set with one week washout and baseline included as covariate). a) Normal probability plot, b) Histogram plot, and c) Residual vs predicted plot. Graphs d, e) and f) show the data sets with extreme values excluded.



An examination of the standard deviations revealed that there was considerable variation in participant reporting for each lighting treatment (large standard deviation values), and that the spread of data differed across the three lighting treatments for eyestrain, headache and lethargy symptoms (maximum/minimum standard deviation values). A typical example is shown in Table 21. The data was assessed to determine if log (std dev/mean) or square root (std dev/$\sqrt{}$mean) transformations would provide equivalent variance across the lighting treatment conditions (max/min values $\cong$ 1). The transformations decreased the variance between lighting treatments to a small extent, but overall did not make a large difference to these values for either eyestrain, headache or lethargy symptoms.

When headache data was examined, normal probability graphs and histograms did not reveal marked non-normality in any of the data sets. A typical example is shown in Figure 24. However the Shiparo-Wilks test was significant for both the complete and screened data sets with a washout period (CW and SW). This outcome did not improve when outliers were removed.

Table 21. Mean and standard deviation values etc for raw data (Complete data set)

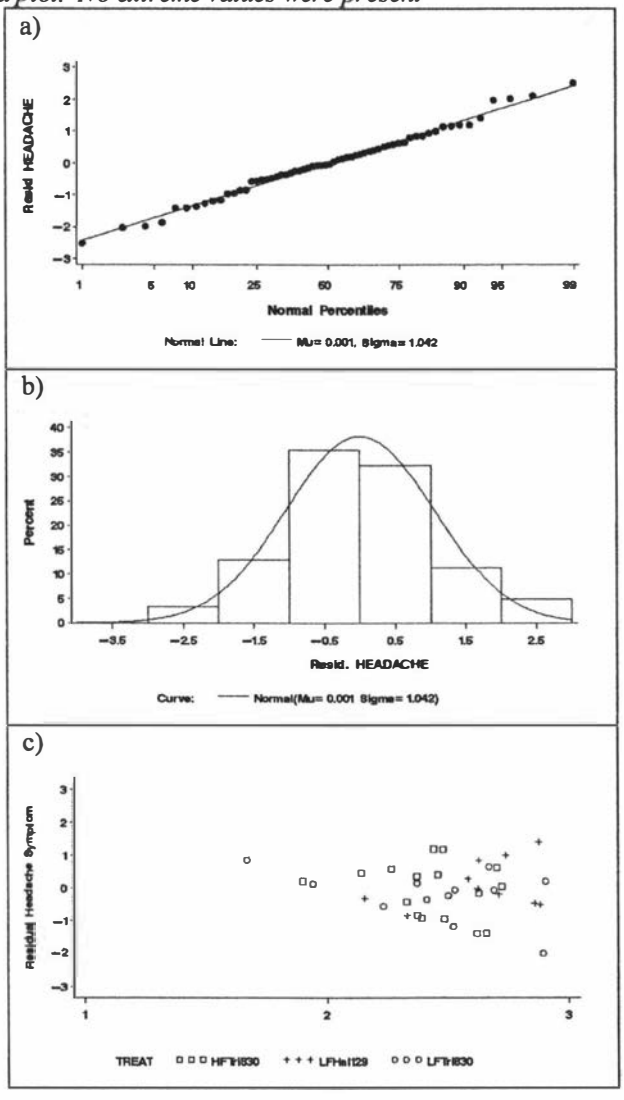
Symptom	Treatment	Freq	Mean	Std dev	Std dev/mean	Std dev/√mean
Eyestrain	HF-Tri	53 *(49)*	1.60 *(1.64)*	0.80 *(0.81)*	0.50 *(0.49)*	0.63 *(0.63)*
	LF-Halo	56 *(53)*	1.86 *(1.73)*	1.11 *(0.99)*	0.60 *(0.57)*	0.82 *(0.75)*
	LF-Tri	58 *(58)*	1.48 *(1.48)*	0.63 *(0.63)*	0.42 *(0.42)*	0.51 *(0.51)*
	Max/min value			1.76 *(1.57)*	1.42 *(1.36)*	1.61 *(1.47)*
Headache	HF-Tri	53 *(49)*	1.53 *(1.51)*	0.67 *(0.65)*	0.44 *(0.43)*	0.54 *(0.53)*
	LF-Halo	56 *(54)*	1.62 *(1.50)*	0.88 *(0.60)*	0.54 *(0.40)*	0.69 *(0.49)*
	LF-Tri	58 *(57)*	1.56 *(1.52)*	0.74 *(0.69)*	0.48 *(0.45)*	0.59 *(0.56)*
	Max/min value			1.31 *(1.15)*	1.22 *(1.13)*	1.28 *(1.14)*
Lethargy	HF-Tri	52 *(50)*	1.70 *(1.71)*	0.80 *(0.81)*	0.47 *(0.47)*	0.61 *(0.62)*
	LF-Halo	56 *(54)*	2.02 *(1.94)*	1.22 *(1.17)*	0.61 *(0.60)*	0.86 *(0.84)*
	LF-Tri	58 *(58)*	1.69 *(1.69)*	0.85 *(0.85)*	0.50 *(0.50)*	0.65 *(0.65)*
	Max/min value			1.53 *(1.44)*	1.30 *(1.28)*	1.41 *(1.35)*

Standardised residual plots were similar to that of the eyestrain data and Levene's test showed that this data met the homogeneity of variance assumption. The low F test statistic and p-values generated in the analyses (Table 22, Table 23, Table 24) provided overwhelming evidence that no difference existed between the lighting treatments with respect to headache symptom severity and therefore no further testing of assumptions was undertaken.

Lastly the lethargy symptom data was examined. The analyses had a similar pattern to the eye symptom data, but generally met assumptions to a greater extent (Figure 25). Normality probability graphs and histograms did not reveal marked deviation from normality and skew and kurtosis values were within acceptable parameters, but

the Shiparo-Wilks test statistic was significant ($p<0.06$). Standardised residual plots generated to examine the homogeneity of variance, showed a similar distribution to that shown for eye symptoms. Levene's test was significant in all cases ($0.02>p>0.01$).

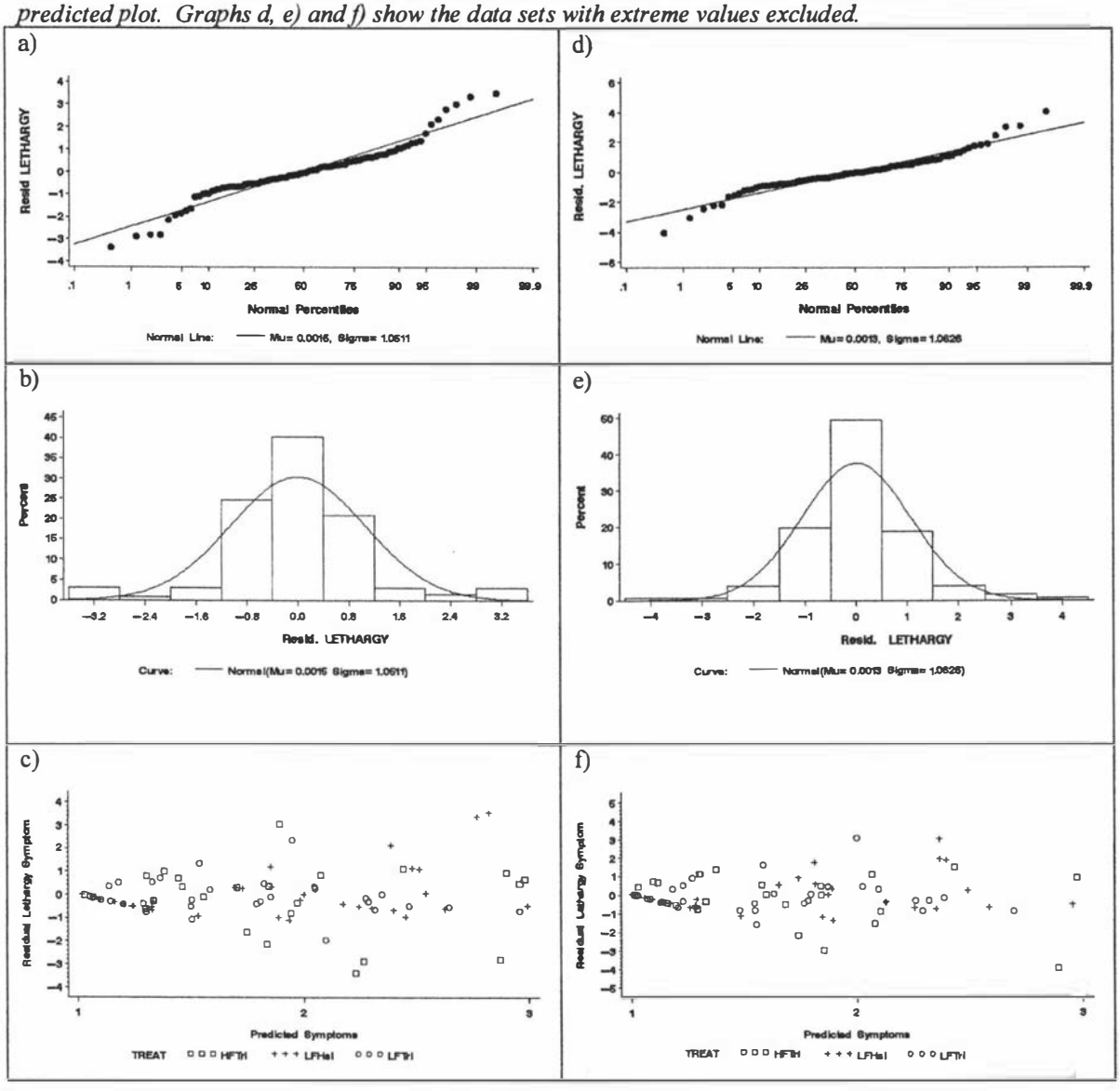
Figure 24. Standardised residual plots of headache symptom severity using data set SWS (screened data set with one week washout – symptoms only) a) Normal probability plot, b) Histogram plot, and c) Residual vs predicted plot. No extreme values were present



Extreme values were examined and the data set was rerun with all outliers removed. As with the eyestrain data, this improved the plots somewhat, and in most cases reduced the value of the Shiparo-Wilks and Levene test, however the values remained significant in the majority of data sets. Examination of the standard deviations for the raw and transformed data showed a small reduction in the heterogeneity of variance,

but also did not suggest that use of these transformations would reduce the heterogeneity of variance to any useful extent.

Figure 25. Standardised residual plots of lethargy symptom severity using data set CW (complete data set with one week washout). a) Normal probability plot, b) Histogram plot, and c) Residual vs predicted plot. Graphs d, e) and f) show the data sets with extreme values excluded.



Discussion

Overall, the visual examinations of the data set in combination with the statistical tests revealed that while some ANOVA assumptions were not met in the data sets, the deviation was small. Removal of outlying or extreme values improved the variance and normality of the data sets somewhat, but generally did not improve the results substantially. Standard transformations (log and square root) were attempted, but again, these made minimal improvement to the results.

The effects of non-normal data is most problematic for small sample sizes, but overall the F-Test is robust to non-normal data '*In summary, for large sample size problems it is reasonable to use the normality assumption. If the sample sizes are small, then the assumption should be checked. If a violation of the assumption is found, then the effect on tests is not all that great*' (Weber and Skillings, 2000).

ANOVA is also robust to unequal variances among the treatments when sample sizes are the same or nearly the same. '*In summary, minor violations in the equal variance assumption can be ignored, especially when the sample sizes are nearly the same*' (Weber and Skillings, 2000). The sample sizes are not large in these analyses, but the amount of data in each sample is comparable, therefore any effects on the data analyses should be minimal.

In conclusion, the violations were not extreme and the majority of data sets appeared to meet assumptions to a large extent when visually examined. Other transformations, plus non-parametric analyses were considered. However, when balanced against the other limitations of the data set and the complexity in interpretation that would inevitably result, it was concluded that there would be little advantage or gain in statistical validity by conducting further complicated transformations.

Lighting Treatment Differences

The ANOVA results first consider the effect that lighting treatments had on symptom severity, followed by office differences, trials and interactions. Taken as a whole there were no significant trial effects or significant trial*treatment interactions, therefore each aspect of the analyses was discussed independently.

The results are outlined in three separate sections, corresponding to the three groups of data responses. Firstly, data sets CW, SW and C are considered comprising of the complete and screened data sets with and without a washout period (Table 22). Secondly, data sets CW:CVB, SW:CVB, CW:CVG and CW:CVA are outlined: the complete and screened data sets with the baseline symptoms, gender and age treated as covariates (Table 23). Finally, data sets CS, CWS and SWS are discussed, with

these data sets considering symptoms experienced by participants and excluding responses where symptoms were not reported (Table 24).

Extreme values were identified as either possible or probable outliers. Possible outliers were classified as those that were greater than three standard deviations outside the mean. Probable outliers were classified as greater than five standard deviations outside the mean. For each data set analysed, the data was checked for extreme values and all values that were possible or probable outliers were removed from the data, the ANOVA rerun and the assumptions re-examined. Any change that was present in the F test statistic or p-value is identified in the ANOVA results table (italic figure in brackets). In the majority of cases, these extreme values had some influence, as the F test and p-values reduced when the data was removed. In some cases, the data went from significant ($p<0.05$), to non-significant outcomes. Removal of these influential points usually improved the normality of the data, but had limited influence on the homogeneity of variance.

In addition, extreme points were highlighted as either possible or probable outliers and identified by participant, office, trial and office. If there was no indication that these extreme data points were incorrectly entered, they were assumed to be valid entries. These participants are discussed in further detail in the discussion for this section and in Chapter Five (Medical Study).

Table 22. Results of ANOVA - data sets CW, SW and C

CW - Complete data set with one week washout							
Symptom	MSE value[55]	F Test	p-value	Treatment	N[56]	Mean	Duncan
Eyestrain symptoms	0.27 *(0.14)*[57]	3.34 *(1.72)*	0.04 *(0.19)*	LFHalo HFTri LFTri	53 *(50)* 47 *(45)* 52 *(52)*	1.79 *(1.68)* 1.56 *(1.52)* 1.49 *(1.49)*	A *(A)* B *(B)* B *(B)*

[55] The MSE value is the Mean Squared Error value and is an estimate of the within-group variance (σ^2). Table 21 provides the standard deviations for each lighting treatment condition for the complete data set.

[56] The average monthly symptom severity provided by N participants exposed to this lighting treatment condition.

Headache symptoms	0.13	0.87	0.424	LFHalo HFTri LFTri	53 47 51	1.58 1.49 1.51	A A A
Lethargy symptoms	0.33 *(0.19)*	6.29 *(4.67)*	0.003 *(0.01)*	LFHalo HFTri LFTri	53 *(51)* 47 *(43)* 52 *(52)*	2.06 *(1.98)* 1.68 *(1.66)* 1.69 *(1.69)*	A *(A)* B *(B)* B *(B)*
SW – Screened data set with one week washout							
Eyestrain symptoms	0.27 *(0.13)*	2.98 *(1.38)*	0.057 *(0.26)*	LFHalo HFTri LFTri	53*(51)* 46 *(43)* 50 *(50)*	1.78 *(1.69)* 1.55 *(1.52)* 1.47 *(1.47)*	A *(A)* B *(B)* B *(B)*
Headache symptoms	0.13 *(0.10)*	0.61 *(0.37)*	0.55 *(0.69)*	LFHalo HFTri LFTri	53 *(52)* 47 *(46)* 50 *(50)*	1.55 *(1.53)* 1.49 *(1.46)* 1.48 *(1.48)*	A *(A)* A *(A)* A *(A)*
Lethargy symptoms	0.40 *(0.21)*	4.13 *(2.92)*	0.02 *(0.06)*	LFHalo HFTri LFTri	52 *(48)* 47 *(46)* 50 *(50)*	2.01 *(1.88)* 1.66 *(1.68)* 1.61 *(1.61)*	A *(A)* B *(B)* B *(B)*
C – Complete data set							
Eyestrain symptoms	0.29 *(0.14)*	4.15 *(2.00)*	0.02 *(0.14)*	LFHalo HFTri LFTri	56 *(53)* 52 *(49)* 58 *(58)*	1.86 *(1.73)* 1.60 *(1.64)* 1.48 *(1.48)*	A *(A)* B *(B)* B *(B)*
Headache symptoms	0.29 *(0.09)*	1.64 *(0.95)*	0.20 *(0.39)*	LFHalo HFTri LFTri	56 *(54)* 52 *(49)* 58 *(57)*	1.62 *(1.50)* 1.53 *(1.51)* 1.56 *(1.52)*	A *(A)* A *(A)* A *(A)*
Lethargy symptoms	0.35 *(0.24)*	4.52 *(2.10)*	0.01 *(0.14)*	LFHalo HFTri LFTri	56 *(54)* 52 *(50)* 58 *(58)*	2.02 *(1.94)* 1.70 *(1.71)* 1.69 *(1.69)*	A *(A)* B *(B)* B *(B)*

Table 23. Results of ANOVA - data sets CW:CVB, SW:CVB, CW:CVG, CW:CVA

CW:CVB – Complete data set with one week washout and baseline (one week washout) as a covariate							
Symptom	MSE	F test	p-value	Treatment	N	Mean	Duncan
Eyestrain Symptoms	0.24 *(0.15)*	2.20 *(2.23)*	0.12 *(0.12)*	LFHalo HFTri LFTri	37 *(36)* 35 *(34)* 38 *(38)*	1.84 *(1.78)* 1.60 *(1.53)* 1.55 *(1.55)*	A *(A)* B *(B)* B *(B)*

[57] The italic figures in brackets represent the changes to the F Test statistic and p-values when extreme values are removed.

Headache symptoms	0.12	0.82	0.44	LFHalo HFTri LFTri	37 36 34	1.61 1.49 1.47	A A A
Lethargy symptoms	0.25 *(0.15)*	3.01 *(2.71)*	0.057 *(0.07)*	LFHalo HFTri LFTri	37 *(36)* 35 *(33)* 38 *(38)*	2.01 *(1.98)* 1.71 *(1.65)* 1.77 *(1.77)*	A *(A)* B *(B)* B *(B)*
SW: CVB – Screened data set with one week washout and baseline (one week washout) as a covariate							
Eyestrain Symptoms	0.26	2.26	0.11	LFHalo HFTri LFTri	36 33 35	1.79 1.58 1.51	A B B
Headache symptoms	0.14	0.2	0.82	LFHalo HFTri LFTri	37 35 38	1.58 1.52 1.47	A A A
Lethargy symptoms	0.30 *(0.22)*	3.1 *(1.73)*	0.05 *(0.19)*	LFHalo HFTri LFTri	35 *(34)* 33 *(33)* 35 *(35)*	1.98 *(1.91)* 1.66 *(1.66)* 1.60 *(1.60)*	A *(A)* B *(B)* B *(B)*
CW: CVG – Complete data set with one week washout and gender as a covariate							
Eyestrain Symptoms	0.32	2.53	0.09	LFHalo HFTri LFTri	34 31 34	1.94 1.67 1.64	A A/B B
Headache symptoms	0.15	0.69	0.50	LFHalo HFTri LFTri	34 31 34	1.62 1.53 1.52	A A A
Lethargy symptoms	0.32	2.77	0.07	LFHalo HFTri LFTri	34 31 34	2.06 1.69 1.75	A B B
CW:CVA – Complete data set with one week washout and age as a covariate							
Eyestrain symptoms	0.32	2.53	0.09	LFHalo HFTri LFTri	34 31 35	1.94 1.67 1.63	A B A/B
Headache symptoms	0.15	0.69	0.50	LFHalo HFTri LFTri	34 31 35	1.61 1.53 1.51	A A A
Lethargy symptoms	0.32	2.77	0.07	LFHalo HFTri LFTri	34 31 35	2.06 1.69 1.73	A B B

Table 24. Results of ANOVA - data sets CS, CWS, SWS

Symptom	MSE	F test	p-value	Treat	N	Mean	Duncan
CS – Complete data set – symptoms only (symptom severity >1)							
Eyestrain symptoms	0.36 *(0.16)*	4.34 *(3.74)*	0.02 *(0.03)*	LFHalo HFTri LFTri	36 *(34)* 32 *(32)* 33 *(32)*	3.19*(3.04)* 2.84*(2.84)* 2.61*(2.60)*	A *(A)* B*(A)* B*(B)*
Headache symptoms	0.50 *(0.34)*	1.57 *(1.91)*	0.22 *(0.16)*	LFHalo HFTri LFTri	35 *(34)* 36 *(34)* 37 (37)	3.10*(3.04)* 2.93*(2.86)* 2.77*(2.77)*	A*(A)* A*(A)* A*(A)*
Lethargy symptoms	0.30	5.62	0.006	LFHalo HFTri LFTri	34 36 36	3.32 2.81 3.00	A B B
CWS – Complete data set – with one week washout – symptoms only							
Eyestrain symptoms	0.19 *(0.14)*	3.78 *(2.53)*	0.03 *(0.09)*	LFHalo HFTri LFTri	30 *(29)* 24 *(24)* 30 *(30)*	3.11*(3.09)* 2.70*(2.70)* 2.52*(2.52)*	A *(A)* B *(B)* B *(B)*
Headache symptoms	0.48	1.69	0.20	LFHalo HFTri LFTri	30 30 31	3.04 2.87 2.80	A A A
Lethargy symptoms	0.35	3.35	0.05	LFHalo HFTri LFTri	34 28 31	3.24 2.92 2.85	A B B
SWS – Screened data set – with one week washout – symptoms only							
Eyestrain symptoms	0.16	8.49	0.001	LFHalo HFTri LFTri	29 22 25	3.15 2.74 2.66	A B B
Headache symptoms	0.43	1.92	0.16	LFHalo HFTri LFTri	26 26 28	3.18 2.93 2.76	A A/B B
Lethargy symptoms	0.29	2.59	0.09	LFHalo HFTri LFTri	32 27 26	3.21 2.91 2.90	A B B

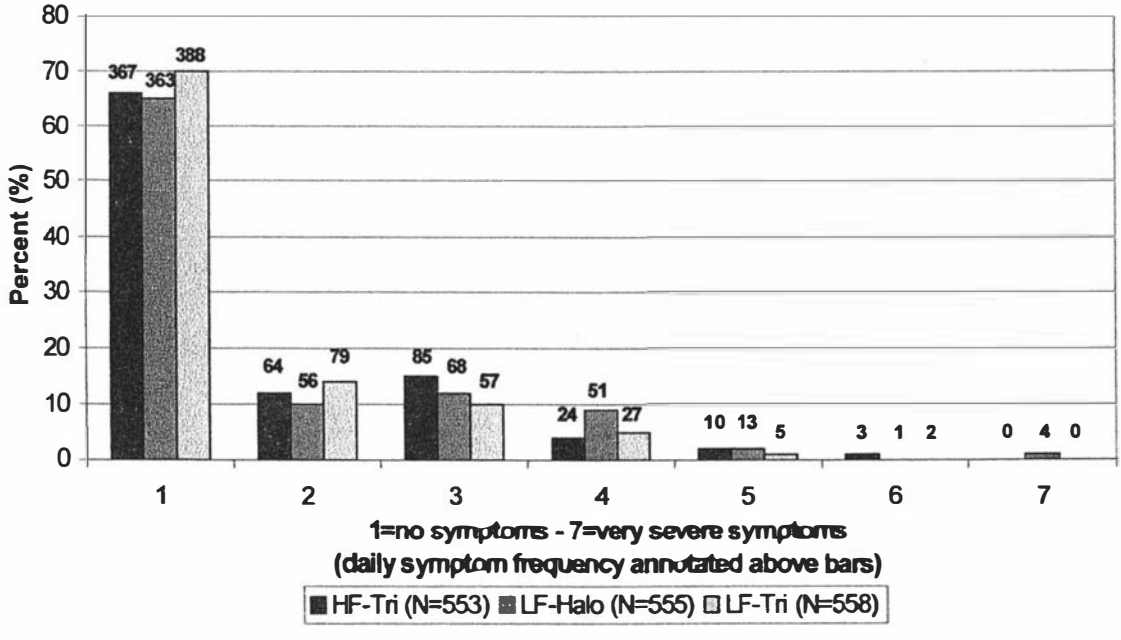
Eyestrain Symptoms – Lighting Treatment Differences

The eyestrain symptom severity was initially examined using a bar graph. Figure 26 shows the participants daily responses for the complete data set. The graph showed that between 30% and 35% of participants experienced eyestrain symptoms during their work shifts (symptom severity of greater than 1). Participants experienced

symptoms least frequently in the low frequency triphosphor lighting treatment. Eye symptom severity of 2 or 3 was most frequently reported with 27%, 22% & 24% of all responses reported in the HF-Tri, LF-Halo and LF-Tri lighting treatments respectively. Almost 10% of participants reported symptom severity of 4 in the LF-Halo lighting treatments in comparison to the HF-Tri (4%) and LF-Tri (5%) lighting treatments. The remainder of responses were spread over severity symptoms of 5, 6 or 7, with 3% of the HF-Tri and LF-Halo responses and 1% of the LF-Tri responses in these categories. Figure 26 suggests that participants experienced more severe symptoms in the LF-Halo lighting treatment, with a larger proportion reporting symptom severity of 4 or above in comparison to the other lighting treatments.

Analysis of Variance (ANOVA) was used to determine if the symptoms experienced by participants differed between lighting treatments and used the average monthly symptom data (Table 22). A typical ANOVA table is shown in Appendix L. In data sets CW, SW & C, the ANOVA provided evidence to suggest that eyestrain symptoms differed between the three lighting treatments (F test 2.98 - 4.15, $0.02<p<0.057$).

Figure 26. Eyestrain Symptoms by Treatment - Complete Data Set



Duncan's MCP revealed that the Low Frequency Halophosphate (LF-Halo) lighting treatment was significantly different ($\alpha = 0.05$) from the Low Frequency Triphosphor (LF-Tri) and High Frequency Triphosphor (HF-Tri) lighting treatments. Participants experienced more severe eyestrain in the LF-Halo treatment (mean value 1.78-1.86) in comparison to the LF-Tri or HF-Tri lighting treatments (mean value 1.47-1.48) in all three data sets. When outliers were removed from the data sets, the lighting treatments were not significantly different. However, Duncan's MCP test, which is less conservative, found that the LF-Halo treatment remained significantly different to the other lighting treatments. The difference between mean values was reduced when outliers were removed.

In data sets where the baseline, age or gender data was treated as a covariate, the lighting treatments were not found to be significantly different (Table 23). However, Duncan's MCP found that participants experienced significantly more severe eyestrain symptoms in the LF-Halo treatment when the baseline was treated as a covariate. This outcome did not change when the outliers were removed from the data set.

In the symptoms only data (CS, CWS, SWS) all three analyses (Table 24) returned significant F test statistics (F test=3.78-8.49, $0.03>p>0.001$). As is reported in the other analyses the Duncan's MCP and mean values revealed that participants experienced significantly more severe eyestrain in the LF-Halo treatment (mean value 3.11-3.19) in comparison to the LF-Tri and HF-Tri treatments (mean value 2.52-2.70). Only two of the data sets included outliers. When these were removed, the p-value was reduced towards non-significant levels in one of the data sets ($p=0.09$).

Headache Symptoms - Lighting Treatment Differences

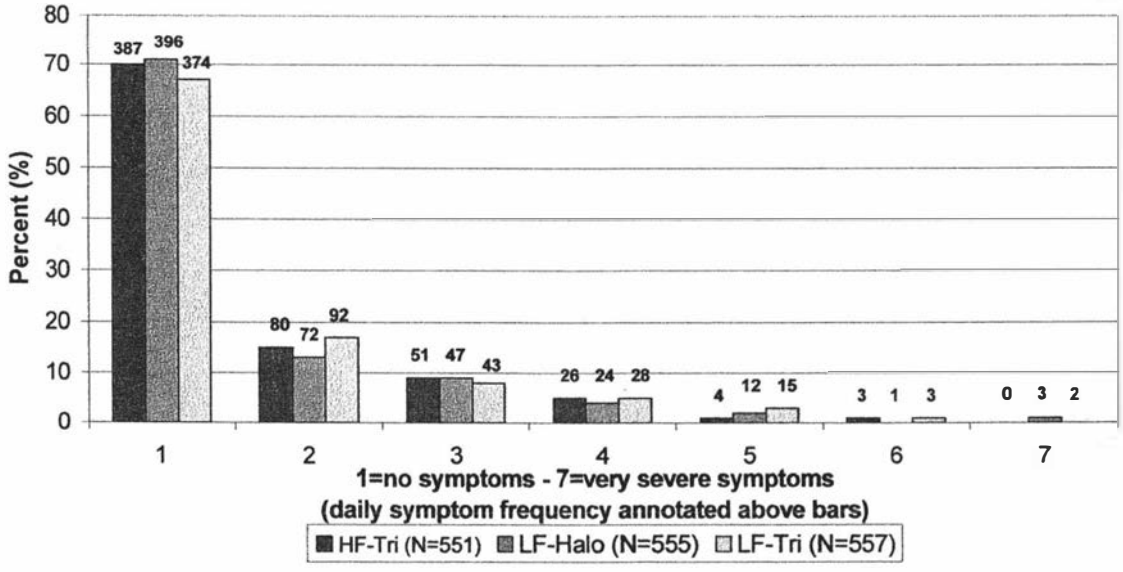
Headache symptom severity data was initially examined using a bar graph as shown in Figure 27. Approximately 30% - 35% of participants experienced headache symptoms during their work shifts. The largest proportion of participants reported headache symptom severity of 2 (16%, 13% and 17% of HF-Tri, LF-Halo and LF-Tri respectively), with just under 10% reporting symptom severity of 3, approximately 5% reporting symptom severity of 4 and less than 5% reporting severe symptoms (5

or over). There was no apparent difference in either symptom incidence or severity across the three lighting treatments.

ANOVA was used to determine if the headache symptoms experienced by the participants differed across lighting treatments (Table 22, Table 23 and Table 24). The analysis did not reveal significant differences in headache symptoms experienced by participants in the three lighting treatments for all data sets (F Test 0.61-1.92, $0.16<p<0.55$). Average headache severity varied from 1.47-1.62 in the data sets that considered all responses and 2.76-3.18 in the symptoms only data set.

Duncan's MCP did not reveal any differences in headache symptom severity with respect to lighting treatments, however in all cases participants reported the most severe symptoms in the LF-Halo treatment with the HF-Tri and LF-Tri treatments showing more equivalence. Extreme values were not influential.

Figure 27. Headache Symptom Severity – Complete Data Set

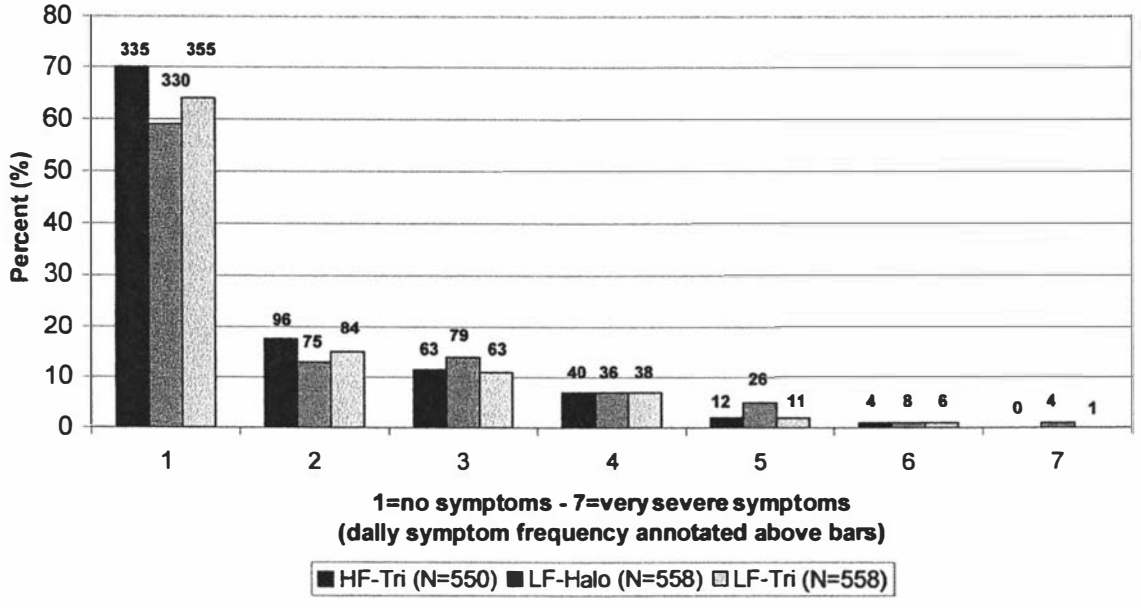


Lethargy Symptoms – Lighting Treatment Differences

Lethargy symptoms were the most frequently experienced during the work shift (Figure 28). Participants experienced the most lethargy symptoms in the

Low Frequency Halophosphate lighting treatment (41%) followed by the Low Frequency Triphosphor (36%) and the least symptoms in the High Frequency Triphosphor lighting treatment (30%). Participants most frequently reported lethargy symptom severity of 2 or 3 with 24%, 28% and 26% of symptoms reported in the HF-Tri, LF-Halo and LF-Tri lighting treatments respectively. Lethargy symptom severity of 4 was reported by 7% of participants in all three lighting treatments. Severe lethargy symptoms were reported most frequently in the LF-Halo lighting treatment with 7% of participants reporting either a 5, 6 or 7, in comparison to the HF-Tri and LF-Tri (3%). Overall, the highest incidence of symptoms and the most severe symptoms were apparent in the low frequency halophosphate lighting treatment.

Figure 28. Lethargy Symptom Severity - Complete Data Set



The ANOVA revealed that there were significant differences in the lethargy symptom severity and incidence experienced by participants in the three lighting treatments (Table 22) in data sets C, CW and SW (F test 4.13-6.29, $0.02<p<0.003$). Duncan's MCP revealed that participants experienced the most severe lethargy symptoms in the LF-Halo lighting treatment (average symptom severity 2.01-2.06) in comparison to the LF-Tri or HF-Tri lighting treatments (average symptom severity 1.61-1.69). When outliers were removed from the data sets, treatment differences remained significant in data sets S & CW, but were not significantly different in data set C.

Duncan's MCP tests revealed that participants experienced more severe symptoms in the LF-Halo treatment when compared to the LF-Tri or HF-Tri treatments.

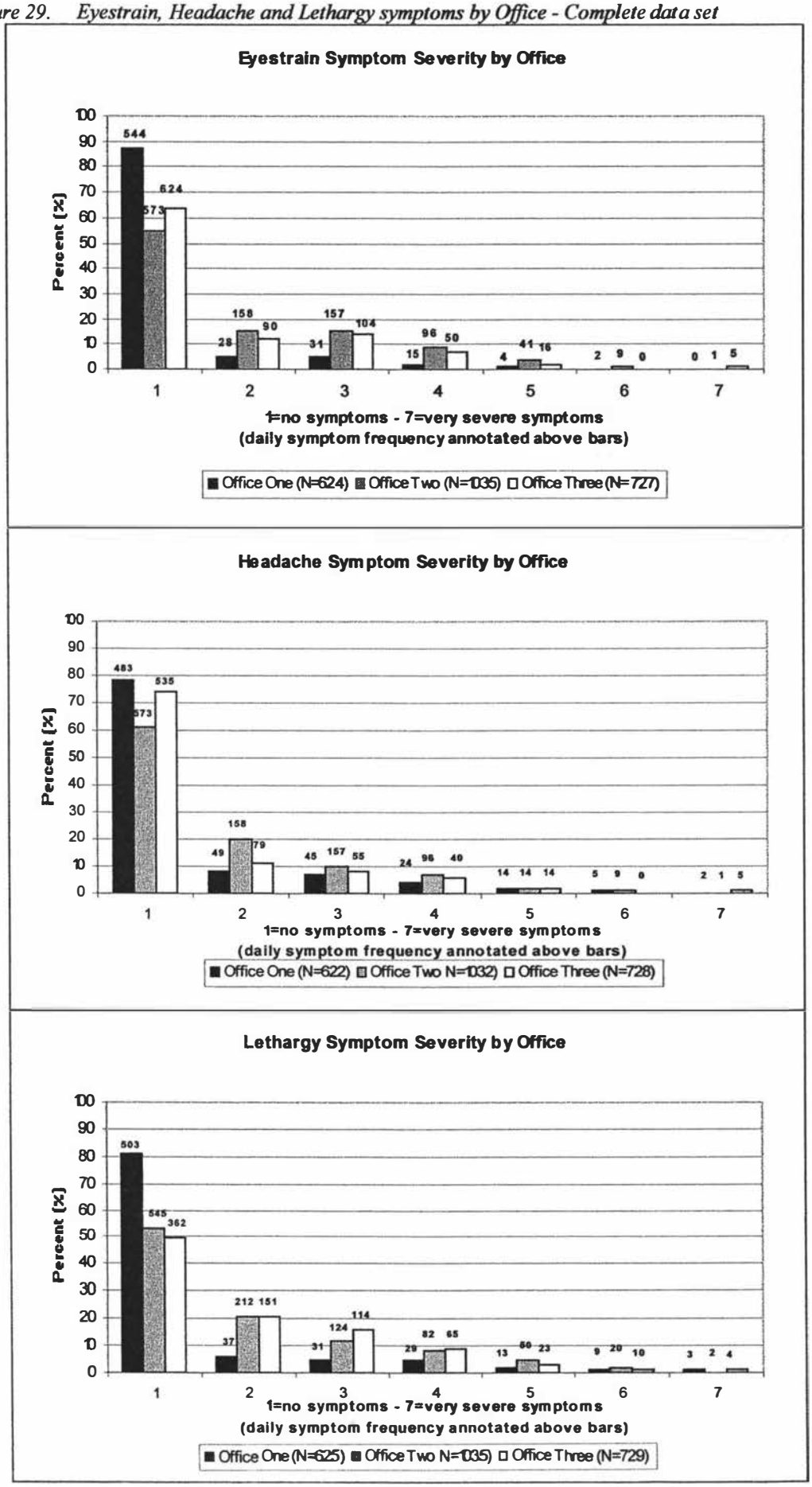
In the four analyses that utilised the baseline symptoms, age and gender data as a covariate (Table 23), there was some evidence to suggest that lethargy symptoms differed between lighting treatments ($p<0.1$). However removal of outliers in the two data sets with the baseline as a covariate further reduced the F test values. There were no outliers in the analyses that treated age and gender as covariates. In all cases, the less conservative Duncan's MCP test found that the LF-Halo was significantly different to the other two lighting treatments.

The lighting treatments were significantly different in the complete and complete with washout data sets in the symptoms only data (Table 24), with the more conservative Duncan's MCP finding that participants experienced significantly more severe lethargy symptoms in the low frequency halophosphate lighting treatment in all three analyses (mean value 3.11-3.19) in comparison to the LF-Tri and HF-Tri treatments (2.52-2.70).

Office Differences

The eyestrain, headache and lethargy data for each of the three offices was examined. Figure 29 shows the eyestrain, headache and lethargy symptoms in each office during Trials One, Two and Three in the complete data set. The graphs show that participants in Office One experienced less eyestrain, headache and lethargy symptoms than those in Offices Two and Three, with participants reporting eyestrain, headache and lethargy symptoms in 13%, 22% and 18% of shifts respectively. In comparison, Office Two participants experienced eyestrain, headache and lethargy symptoms in 35%, 39% and 47% of shifts and Office Three participants reported eyestrain, headache and lethargy symptoms in 36%, 26% and 50% of shifts. Despite the difference in incidence rate across the three offices, there was no apparent differences in symptom severity.

Figure 29. Eyestrain, Headache and Lethargy symptoms by Office - Complete data set



The ANOVA found evidence to suggest that eyestrain symptoms experienced by participants in the three offices differed in data sets SW, C and CW (F test 2.74-3.80, $0.02<p<0.07$). Duncan's MCP revealed that the participants in Office One experienced significantly lower incidence and severity of eye symptoms (mean value 1.21-1.29) than Offices Two and Three (mean value 1.68-1.80). Removal of outliers did not affect this outcome (Table 25).

In the analyses that utilised the baseline data as a covariate, the offices were not significantly different (Table 26). When age or gender were treated as covariates, there was some evidence to suggest that the offices differed, ($p<0.1$). Duncan's MCP found that Office Two was significantly different to Office One, but not to Office Three. Participants in the three offices did not experience significantly different eye symptom severity in the symptoms only data sets (Table 27).

The ANOVA revealed no significant differences between the three offices with respect to headache symptom incidence and severity (F test statistic 0.02-0.7, $0.50<p<0.98$). Average headache severity varied from 1.39-1.61 when symptom incidence and severity was included in the analyses, and from 2.81-3.11 in the symptoms only data sets. Removal of extreme values did not affect the overall outcome.

The ANOVA found no significant differences between the three offices with respect to lethargy symptom incidence and severity. Duncan's MCP did not show clear differences between offices. Average lethargy severity varied between 1.34-2.12 in the data sets that included symptom incidence and severity. In the symptoms only data set, the average lethargy severity varied between 2.79-3.56.

All analyses were checked for significant differences between trials and the significance of the trial*treatment interactions. In both cases only one significant result was revealed. Given the large number of analyses run, and the lack of significance in other analyses, this was treated as spurious and ignored.

Table 25. Results of ANOVA - data sets CW, SW and C

Symptom	MSE value	F Test	p-value	Office	N	Mean	Duncan
CW - Complete data set with one week washout							
Eyestrain symptoms	0.27 *(0.14)*	2.74 *(2.23)*	0.07 *(0.12)*	Office One Office Two Office Three	43 *(43)* 67 *(65)* 42 *(39)*	1.29 *(1.29)* 1.79 *(1.74)* 1.68 *(1.58)*	A *(A)* B *(B)* A/B *(A/B)*
Headache symptoms	0.13	0.31	0.73	Office One Office Two Office Three	42 67 42	1.52 1.59 1.43	A A A
Lethargy symptoms	0.33 *(0.19)*	1.60 *(1.41)*	0.21 *(0.25)*	Office One Office Two Office Three	43 *(42)* 67 *(64)* 42 *(40)*	1.51 *(1.49)* 1.93 *(1.89)* 1.96 *(1.93)*	A *(A)* A *(A)* A *(A)*
SW – Screened data set with one week washout							
Eyestrain symptoms	0.27 *(0.13)*	3.80 *(3.35)*	0.028 *(0.04)*	Office One Office Two Office Three	43*(43)* 66 *(64)* 40 *(37)*	1.21 *(1.21)* 1.79 *(1.77)* 1.71 *(1.61)*	A *(A)* B *(B)* A/B *(A/B)*
Headache symptoms	0.13 *(0.10)*	0.27 *(0.41)*	0.77 *(0.66)*	Office One Office Two Office Three	43 *(43)* 66 *(66)* 41 *(39)*	1.43 *(1.43)* 1.57 *(1.57)* 1.48 *(1.41)*	A *(A)* A *(A)* A *(A)*
Lethargy symptoms	0.40 *(0.21)*	2.67 *(2.95)*	0.77 *(0.06)*	Office One Office Two Office Three	43 *(41)* 65 *(64)* 41 *(38)*	1.41 *(1.34)* 1.84 *(1.81)* 2.00 *(1.98)*	A *(A)* A/B *(A)* A *(A)*
C – Complete data set							
Eyestrain symptoms	0.29 *(0.13)*	3.51 *(3.10)*	0.04 *(0.05)*	Office One Office Two Office Three	50 *(50)* 71 *(70)* 45 *(40)*	1.29 *(1.29)* 1.80 *(1.81)* 1.80 *(1.67)*	B *(A)* A *(A)* A *(A/B)*
Headache symptoms	0.29 *(0.09)*	0.02 *(0.04)*	0.98 *(0.39)*	Office One Office Two Office Three	50 *(48)* 71 *(69)* 45 *(43)*	1.58 *(1.51)* 1.57 *(1.53)* 1.55 *(1.48)*	A *(A)* A *(A)* A *(A)*
Lethargy symptoms	0.35 *(0.24)*	1.77 *(1.51)*	0.18 *(0.23)*	Office One Office Two Office Three	50 *(49)* 71 *(70)* 45 *(43)*	1.51 *(1.51)* 1.92 *(1.89)* 1.94 *(1.51)*	A *(A)* A *(A)* A *(A)*

Table 26. Results of ANOVA - data sets CW:CVB, SW:CVB, CW:CVG, CW:CVA

Symptom	MSE	F test	p-value	Office	N	Mean	Duncan
CW:CVB – Complete data set with one week washout and baseline (one week washout) as a covariate							
Eyestrain Symptoms	0.24 *(0.15)*	1.17 *(0.79)*	0.32 *(0.46)*	Office One Office Two Office Three	27 *(27)* 45 *(44)* 38 *(37)*	1.27 *(1.27)* 1.90 *(1.86)* 1.65 *(1.59)*	A *(A)* B *(B)* A/B *(A/B)*
Headache symptoms	0.12	0.40	0.67	Office One Office Two Office Three	24 45 38	1.39 1.64 1.48	A A A
Lethargy symptoms	0.25 *(0.15)*	1.32 *(1.24)*	0.28 *(0.30)*	Office One Office Two Office Three	27 *(26)* 45 *(43)* 38 *(38)*	1.67 *(1.65)* 1.83 *(1.77)* 1.95 *(1.95)*	A *(A)* A *(A)* A *(A)*
SW: CVB – Screened data set with one week washout and baseline (one week washout) as a covariate							
Eyestrain Symptoms	0.25	1.26	0.29	Office One Office Two Office Three	27 44 33	1.21 1.92 1.58	A B A/B
Headache symptoms	0.14	0.70	0.50	Office One Office Two Office Three	27 45 38	1.43 1.61 1.49	A A A
Lethargy symptoms	0.30 *(0.22)*	1.64 *(1.93)*	0.21 *(0.16)*	Office One Office Two Office Three	27 *(26)* 42 *(42)* 34 *(34)*	1.51 *(1.41)* 1.78 *(1.78)* 1.90 *(1.90)*	A *(A)* A *(A)* A *(A)*
CW: CVG – Complete data set with one week washout and gender as a covariate							
Eyestrain Symptoms	0.32	2.62	0.09	Office One Office Two Office Three	26 42 31	1.31 1.97 1.82	A B A/B
Headache symptoms	0.15	0.17	0.85	Office One Office Two Office Three	26 42 31	1.49 1.61 1.53	A A A
Lethargy symptoms	0.32	2.50	0.09	Office One Office Two Office Three	26 42 31	1.39 1.90 2.12	A A/B B
CW:CVA – Complete data set with one week washout and age as a covariate							
Eyestrain symptoms	0.32	3.23	0.05	Office One Office Two Office Three	27 42 31	1.31 1.97 1.82	A B A/B

Headache symptoms	0.15	0.25	0.78	Office One	27	1.48	A
				Office Two	42	1.61	A
				Office Three	31	1.55	A
Lethargy symptoms	0.32	2.66	0.08	Office One	27	1.37	A
				Office Two	42	1.90	A/B
				Office Three	31	2.12	B

Table 27. Results of ANOVA - data sets CS, CWS, SWS

CS – Complete data set – symptoms only (symptom severity >1)							
Symptom	MSE	F test	p-value	Office	N	Mean	Duncan
Eyestrain symptoms	0.36 *(0.16)*	0.25 *(0.08)*	0.78 *(0.92)*	Office One	24 *(24)*	2.78*(2.77)*	A *(A)*
				Office Two	48 *(46)*	2.96*(2.87)*	A *(A)*
				Office Three	29 *(28)*	2.90*(2.83)*	A *(A)*
Headache symptoms	0.50 *(0.36)*	1.53 *(1.05)*	0.59 *(0.36)*	Office One	38 *(38)*	3.09*(3.09)*	A*(A)*
				Office Two	44 *(41)*	2.81*(2.69)*	A*(A)*
				Office Three	26 (26)	2.90*(2.90)*	A*(A)*
Lethargy symptoms	0.30	3.00	0.06	Office One	21	3.56	A
				Office Two	53	2.99	B
				Office Three	32	2.79	A/B
CWS – Complete data set – with one week washout – symptoms only							
Eyestrain symptoms	0.19 *(0.14)*	0.75 *(0.88)*	0.48 *(0.42)*	Office One	17 *(17)*	2.61*(2.61)*	A *(A)*
				Office Two	43 *(43)*	2.93*(2.93)*	A *(A)*
				Office Three	24 *(23)*	2.64*(2.59)*	A *(A)*
Headache symptoms	0.48	0.48	0.62	Office One	30	3.03	A
				Office Two	38	2.92	A
				Office Three	23	2.71	A
Lethargy symptoms	0.35	1.08	0.35	Office One	18	3.32	A
				Office Two	45	3.04	A
				Office Three	30	2.80	A
SWS – Screened data set – with one week washout – symptoms only							
Eyestrain symptoms	0.16	0.25	0.78	Office One	11	2.91	A
				Office Two	42	2.94	A
				Office Three	23	2.73	A
Headache symptoms	0.43	0.36	0.70	Office One	23	3.11	A
				Office Two	37	1.92	A
				Office Three	20	2.81	B

Lethargy symptoms	0.29	0.74	0.49	Office One	15	3.33	A
				Office Two	41	3.01	A
				Office Three	29	2.86	A

3.5 Weekly Average Symptoms Analyses

A repeated measures analysis using the weekly average symptoms data was undertaken to provide estimates of any carryover effect that may exist. As is discussed in the Experimental Methodology, this analysis does not provide accurate estimates. For similar reasons, the analysis cannot be used to provide estimates of treatment effects.

The results reveal that there were significant differences in the average eyestrain symptom severity experienced by participants during the four weeks of each trial period for both the complete and screened data sets (Table 28). Participants experienced significantly more severe average eyestrain symptoms in Week One of the trial periods (average eyestrain 2.01-2.04), with Weeks Two, Three and Four not significantly different (average eyestrain 1.70-1.76).

Neither headache symptoms nor lethargy symptoms experienced by the participants were significantly different across the four weeks of the trial period, although for both headache and lethargy the most severe symptoms were reported in Week One. The outcome was similar for both the complete and screened data sets. None of the analyses had significant interactions.

Table 28. Results of ANOVA for weekly average symptoms analyses - data sets CW, SW and C

Complete data set (C)							
Symptom	MSE	F Test	p-value	Week	N	Mean	Duncan
Eyestrain symptoms	0.35	3.84	0.01	Week One	65	2.02	A
				Week Two	65	174	B
				Week Three	65	1.70	B
				Week Four	65	1.76	B

Headache symptoms	0.32	1.63	0.18	Week One	65	1.66	A
				Week Two	65	1.48	A
				Week Three	65	1.47	A
				Week Four	65	1.56	A
Lethargy symptoms	0.43	0.45	0.72	Week One	65	1.83	A
				Week Two	65	1.81	A
				Week Three	65	1.71	A
				Week Four	65	1.78	A
Screened data set (S)							
Eyestrain symptoms	0.40	3.81	0.01	Week One	62	2.04	A
				Week Two	62	1.74	B
				Week Three	62	1.72	B
				Week Four	62	1.74	B
Headache symptoms	0.32	1.53	0.21	Week One	65	1.64	A
				Week Two	65	1.45	A
				Week Three	65	1.46	A
				Week Four	65	1.54	A
Lethargy symptoms	0.41	1.05	0.37	Week One	60	1.80	A
				Week Two	60	1.63	A
				Week Three	60	1.62	A
				Week Four	60	1.72	A

3.6 Discussion: Symptom Severity and Lighting Treatments

Monthly Average Symptoms Analyses

Eyestrain Symptoms

The analyses provided evidence to suggest that participants reported more severe eye symptom incidence and severity in the LF-Halo lighting treatment, as compared to the LF-Tri and HF-Tri conditions in the complete (C) and complete with washout (CW) data sets ($p<0.05$). However, lighting treatments were not significantly different when extreme data points were removed showing that participants who experienced severe eyestrain symptoms were influential. Where baseline, age or gender data was treated as a covariate, there was some evidence to indicate that the lighting treatments differed ($p\cong0.1$). These results suggest that inherent differences between participants in the three offices may have influenced the analyses. However, these analyses

featured a smaller sample size and the corresponding reduction in power may have impacted on these results. The average eyestrain severity experienced by participants in the LF-Halo lighting treatment for these analyses was approximately 1.9, 0.3 more severe than in the LF-Tri and HF-Tri lighting treatments.[58]

Where only symptom severity data was included in the analyses, there was evidence to suggest that participants who experienced eyestrain rated it as more severe in the low frequency halophosphate lighting treatment ($p<0.05$) although removal of outlying responses reduced the p-values to non significant values ($p<0.1$). In this lighting treatment, the average eyestrain severity was approximately 3.2 and was 0.4 more severe than in the LF-Tri or HF-Tri lighting treatments.

These findings found an overall increase in perceived symptom severity of between 10% to 15% in the low frequency halophosphate lighting treatment. This can be seen in Figure 26. The number of participants who were asymptomatic in the LF-Halo lighting treatment was only slightly less than those in the HF-Tri lighting treatment, however, the number of participants reporting severe symptoms (4 or above), was greater than in the LF-Tri or HF-Tri lighting treatments. Almost twice as many participants reported symptom severity of 4 in the LF-Halo lighting treatment (9%) in comparison to the HF-Tri (4%) or LF-Tri (5%) lighting treatments.

Headache Symptoms

The visual examination of the data along with the ANOVA revealed no significant differences in the incidence or severity of headache symptoms experienced by participants under the lighting treatments. If any differences exist, they are extremely small.

Lethargy Symptoms

The data analyses presented strong evidence to suggest that lethargy symptom incidence and severity may differ under the different lighting treatments. The ANOVA found the low frequency halophosphate lighting treatment to be significantly

[58] Participants reported symptom severity on a 7 point Likert scale, where 1=no symptoms and 7= very severe symptoms.

different to the low frequency triphosphor or high frequency triphosphor lighting treatments conditions in the complete (C), complete with washout (CW) and screened with washout (SW) data sets ($p<0.05$). Removal of outliers was only influential in data set C. As in the eyestrain symptom severity analyses, when baseline, age or gender data were treated as a covariate, there was some evidence to indicate that the lighting treatments differed ($p\cong0.1$). The average lethargy severity experienced by participants in the LF-Halo lighting treatment for these analyses was approximately 2.0, 0.3 more severe than in the LF-Tri and HF-Tri lighting treatments and representing a difference of 10% to 15% in lethargy symptom severity [59]. This can be seen in Figure 24, where more participants report symptoms in the LF-Halo lighting treatment (41%) in comparison to the HF-Tri (30%) and LF-Tri lighting treatments (36%) and the increase in both mild and severe symptoms reported in this lighting treatment condition

Where only symptom severity data was included in the analyses, there was strong evidence to suggest that participants experienced more severe symptoms in the low frequency halophosphate lighting treatment, with data sets C and CW statistically significant, and data set S providing some evidence to suggest that the lighting treatments differed ($p<0.1$). Again, in the LF-Halo lighting treatment the average lethargy severity was approximately 3.2, 0.3 more severe than in the LF-Tri or HF-Tri lighting treatments. As discussed above, Figure 24 shows increased reporting of mild and severe symptoms in the LF-Halo lighting treatment.

Lighting Treatments and Offices

The ANOVA confirmed that Office One differed from Offices Two and Three with respect to eyestrain symptoms in the complete (C), complete with washout (CW) and screened with washout (SW) data sets. When the baseline data was treated as a covariate, the offices were not significantly different, providing some reassurance that this data accurately captured baseline responses. When the age and gender data was treated as a covariate, there was little evidence to suggest that the offices differed with

[59] Participants reported symptom severity on a 7 point Likert scale, where 1=no symptoms and 7= very severe symptoms.

respect to eye symptom severity. There were no differences between the offices when symptom severity only was considered, suggesting that the distribution of symptom severity was equivalent across the three offices and that the offices differed primarily with respect to symptom incidence. Extreme values were not influential in these analyses.

In the baseline data, Office Two was found to differ significantly from the other two treatments, however this was not repeated in the main study and can probably be explained by the perceived difference in lighting conditions from the existing lighting to the baseline lighting. This is discussed in Chapter Two (Experimental Methodology).

The visual examination of the data suggested that the three offices may differ with respect to headache symptoms. However, the ANOVA revealed no differences between the participants with respect to headache symptom incidence or severity. Figure 29 also suggested that lethargy symptom incidence and severity differed between offices, however the ANOVA did not return statistically significant results.

Average Weekly Symptoms Analyses

The analyses revealed that Week One was significantly different to Weeks Two, Three and Four with respect to eyestrain symptom severity. Headache and lethargy symptom severity did not differ across the four weeks of the study although in all cases participants experienced the most severe symptoms in Week One of the trial period. The outcome did not differ between the complete and screened data sets.

Overall, the data provided some evidence to suggest that a carry over effect was present. Therefore, it must be assumed that the preceding lighting treatment may have influenced the responses of the participants to some extent for an initial period of the following lighting treatment and a washout period was imposed for the majority of the analyses. However, as the trial*week interaction was not significant, any carryover effect was not highly influential.

Overall the results from this study provided some grounds to suggest that a carryover effect was present. Therefore future trials should ensure that carry over effects can be detected and avoided if necessary by including a washout period immediately following each lighting treatment.

Discussion: Differences between Data Sets

A number of analyses considered factors that may have influenced the experimental outcomes and the ANOVA revealed some differences between these data sets. These are discussed below.

1. Screening non work related symptoms

The analyses undertaken compared the complete and screened data sets to determine if symptoms differed with respect to lighting treatments and offices. In eight of the nine analyses, the F test values were lower for lighting treatment differences in the screened data sets. Mean values remained comparable or were slightly lower for these analyses. Differences were less clear for the office data as the differences between data sets was smaller.

This outcome suggests that screening symptoms that do not disappear or reduce after the work day is concluded may not be valid for this group of participants. The analyses showed that more evidence was provided to suggest that the lighting treatments differed (higher F Test values) when all symptoms were included, regardless of whether they continued or abated after the work shift. The model frequently adopted for studies examining the effect of the indoor environment on health assumes that when symptoms do not disappear or reduce after the work shift is completed they are due to non work related factors, typically illness such as influenza or seasonal allergies (hayfever) that are independent of the workplace (World Health Organisation, 1984). If this was the case, then it would be expected that the additional data would decrease the difference between lighting treatments and reduce F Test values, as symptoms reported would be unrelated to workplace conditions. As the opposite appears to be the case, it suggests that valuable information may be discarded by screening the data for symptoms that remain once the work environment is left.

It is possible that this outcome was because the study population were shift workers. Many of the office personnel were also involved in tertiary study, were homemakers (many with children) or had other part time or even full time work. Therefore these participants are likely to be fatigued, leading to increased symptom incidence and/or severity, which may have influenced the prevalence at the end of the work day. In addition, office personnel who work an evening shift are likely to go home and shortly thereafter to bed. There may not be a sufficient period of time for symptoms to reduce or disappear. Therefore, this method of analysis may not be appropriate for shift workers.

Alternatively, symptoms caused or influenced by the lighting conditions studied in this research may not disappear or reduce after the work shift is concluded. If the symptoms are due to visual fatigue, and have a physiological basis, then the symptoms may not abate until the eye is rested by sleep. This is supported by research on fluorescent light flicker that reveals underlying physiological mechanisms theorised to cause differences in visual performance, comfort and fatigue under light of differing frequencies (Eysel & Burandt, 1984; Kennedy & Murray, 1991). Further, the study by Veitch & Newsham (1998a) showed that visual fatigue could be measured after exposure to differing flicker frequencies. This study did not show differences due to fluorescent light flicker, however the mechanisms may be comparable. Therefore in this experiment, the data sets that include the complete data set are likely to provide a better basis for assessing lighting treatment differences.

2. Treating the baseline, age and gender data as covariates;

The analyses considered the influence that office, age and gender differences had on symptoms reported by participants. When treatment differences were considered, all analyses had comparable trends to the other analyses undertaken, but with lower F test and corresponding p-values. The covariate data was not available for all participants therefore a smaller number of data points were available for analyses. Fewer data points reduces the statistical power of the analyses and inflates the probability of a Type II (β) error, decreasing the probability of detecting any effect that may be present.

Therefore, as the baseline, age and gender balance across the three offices appeared to have minimal impact on the ANOVA outcomes and a smaller data set was used for the analyses it is probable that the power of the study was reduced and that differences between the offices due to these factors is unlikely to have been large or very influential.

3. Excluding responses in which the participants had no symptoms.

These analyses excluded responses where symptoms were not experienced. The ANOVA provided strong evidence to show that eye and lethargy symptom severity differed between lighting treatments. In the eye symptom analyses, F test values were higher than in the data sets that included 'no symptom' responses, showing that the difference between lighting treatments could largely be attributed to participants experiencing more severe symptoms in the low frequency halophosphate lighting treatment. In the lethargy symptom analyses the lower F test value indicated that both symptom incidence and severity differed between lighting treatments.

These results suggest that participants who experience symptoms frequently in the workplace, were more sensitive to changes in lighting conditions than those who rarely or never report symptoms. Participants experiencing eyestrain and lethargy symptoms, reported that these symptoms were more severe in the low frequency halophosphate lighting treatment, in comparison to the low frequency triphosphor or high frequency triphosphor lighting conditions[60].

Extreme Values

Thirteen individuals reported outlying responses across the three trials with seven participants reporting severe symptoms in only one trial, five participants experiencing severe symptoms in two trials and one participant experiencing severe symptoms in all three trials. No relationship appeared to be present between the trials or the lighting treatments in which participants experienced symptoms.

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[60] More than 35% of participants reported severe eyestrain, headache or lethargy symptoms across the three trials (symptom severity of 5 or over). Therefore there was no evidence to suggest that a small group of participants were influential.

Seven of these individuals took part in the medical study[61] and were found to have the following: insomnia (2), poor vision (1), back strain (5), hayfever (2), asthma (2). In four cases the results from the medical study strongly suggested that symptoms could be attributed in part to these factors. In particular, the participant who experienced severe symptoms in all three trials had very poor vision and her symptoms are likely to be solely attributed to this. Interestingly, she did not experience severe eyestrain, but did report severe headaches and concentration difficulties. The final three participants who took part in the medical study experienced symptoms that could not be attributed to factors outside of the work environment.

The participants who experienced extreme symptoms did not appear to be exceptional. Many symptoms experienced by participants could be explained (at least in part) by external factors or medical conditions, however in up to one third of cases, symptoms could not be adequately explained by these factors alone[62]. However, given the influential nature of their responses, which constituted only a small proportion of the total data points, examining the results without these data point included was appropriate.

3.7 Conclusions: Symptom Severity and Lighting Treatments

The relationship between average monthly symptom severity and lighting treatments was explored by Analysis of Variance (ANOVA), with Duncan multiple range comparison test used to determine differences between treatments. The data was initially screened and extraneous values excluded from the data set. As is discussed elsewhere, the exploratory nature of this study lead to the data being screened in a number of ways to better describe the relationship between the lighting treatments and identify influential parameters. The results suggested that screening non-work related symptoms may have excluded valuable information, and that differences between the participants in the offices (treating baseline, age and gender information as covariates)

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[61] Participants 1-9, 1-25, 2-5, 2-13, 2-54, 3-2, 3-26. These individuals can be examined in more detail in Chapter 5 (Medical Study).

[62] This is discussed in further detail in Chapter Five (Medical Study).

was unlikely to be very influential. The one-week washout period was found to be important, as the repeated measures ANOVA suggested that a carryover effect may have been present for eyestrain symptoms. The symptoms only analyses strongly suggested that symptom severity as well as symptom incidence differed between lighting treatments. Participants who reported outlying responses were found to be influential.

Therefore, the complete data set with a one-week washout period, excluding outliers, is likely to give the most definitive answer as to whether symptom incidence and severity differed with lighting treatments (Table 26). The results of this analysis considered alongside the other findings (Tables 22-24) provide some evidence to suggest that eyestrain severity differs between lighting treatments. Strong evidence is presented to suggest that lethargy symptom incidence and severity differs between lighting treatments. Headache incidence and severity was not shown to differ. The data did not meet all requisite assumptions with respect to normality and homogeneity, but ANOVA is reasonably robust to unequal variance and non-normal data. These deviations were most marked in the eyestrain data, with the lethargy data and the symptoms only data meeting the assumptions to a much greater extent.

Overall, the differences found between the lighting treatments appeared to be due to increased reporting of severe eyestrain and lethargy symptoms, strongly suggesting that participants who were sensitive to environmental conditions in the workplace were significant contributors to the results found.

Office One participants reported less eyestrain incidence and severity when compared to Offices Two and Three, but headache and lethargy symptoms were not significantly different. The symptoms only analyses were not significant suggesting that despite the differences in symptom incidence, symptom severity was comparable across offices. Office One did not appear to be exceptional in gender, age, eyeglass history or medical background. Therefore these differences may be attributed to differences in organisational culture or physical environmental conditions. No significant differences were observed between the trials and there was no interaction between trials and treatments.

Table 29. Results of ANOVA – Complete data set with one week washout

CW - Complete data set with one week washout							
Symptom	MSE Value	F Test	p-value	Treatment	N	Mean	Duncan
Eyestrain symptoms	0.27 *(0.14)*	3.34 *(1.72)*	0.04 *(0.19)*	LFHalo HFTri LFTri	53 *(50)* 47 *(45)* 52 *(52)*	1.79 *(1.68)* 1.56 *(1.52)* 1.49 *(1.49)*	A *(A)* B *(B)* B *(B)*
Headache symptoms	0.13	0.87	0.424	LFHalo HFTri LFTri	53 47 51	1.58 1.49 1.51	A A A
Lethargy symptoms	0.33 *(0.19)*	6.29 *(4.67)*	0.003 *(0.01)*	LFHalo HFTri LFTri	53 *(51)* 47 *(43)* 52 *(52)*	2.06 *(1.98)* 1.68 *(1.66)* 1.69 *(1.69)*	A *(A)* B *(B)* B *(B)*
CWC - Complete data set with one week washout: Symptoms only							
Symptom	MSE value	F Test	p-value	Treatment	N	Mean	Duncan
Eyestrain symptoms	0.19 *(0.14)*	3.78 *(2.53)*	0.03 *(0.09)*	LFHalo HFTri LFTri	30 *(29)* 24 *(24)* 30 *(30)*	3.11*(3.09)* 2.70*(2.70)* 2.52*(2.52)*	A *(A)* B *(B)* B *(B)*
Headache symptoms	0.48	1.69	0.20	LFHalo HFTri LFTri	30 30 31	3.04 2.87 2.80	A A A
Lethargy symptoms	0.35	3.35	0.05	LFHalo HFTri LFTri	34 28 31	3.24 2.92 2.85	A B B

These results do not show that increased flicker frequency and reduced modulation depth affected the incidence or severity of eyestrain, lethargy and headache symptoms. The low frequency halophosphate lighting treatment represented the low frequency - low modulation depth condition, in comparison to the low frequency triphosphor lighting treatment (low frequency – high modulation depth) and the high frequency triphosphor lighting treatment (high frequency – low modulation depth). The LF-Tri and HF-Tri were not shown to be significantly different.

This study provides evidence to justify the use of energy efficient triphosphor fluorescent lamps in preference to the less energy efficient halophosphate lamps on the grounds that they may reduce eyestrain and lethargy symptoms as well as energy consumption. The study did not suggest that high frequency control gear which has

lower energy consumption than low frequency control gear influenced the health symptoms experienced by office personnel.

3.8 Perception of Flicker from Lamps

Participants were asked on a weekly basis whether they were able to perceive flicker from the fluorescent lamps while at their work station.

In 8% of the questionnaires received, participants reported that they were able to see flicker from the lighting. Overall, this included one third of the participants. However, the vast majority of the participants did not report observing flicker consistently throughout any one trial period, with most participants' only perceiving flicker once or twice throughout the study period.

Flicker from the low frequency triphosphor lamps (modulation 40%) was perceived more than twice as often as the low frequency halophosphate (modulation 18%) and high frequency triphosphor conditions (Table 30). Participants in Office Two detected flicker from the fluorescent lamps most frequently, followed by participants in Office One and Three.

Throughout the duration of the study, participants were invited to outline any aspect of the work environment that they liked or disliked. Fluorescent light flicker was not identified by any of the participants.

Table 30. Frequency of participants perceiving flicker from fluorescent lamps

	Base 1	**LFTri**	**LFHalo**	**HFTri**	**Total**
Office One	6	6	1	1	14
Office Two	10	12	7	8	37
Office Three	2	1	1	1	5
Total	18	19	9	10	56

Discussion: Perception of Flicker

The average Critical Fusion Frequency is approximately 60 Hz, depending upon viewing conditions, with some occupants able to perceive flicker frequencies of up to 100 Hz. On this basis, the vast majority of participants in this study should not be able to see flickering from the low frequency triphosphor and halophosphate fluorescent lamps.

Therefore the high incidence of participants detecting flicker in the low frequency lighting conditions is surprising. In addition, it seems extremely unlikely that participants could perceive flicker in the high frequency lighting treatment as this flicker frequency is far above that perceptible by the human visual system and the residual 100 Hz modulation was extremely small (3%) and again very likely to be imperceptible.

The results showed that participants in Office Two perceived flicker more frequently than those in Office One and Three. This, in part, is likely to be due to the higher participation rate in this office. In addition, participants in this office, and in Office One, were able to see fluorescent lamps in an adjacent room, although these were remote from the participants work stations. Research has shown that flicker is perceived most frequently by women and those aged less than 30 (Lindner & Kropf, 1993), however the age balance was comparable across the three offices and there was a higher proportion of men in Office Two when compared to Offices One and Three.

Previous laboratory and field studies have demonstrated that a 50 Hz flicker is perceptible to many individuals. A 50 Hz flicker frequency is present at the lamp ends when the lighting is operated with low frequency ballasts, or when the lamp is malfunctioning or aged. Participants may have been able to see a 50 Hz flicker under the following circumstances:

- Participants may have seen non experimental lamps in an adjacent room as the questionnaire did not qualify that the flicker had to be perceived in the space the occupants were occupying;

- One or more of the fluorescent lamps may have been malfunctioning and producing a 50 Hz flicker due to uneven firing of the electrodes at the end of the lamps which was visible to a number of participants;
- The low frequency lamps flicker at 100 Hz, but at the lamp ends the 50 Hz discharge of the electrodes can be visually detected. Participants may have observed this.

Each of these explanations may explain why the flicker was only perceived infrequently. However, the results do suggest that the flicker from the low frequency fluorescent lamps with high modulation (LF-Tri and baseline lighting) was more visually detectable than that of fluorescent lamps with low modulation rates (LF-Halo and HF-Tri), supporting previous research that has suggested that modulation depth affects flicker perception, visual perception and visual comfort (Collins & Hopkinson, 1954; Neary & Wilkins, 1989; Veitch & McColl, 1995). If a small number of participants were able to see the flicker then this result is plausible.

Most importantly the participants did not report that flicker from the fluorescent lamps was visually disturbing, influenced satisfaction with the lighting or symptom incidence or severity.

Several studies have reported that fluorescent light flicker is negatively perceived by office workers (Collins & Hopkinson, 1954; Brundrett, 1974; Stone, 1992). This study does not suggest that when flicker was perceived, it had negative consequences. As the fluorescent lamps used in this study were all new, this supports previous research that has concluded that the flicker from well maintained lamps is unlikely to be perceived or to present a visual disturbance to the vast majority of office personnel (Collins & Hopkinson, 1954).

Some evidence is presented to suggest that flicker perceptibility was influenced by the modulation depth of the fluorescent lamps and control gear. However overall, flicker was perceived infrequently in all lighting treatments.

No relationship was evident between flicker perception and satisfaction with the lighting, overall office environment, productivity or symptom incidence or severity. Future research that examines this aspect of fluorescent lighting should qualify the space in which the flicker is detected.

3.9 Actual Productivity Results

The analysis considered the relationship between the actual productivity of the participants and:

- Lighting treatments;
- Eyestrain, headache and lethargy symptoms experienced in the work place;
- Perceived productivity;
- Satisfaction with the overall work environment, lighting, air-conditioning and temperature;
- Job satisfaction.

Data Availability

Office management routinely collected the productivity data utilised in this section in Offices One and Two. Participants were required to give their written permission before their productivity data was used in the study. The productivity data was not available from Office Three.

Table 31. Productivity data available for analysis. C = Complete data set, CW = Complete data set with one week washout.

	HF-Tri		LF-Halo		LF-Tri	
	C	CW	C	CW	C	CW
Office One	23	19	13	10	17	13
Office Two	53	42	45	35	49	37
Total	**76**	**61**	**58**	**45**	**66**	**50**

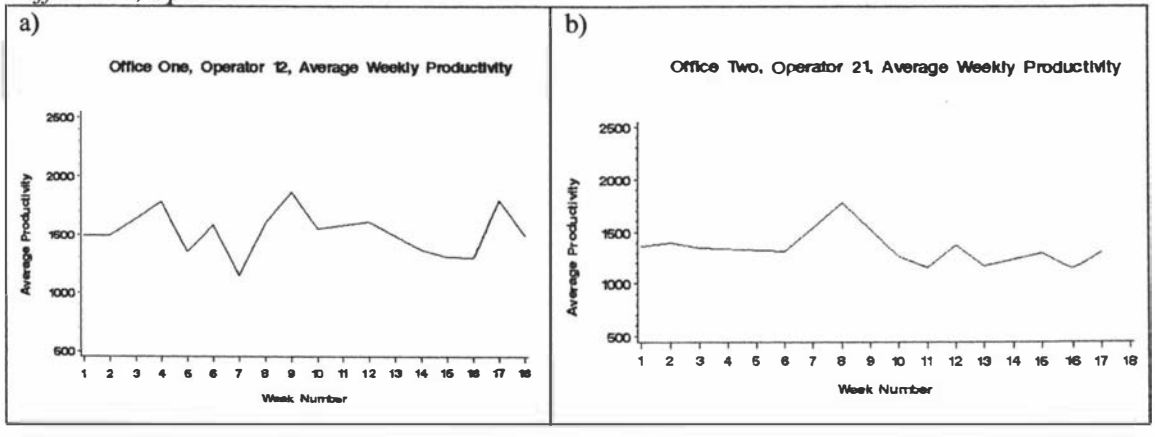
The analyses required the average weekly productivity and average weekly symptom severity questionnaire data from each participant. Data was available from 31 participants including 10 participants from Office One (36%) and 21 participants from

Office Two (65%). However only 16% of the total average weekly productivity data from Office One and 34% of the average productivity data from Office Two was available for analyses[63] (Table 31).

Individual Participant's Productivity Data

The productivity data across the study period (including baseline periods) from each individual was initially examined. Those participants who had been in the offices for less than six months or whose data counts increased during the study had their data excluded[64]. If data counts were inconsistent or influential the data was also excluded[65]. Typical examples of these profiles are shown in Figure 30, and a complete set of profiles for all participants (before screening) is shown in Appendix J.

Figure 30. Typical Productivity Data from Offices One and Two a) Office One, Operator 12, b) Office Two, Operator 21.



The visual examination revealed that there was considerable variation in the weekly average productivity for each individual across the study. Data from participants in Office One frequently had distinct peaks and troughs in their productivity counts. There did not appear to be any pattern over time across participants. The profile of

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[63] Participants did not necessarily complete questionnaires for every shift that they worked, and questionnaire data was excluded if the participant did not work the entire shift under the experimental lighting conditions.

[64] Participants whose productivity data was excluded are identified in Appendix J by a dotted line that runs through the data points and a solid line that crosses the title of the graph.

[65] These data points are identified in Appendix J by a circle around the data point.

Office Two individuals was less variable. No relationship between lighting treatments or trials was evident from visually examining this collection of data.

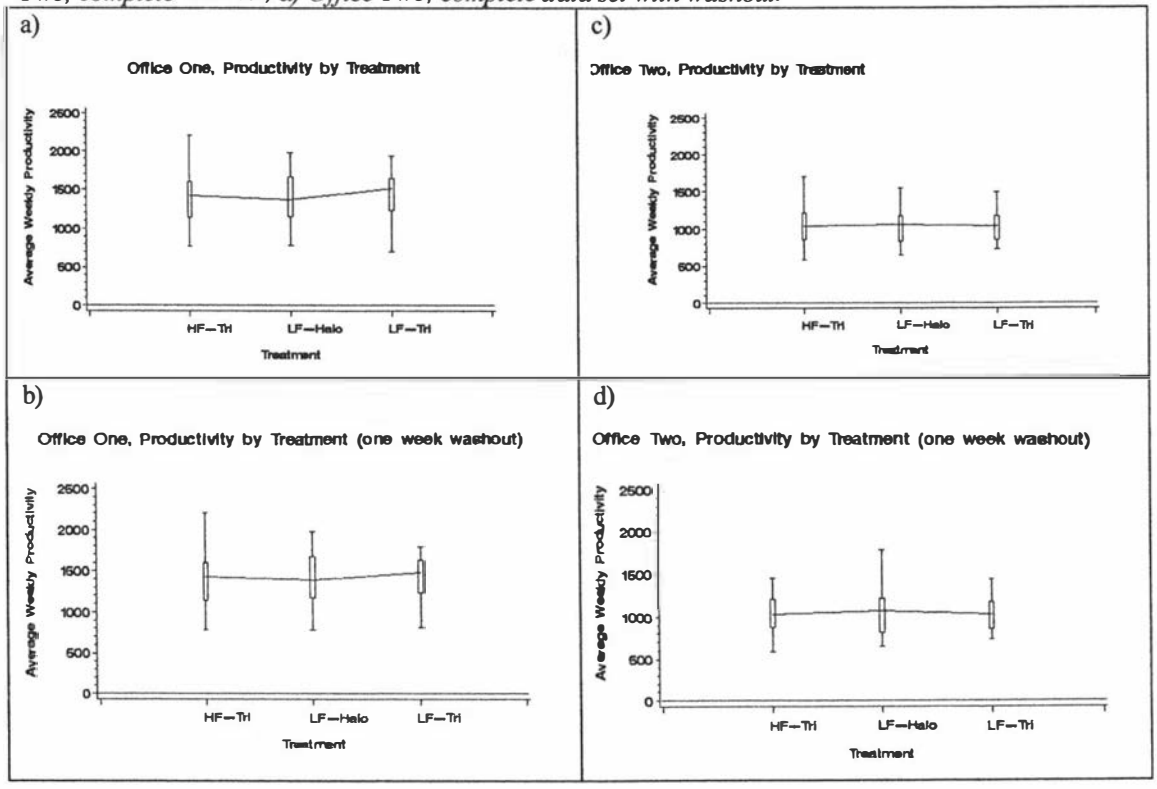
Actual Productivity and Lighting Treatments

The actual productivity data sets from Offices One and Two were initially examined to determine if they could be combined. A two sample T test was used to test the two data sets, which were shown to be significantly different (p value < 0.001) and were therefore treated independently in subsequent analyses.

Table 32. Average weekly productivity (units/hour), mean values for each lighting treatment (Complete data set)

	HF-Tri	LF-Halo	LF-Tri
Office One	1380	1385	1430
Office Two	1047	1043	1029

Figure 31. The relationship between average weekly productivity (units/hour) and lighting treatments a) Office One, complete data set, b)Office One, complete data set with washout, c) Office Two, complete data set, d) Office Two, complete data set with washout.



The relationship between the lighting treatments and actual productivity for the two offices was visually examined using box plots (Figure 31). The complete data set and the complete data set with a one-week washout were considered. The symptoms only data was not included, as there were insufficient data points to provide meaningful results.

The box plots revealed that there was considerable variation in the spread in the data within the three lighting treatments in both Office One and Office Two. The graphs did not reveal any meaningful differences between conditions and there was little difference in the overall mean values for each lighting treatment (less than 100 units/hour) or trends across offices (Table 32).

Actual Productivity and Symptom Severity

The relationship between actual productivity and eyestrain, headache and lethargy symptoms was visually examined using scatter plots. A regression line was fitted to these plots to observe the relationship between the two variables. The data sets were also examined using linear regression models in order to determine the amount of variation explained by the model and the quality of the fitted model.

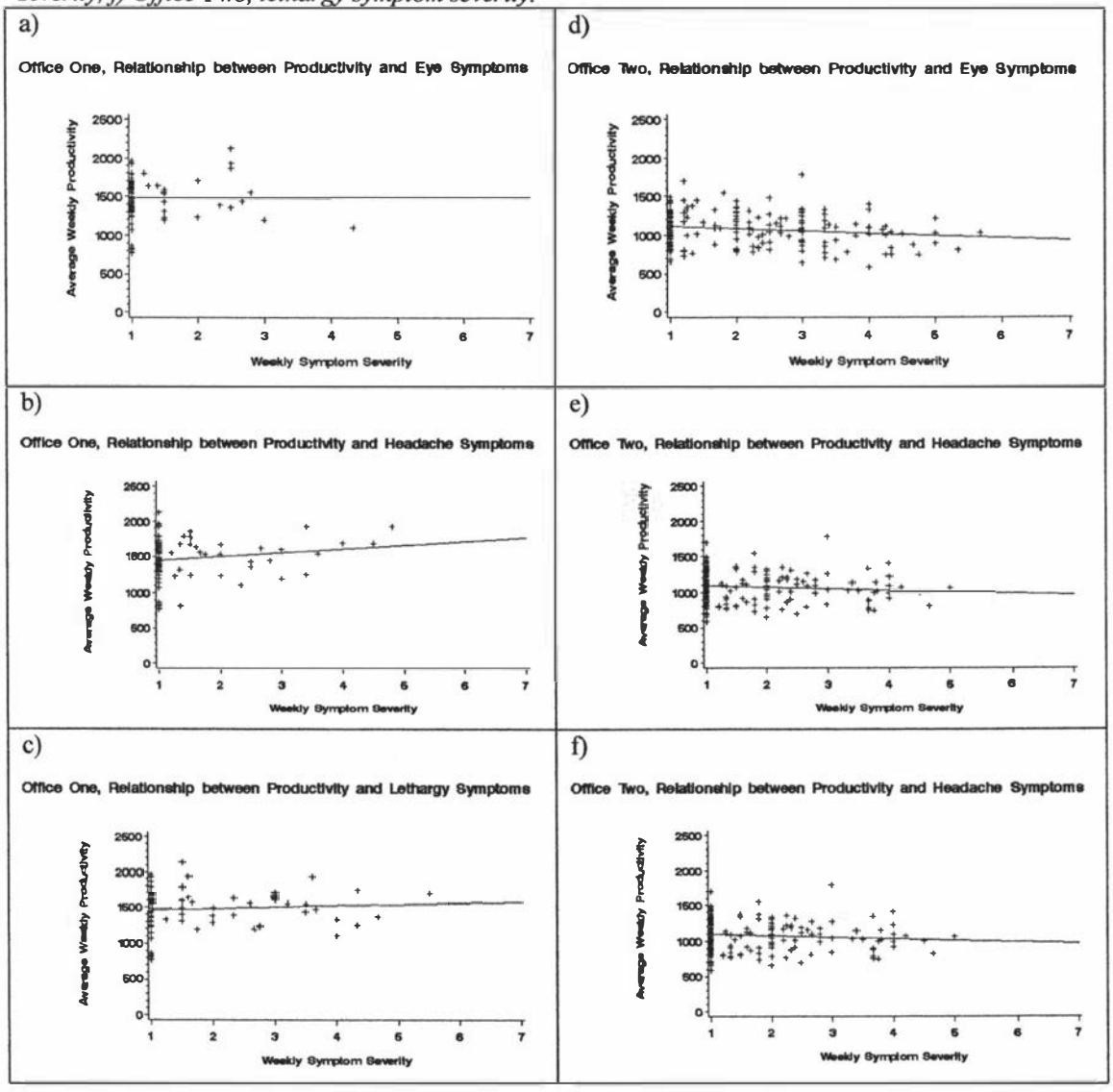
Figure 32 shows typical scatter plots with fitted regression line, for eyestrain, headache and lethargy data in Offices One and Two (data set C+B). The graphs show that there were considerable differences in the data between the two offices. In Office One only a small amount of data (<20 points) was available in which symptom severity was above 1[66] and both productivity and questionnaire data was available.

A larger amount of data was available in Office Two. The fitted regression line showed a small decrease in productivity as symptom severity increased for eyestrain, headache and lethargy symptoms. The coefficient of variation or (r^2) value was calculated to determine the quality of the model fitted (the amount of variation explained by the model) with larger r^2 values giving a better fit. Then linear

[66] 1 = no symptoms.

regression was used to determine whether or not a significant relationship between the two variables was present. The results of the analyses are shown in Table 33.

Figure 32. The relationship between average weekly productivity and symptom severity for data set C+B, a) Office One, eye symptom severity, b) Office One, headache symptom severity, c) Office One and lethargy symptom severity, d) Office Two, eye symptom severity, e) Office Two, headache symptom severity, f) Office Two, lethargy symptom severity.



A significant relationship was present between actual productivity and eye symptoms and actual productivity and lethargy symptoms in Office Two for data sets C+B ($0.003>p>0.002$), with 2% and 5% respectively of the variation (r^2 value) explained. The least squares linear regression line expressing actual productivity as a function of lethargy or eyestrain symptom severity is shown in Equation 1. The equation shows that with an overall change of one symptom (on a seven point Likert scale), productivity changes by 39 units per hour for lethargy and 28 units per hour for eye

symptoms, or 3% and 2% respectively. There were no significant relationships between symptom severity and actual productivity for data sets C or CS for Office Two and less than 10% of the variance was explained by the model for the other analyses. There were no significant relationships between the variables in Office One, although the r^2 value was much higher in these analyses.

Equation 1. Least squares simple linear regression equations a) Productivity and lethargy b) Productivity and eyestrain

a) Productivity = 1153 – 39(lethargy symptom)

b) Productivity = 1136 – 28(eyestrain symptom)

The linear regression model was also fitted using a weighted function to determine if the data was able to be further segregated as the majority of the data was clustered at symptom severity =1 (no symptoms) on the horizontal axis, but this did not change the outcomes.

Scatter plots with fitted regression lines were used to examine the relationship between and actual productivity and symptoms within each lighting treatment using data set C, but the number of data points each in grouping was small and no trends or patterns were evident.

Actual Productivity and Perceived Productivity, Perception of the Work Environment and Job Satisfaction

The relationship between actual productivity and perceived productivity, perception of the work environment and job satisfaction was examined using box plots. Figure 33 shows the box plots for each of the two offices (data set C+B). The graphs do not show any relationship between actual productivity and the perceived effect of the work environment on productivity, or satisfaction with other aspects of the work environment (job satisfaction, satisfaction with environment, temperature and air circulation).

Table 33. Results of linear regression for Offices One and Two, data sets C+B, C and CS.

	Office One			Office Two		
Symptom	R^2 value	Std Error	p-value	R^2 value	Std Error	p-value
C+B – Complete data set plus baseline						
Eyestrain Symptoms	0.000	53	0.97	0.02	12.9	0.03
Headache Symptoms	0.03	36	0.15	0.009	15.8	0.18
Lethargy Symptoms	0.006	28.8	0.51	0.05	12.04	0.002
C – Complete data set						
Eyestrain Symptoms	0.002	139	0.75	0.004	20.53	0.49
Headache Symptoms	0.056	49.87	0.13	0.003	24.5	0.56
Lethargy Symptoms	0.065	37.52	0.10	0.006	19.65	0.39
CS – Complete data set symptoms only						
Eyestrain Symptoms	0.25	61.5	0.25	0.02	20.7	0.23
Headache Symptoms	0.32	84.78	0.19	0.03	22.87	0.14
Lethargy Symptoms	0.05	73.3	0.61	0.07	18.7	0.2

The plots show some variation in average productivity values for the perceptual measures, but the spread of data does not suggest that any significant relationship is present. Incomplete box and whisker plots at the extreme ends of the graphs indicate a smaller number of data points. This is more marked in Office One.

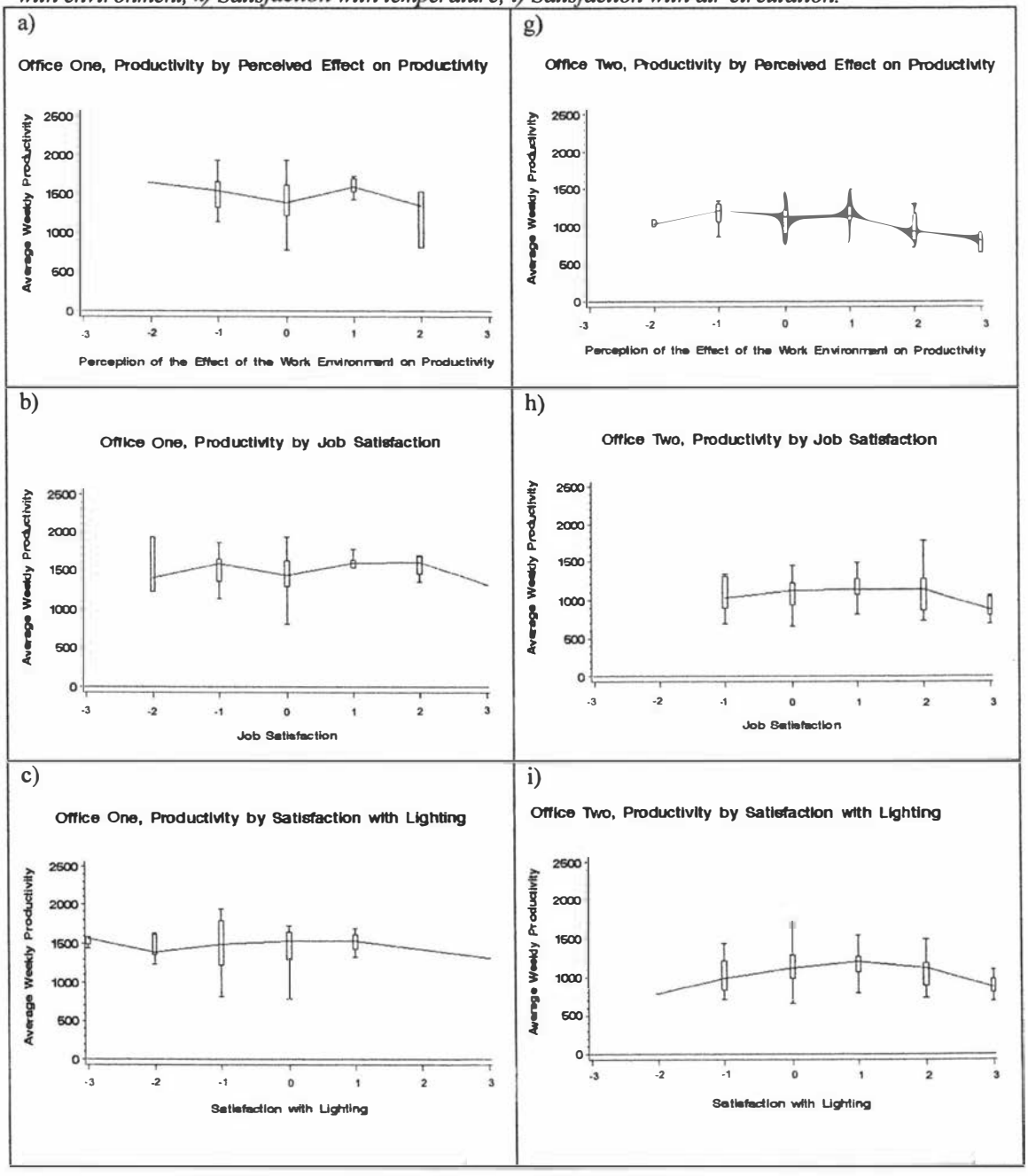
Discussion: Actual Productivity

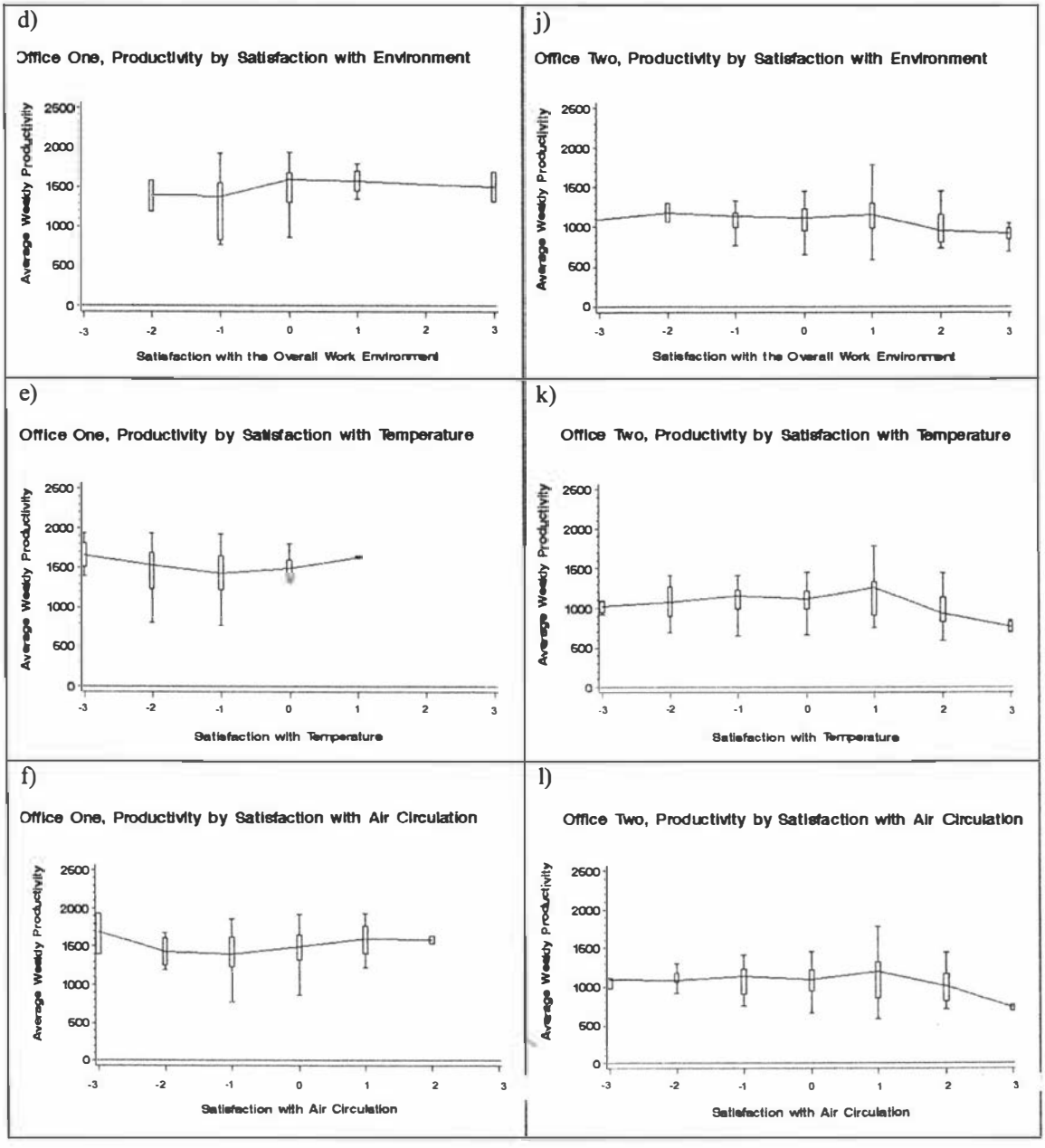
Variation in Actual Productivity between Individuals

The results show that there was a large amount of variation in productivity from any one individual as well as between individuals and offices during the study period. This variation is unsurprising given the enormous range of factors that are known to affect the productivity of an individual. The demographics section shows the

participants varied substantially in age, gender, number of years working as a data processor, number of shifts worked per week and hours per shift. In addition, participants varied with respect to their general wellbeing, motivation, job satisfaction, and symptoms experienced in the workplace. Each of these factors may influence the productivity of the individual (Rohles, 1994).

Figure 33. The relationship between average weekly productivity and perception of the work environment for data set C+B. Office One: a)The perceived effect of the work environment on productivity, b) Job satisfaction, c) Satisfaction with lighting, d) Satisfaction with environment, e) Satisfaction with temperature, f) Satisfaction with air circulation. Office Two: g) The perceived effect of the work environment on productivity, h) Job satisfaction, i) Satisfaction with lighting, j) Satisfaction with environment, k) Satisfaction with temperature, l) Satisfaction with air circulation.





There were also differences in the data entry machine used. While machinists did not have a particular workstation allocated to them, the staff did have preferences for a particular machine or location. Although the data entry machines all carried out the same task, different machines were faster, jammed less frequently, were able to take a larger number of cheques, or were ergonomically better for a particular individual[67].

[67] The researcher was aware from talking to staff that different machines were preferred and that some machines blocked less frequently. However specific data was not systematically collected on this aspect of productivity.

The manner in which the data was collected introduced variation. In Office One, participants were required to monitor their productivity over a fixed one hour time period. In Office Two, productivity was monitored over an entire shift. In addition, Office One only measured productivity intermittently and the participants chose when their productivity was monitored, therefore motivation may have been higher.

Taken together, it is apparent that the variability within and between individuals and offices was introduced through a large number of channels. This is typical of field study measures of productivity, and is one of the primary reasons why performance is more easily measured in laboratory studies.

Actual Productivity and Lighting Treatments

The average productivity values for each lighting treatment, and the variation in the data, suggests that if there was any difference in actual productivity between the lighting treatments, it was very small. The largest difference between lighting treatments was less than 3.5% in Office One and less than 2% in Office Two with LF-Tri representing the highest and lowest productivity values in each office respectively. Given the substantial variation of values within each lighting treatment, it seems very unlikely that this small difference would be statistically significant.

Actual Productivity and Symptom Severity

The linear regression results found statistically significant relationships between the actual productivity of the participants and the eyestrain (p-value 0.03) or lethargy symptoms (p-value 0.002) in Office Two using the complete lighting data (including baseline). Other analyses did not show statistically significant relationships.

In Office Two, as eyestrain or lethargy symptom severity increased, actual productivity decreased. The variation explained by the lighting in these relationships was very small in statistical terms, at most explaining 5% of the data. However the size of this effect is not atypical of effect sizes found in lighting literature, and represents a small to medium effect (Veitch and Newsham, 1998). The linear regression equation showed that overall this variation represents a change in overall productivity of 3% for lethargy symptom severity and 2% for eyestrain symptom

severity for each increase in symptom severity of one on the seven point Likert scale used in this study.

It is possible that this relationship was spurious as it was not reflected for both offices that measured productivity or for all data sets. However, the other office only had a small number of data points that were available for analysis, and thus is unlikely to give valid results. Similarly, the other analyses also had less data, therefore the reduced power may have influenced the finding. Further, the outcome seems reasonable. The task completed by the office personnel had a significant visual component, thus any aspect of the office environment that affected the visual component – such as visual discomfort, is likely to influence productivity. Overall the results suggested that for each increase in the level of symptom severity reported, actual productivity declined by approximately 3-5% or 30-60 cheques entered per hour. The difference in symptom severity between the three lighting treatments translated to approximately a 1% decrease in productivity for participants exposed to the LF-Halo lighting treatment. Differences of this size were unlikely to have been detected statistically.

Actual Productivity, Perceived Productivity, Perception of the Work Environment and Job Satisfaction

No statistically significant relationships were found between actual productivity and perception of differing aspects of the work environments. An examination of the distribution of results for Offices One and Two shows the majority of participants reported values of -1, 0 or 1, signalling that most participants did not feel strongly satisfied or dissatisfied with the work environment. This was particularly evident in Office One, possibly explaining the lack of relationship between variables.

The graphs also suggested that some occupants who report being either very satisfied or very dissatisfied tend have lower average weekly productivity. This data represents a very small proportion of the participants, but further analysis of this data would elucidate and possibly identify commonalities between these participants.

Overall, there was no evidence to suggest that actual productivity was related to the participants' perception of the office environment. Further analysis may yield trends within the data and suggest future research directions.

Overall Conclusions: Actual Productivity

The actual productivity of the participants was not shown to differ between lighting treatments. If any effect exists, it is very small. However, a statistically significant relationship was found between symptom severity and actual productivity for eyestrain and lethargy symptoms in Office Two. In this office, as symptom severity increased, productivity decreased. Overall the change presented a small decrease in productivity of 2% and 3% for eyestrain and lethargy symptoms for each increment on a seven point Likert scale. In terms of the symptom incidence and severity differences due to the lighting treatments it represents a difference in productivity of 1%. Although a change of this magnitude seems small, when taken in the context of the overall salary for a company, it is significant.

There did not appear to be a systematic relationship between productivity, satisfaction measures and perception of the work environment. Further analysis of this data may yield more information.

Overall these results did not show any relationship between actual productivity and flicker frequency or modulation depth. If any effect does exist, it is probable that other aspects other aspects of the workplace overwhelmed it.

There was some evidence to suggest that eye symptoms and lethargy symptoms impacted on the productivity of the data entry personnel. This finding is significant and presents a strong argument for improving environmental conditions in the workplace. Very few field studies in this field have demonstrated productivity benefits from changes in workplace conditions and the methodology utilised in this study provides a valuable model for further research in this field.

3.10 Perception of the Work Environment

Introduction

This section discusses the participants' perception of the office environment during the study period, including lighting, air circulation, temperature, overall satisfaction with the work environment, as well as job satisfaction and the perceived effect of the work environment on productivity.

The questionnaire used to collect this data was completed on a weekly basis. Data was collected on a seven point Likert scale, where –3=very dissatisfied, 0=indifferent, 3=very satisfied. A comparable scale was used for the question regarding the perception of the work environment on productivity, where –3=significantly decreased productivity, 0=no impact on productivity, 3=significantly increased productivity.

The average value for each measure is shown in conjunction with line graphs that show the spread of data. Percentage values have been used as opposed to frequency values to enable the data from the three offices to be compared. These graphs include data from the entire study period (data set C+B: Complete plus Baseline).

Satisfaction with Lighting

The spread of data in Figure 34 and average values in Table 34, Table 35 and Table 36 reveal that as a whole the participants in the three offices did not feel strongly about the lighting conditions during the study period.

The majority of the graphs showed a bell shaped curve and average values between –1 and 1 revealing that the vast majority of participants were either indifferent or slightly/somewhat satisfied or dissatisfied with the lighting conditions.

Table 34. Average values for Satisfaction with lighting for each trial.

	Baseline 1	Trial 1	Trial 2	Trial3	Baseline 2
Satisfaction with Lighting	+0.09	+0.11	+0.20	+0.23	+0.63

Table 35. *Average values for Satisfaction with lighting for each office.*

	Office One	Office Two	Office Three
Satisfaction with Lighting	-0.26	+0.36	+0.36

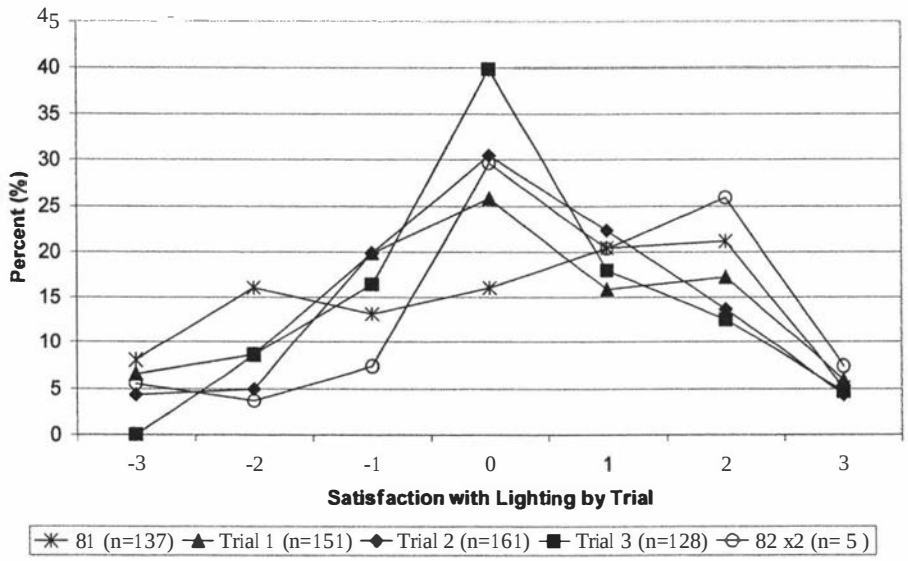
Table 36. *Average values for Satisfaction with lighting for each treatment.*

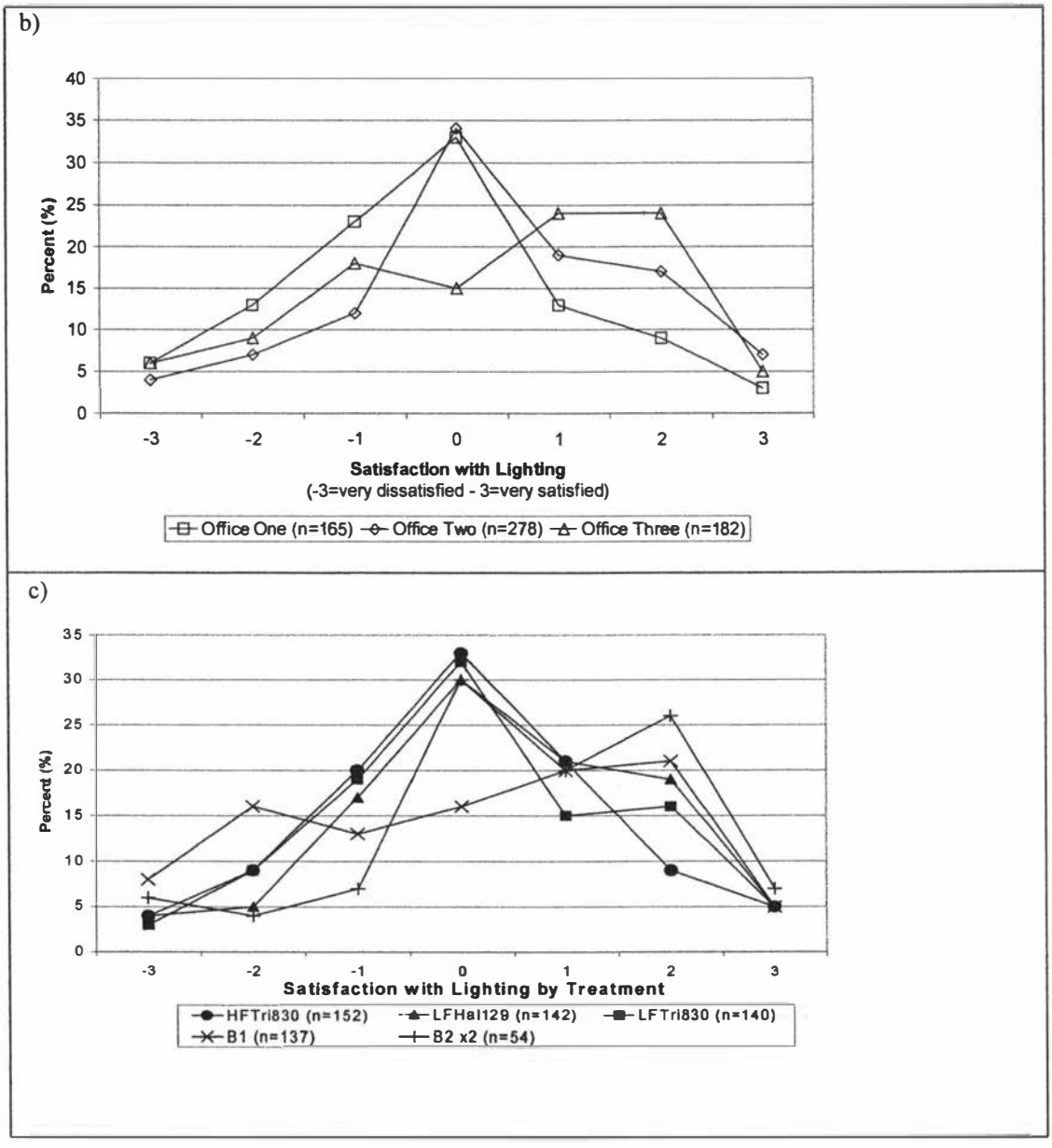
	Baseline 1	HF-Tri	LF-Halo	LF-Tri	Baseline 2
Satisfaction with Lighting	+0.09	+0.04	+0.35	+0.14	+0.63

When considering satisfaction with the lighting by trial, it was clear that as the study progressed satisfaction with lighting conditions increased, however in all periods the average value was above 0, indicating that taken as a whole participants were satisfied with the lighting (Table 34). Participants in Offices Two and Three were more positive about the lighting conditions in comparison to Office One (Table 35). In all three treatment periods the largest majority of participants recorded indifference with the lighting conditions. The highest satisfaction values were recorded in Baseline 2, followed by the LF-Halo, LF-Tri, Baseline 1 and HF-Tri lighting treatments (Table 36).

Figure 34. *Participant's satisfaction with lighting conditions a) by trial, b) by office, c) by treatment*

a)





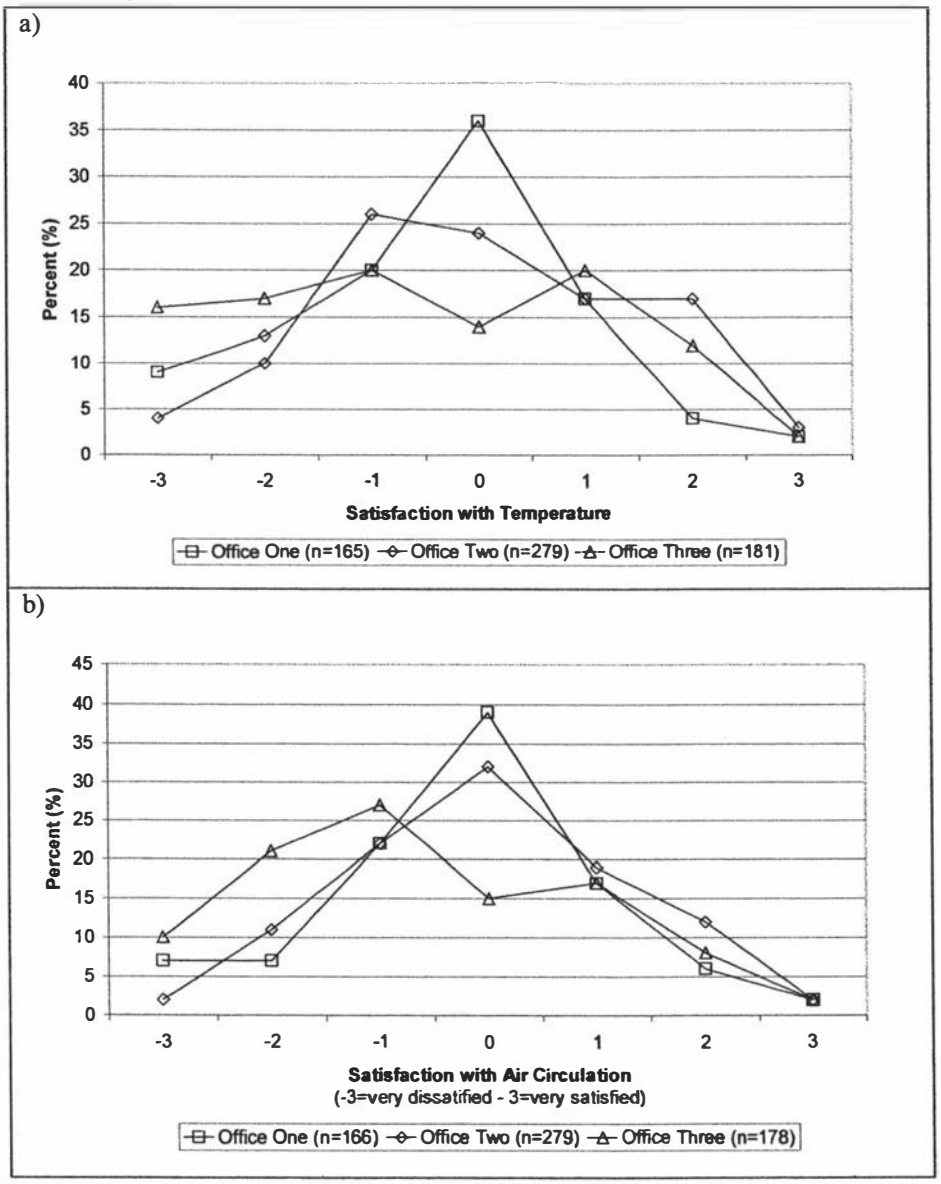
Satisfaction with Temperature, Air Circulation and the Overall Work Environment

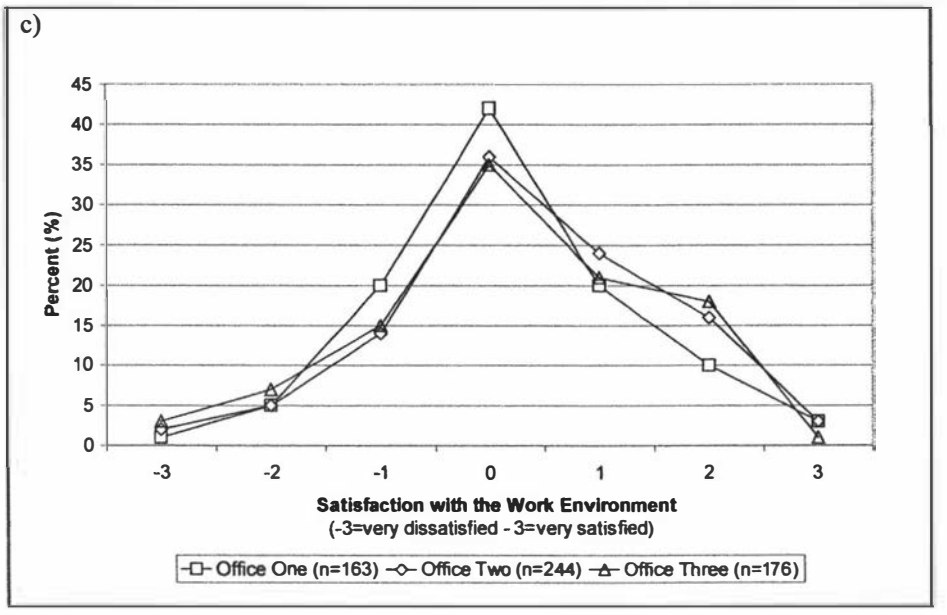
Similar results were recorded by participants when they considered their satisfaction with the temperature, air circulation and the overall work environment during the study period with the majority of responses grouped between –1 and 1 (Figure 35 and Table 37). However, participants in all three offices clearly were less satisfied with the temperature and air circulation in comparison to the overall work environment.

Table 37. Average values for Satisfaction Measures (scale –3 (very dissatisfied) to +3 (very satisfied))

	Office One	Office Two	Office Three
Satisfaction with Lighting	-0.26	+0.36	+0.36
Satisfaction with Temperature	-0.40	0.00	-0.54
Satisfaction with Air Circulation	-0.19	-0.01	-0.61
Satisfaction with the Overall Work Environment	+0.17	+0.35	+0.19
Perceived Effect of the Work Environment on Productivity	+0.14	+0.36	0.00
Job Satisfaction	+0.59	+0.50	+0.43

Figure 35. Participant's satisfaction with the a) Temperature, b) Air Circulation, and c) Work Environment

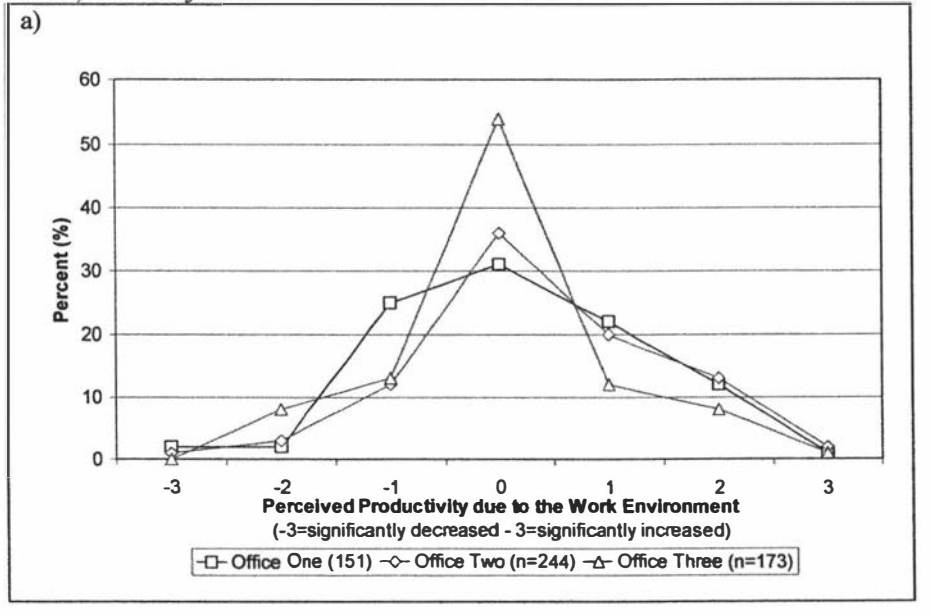


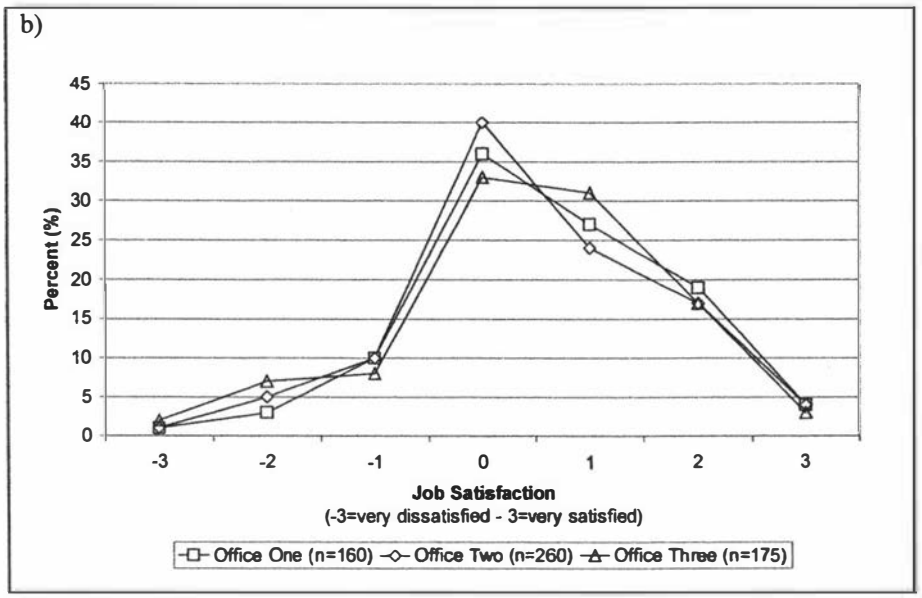


The Perceived Effect of the Work Environment on Productivity

During the study period, participants felt the work environment had minimal effect on their productivity. Offices One and Two had a slightly positive trend, with Office Three participants evenly balanced between positive and negative effect (Table 37 and Figure 36).

Figure 36. Participant's satisfaction with a) Perceived productivity due to the work environment, and b) Job satisfaction.





Job Satisfaction

The average value for job satisfaction was positive in all three offices, showing that taken as a whole, participants were satisfied with their job during the study period. However, the largest proportion of participants recorded indifference (Table 37 and Figure 36).

Aspects of the Work Environment Liked or Disliked

This section discusses responses to the open ended question included as part of the weekly questionnaire and describes aspects of the work environment that participants liked or disliked over the previous week. In total 351 comments were made by 64 participants who completed 260 questionnaires during the study period.

The majority of comments were made with respect to temperature (44%), lighting conditions (40%) and air circulation (12%) with infrequent comments regarding ergonomic aspects of the office space and noise (Table 38). The majority of comments were on aspects of the office that were disliked (90%). Participants commented more during the first baseline period than at any other time, and the number of responses reduced throughout the study.

Table 38. *Aspects of the Office Environment Liked or Disliked by Participants*

Environmental condition	Participant response	Office One	Office Two	Office Three	Total No.
Lighting	Caused symptom	6	10	14	30
	Bright/glarey	13	26	3	42
	Dim	-	-	2	2
	Poor visibility	7	-	11	18
	Ok/Good	6	1	12	19
	Don't like	6	13	10	29
Lighting Total		38	50	52	140
Temperature	Warm/Stuffy	16	47	33	96
	Cold	16	10	9	45
	Variable	3	-	10	13
	Ok	3	11	2	16
	Poor	2	2	3	7
Temp. Total		40	70	57	156
Air Circulation	Humid	1	2	2	5
	Dry	-	2	2	4
	Poor air circulation	7	8	19	35
Air Circ. Total		8	13	23	44

Lighting

The majority of comments regarding the office lighting were from participants who found the lighting to be bright (30%), felt that the lighting caused symptoms (21%), or that they didn't like the lighting (26%). The majority of negative comments were from participants in Office Two. Almost 25% of comments from Office Three were from participants who liked the lighting or found it ok. A significant number of participants in Office One (21%) and Office Three (18%) respectively felt that the lighting reduced visibility. The majority of responses were received during the Baseline Period or in Trial One (Table 39, Figure 37).

Temperature

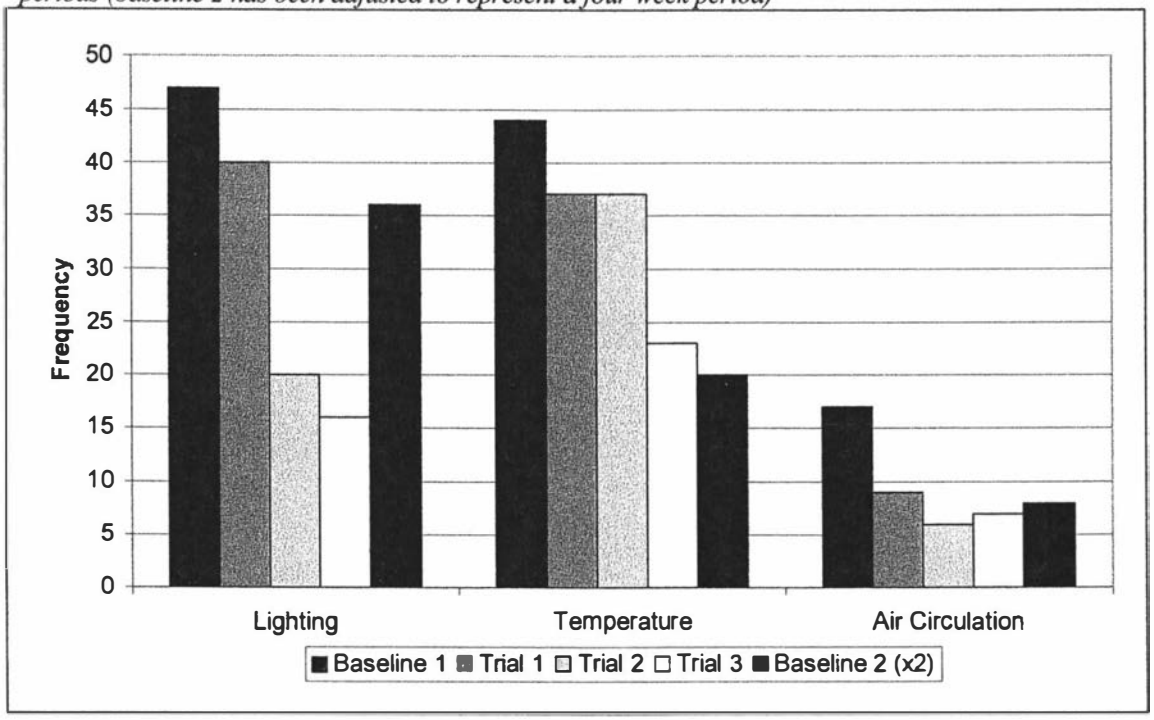
The majority of comments were received from participants who found their office to be too warm or stuffy (63%) or too cold (10%). Negative comments were received from 26%, 42% and 39% of participants in Offices One, Two and Three respectively.

Responses were relatively consistent across the baseline and lighting treatment periods, with more comments in Office Three at the commencement of the study.

Table 39. *Frequency of responses received from each office during the study.*

Office	Trial	Lighting	Temp	Air Circ.	Total
Office One	Baseline 1	15	13	2	33
	Trial 1	11	7	3	21
	Trial 2	1	13	1	15
	Trial 3	3	4	1	6
	Baseline 2	8	3	1	12
Office Two	Baseline 1	25	18	5	48
	Trial 1	9	15	2	26
	Trial 2	6	14	2	21
	Trial 3	5	19	2	27
	Baseline 2	7	4	11	11
Office Three	Baseline 1	7	26	11	44
	Trial 1	20	14	4	38
	Trial 2	14	10	3	27
	Trial 3	6	4	4	14
	Baseline 2	5	3	1	9

Figure 37. *Frequency of responses on aspects of the work environment liked/disliked for the trial periods (baseline 2 has been adjusted to represent a four week period)*



Air Circulation

The majority of comments were from participants who felt the air circulation was poor (79%), with 11% and 9% respectively feeling the air was humid or dry. The most comments were received from participants in Office Three (52%).

Discussion: Perception of the Work Environment

When asked to rank their satisfaction with differing aspects of the work environment during the study on a week by week basis, participants as a whole did not feel that the work environment significantly affected their work ability. The majority of participants felt either indifferent or slightly positive/negative about the lighting, temperature, air circulation and overall work environment. Reflecting this, the work environment was not considered to affect overall satisfaction or productivity to any large extent by the majority of participants.

The data did not suggest that participants rated lighting treatments differently, however the increase in satisfaction with lighting as the study progressed suggests that adaptation to the study conditions may have occurred. This change was particularly evident when comparing the baseline conditions. If the baseline is disregarded, the differences are of less consequence.

Despite the overall responses suggesting relative indifference to the work environment, when participants were satisfied or dissatisfied with the work environment they were able to describe which aspects of the office that they liked or disliked, with 90% of comments unfavourable.

Many of the lighting responses appeared to be related to changes in lighting conditions (Baseline 1 and 2, Trial 1) and may reflect either changes in illuminance levels or the spectral characteristics of the lamp. Both Offices Two and Three had large increases in illuminance at the beginning of the study period. However, whereas participants in Office Two commented most frequently on the change in conditions in the Baseline period, participants in Office Three responded more at the beginning of Trial One. This may reflect the change in Office Two from halophosphate fluorescent

lamps to triphosphor fluorescent lamps as well as the increase in illuminance, as the higher colour rendering triphosphor fluorescent lamps may have been perceived as brighter (Aston & Bellchambers, 1969; Vrabel et al., 1998). In contrast, the change in colour temperature between Baseline One and Trial One appears to have been more notable in Office Three, as while illuminance levels in the space increased at the beginning of the Baseline period, the type of lamp remained the same. In Office One illuminance levels did not increase as appreciably and the existing lamps were a mix of halophosphate and triphosphor fluorescent lamps.

Once participants had adapted to the new lighting conditions, comments decreased, possibly due to response fatigue. As the majority of participants appeared to be indifferent or only slightly satisfied/dissatisfied with the lighting conditions, it can be assumed that for the majority of personnel, the changes to the lighting were not so objectionable that it was necessary to comment upon them every week, suggesting that adaptation was likely.

Dissatisfaction with air circulation was described most frequently in Offices Two and Three, with participants in all three offices experiencing dissatisfaction with temperature. These responses reflect environmental conditions found in these offices as discussed further in Chapter 4 (Environmental Monitoring).

The following section explores the relationship between participants' perception of the work environment, lighting treatments and the symptoms that were experienced in the workplace.

3.11 Perception of the Work Environment, Symptoms and Lighting Treatments

The perceived effect of the work environment on productivity (perceived productivity) and satisfaction with lighting was examined in relation to symptom severity and lighting treatments. The relationship between perceived productivity and other satisfaction measures was also explored.

The relationships were examined using Chi square test for independence to determine if the variables were related, in conjunction with Correspondence Analysis to graphically represent the relationship between variables. These analyses are discussed in detail in Chapter Two (Experimental Methodology).

Perceived Productivity and Eyestrain, Headache and Lethargy symptoms

Chi square analysis was used to determine if eyestrain, headache and lethargy symptoms were related to perceived productivity. Analyses were carried out using data sets C+B (complete plus baseline) and S+B (screened plus baseline data sets). The results showed that all three symptoms (eyestrain, headache, and lethargy) were strongly associated with perceived productivity (Table 40).

Correspondence Analysis (CA) was used to interpret the relationship between the variables (categorical groupings). These relationships were found to be very similar across all analyses, therefore a complete set of results will only be shown for one analyses (self assessed productivity and lethargy symptoms), which will be discussed in detail. All other analyses followed similar trends.

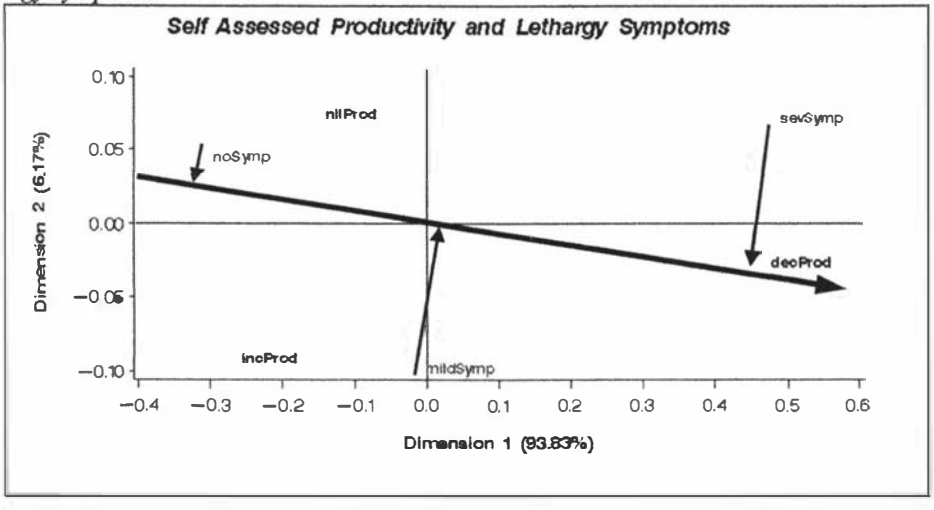
Table 40. Chi square values for Perceived Productivity and Symptom Severity

		Complete data		**Screened data**	
		Chi-square Stat.	p-value	Chi-Square Stat.	p-value
Perceived Productivity	Eyestrain Symptoms	24.7	0.001	22.84	0.001
	Headache Symptoms	43.05	0.001	35.12	0.001
	Lethargy Symptoms	49.34	0.001	40.32	0.001

Figure 38 shows the relationship between lethargy symptoms experienced in the workplace and the perceived effect of the workplace on productivity. The plot represents two separate overlaid plots, one with productivity categories (incProd, noProd and decProd) and one of lethargy symptom categories (noSymp, mildSymp and sevSymp). The horizontal axis, Dimension One explains the majority (93.83%)

of the total variation (inertia) and is proportional to the Chi-square value. The vertical axis (Dimension Two) accounts for the remaining 6.17% of the inertia and may be ignored. Dimension One shows the contrast between productivity categories (incProd and decProd) and the contrast between eye symptom categories (noSymp and sevSymp). The categories further from the origin are the most significant contributors to the inertia or relationship. These are decreased productivity (71% of the productivity inertia) and severe symptoms (61% of symptom inertia) as shown in Table 41. Typical frequencies are shown in Table 42.

Figure 38. The relationship between the perceived effect of the work environment on productivity and lethargy symptoms



To interpret the relationship between symptoms and productivity 'direction vectors' can be drawn through the origin and the category of interest (decProd) with corresponding vectors from other categories (sevSymp, mildSymp, noSymp) projected onto the direction vector of interest. The proximity of the points shows the relationship between them. This is illustrated in Figure 38 where the relationship between decreased productivity and lethargy symptom severity groupings is shown by a direction vector drawn through the origin and decProd, with sevSymp, mildSymp and noSymp projected onto it. Severe lethargy symptoms (sevSymp) were shown to be the most strongly associated with decreased productivity, as this category (sevSymp) is the closest to the category of interest (decProd). This graph is typical of the relationships shown between perceived productivity and eyestrain/headache symptoms.

Table 41. The contribution of categorical groupings to inertia (variation)

Productivity Measures	**Abbrev.**	**Inertia (%)**
Decreased productivity	Decprod	71
No effect on productivity	Nilprod	8
Increased productivity	Incprod	21
Lethargy Measures	**Abbrev.**	**Inertia (%)**
Severe symptoms	Sevsymp	61
Mild symptoms	Mildsymp	5
No symptoms	Nosymp	35

Table 42. Frequency data for lethargy symptoms and perceived productivity (C+B)

Perceived productivity	**Symptom severity**			
	Mildsymp	Nosymp	Sevsymp	Total
Decprod	41	49	38	128
Incprod	55	113	23	188
Nilprod	74	143	34	251
Total	167	305	95	567

Perceived Productivity and Lighting Treatments

Chi-square analysis was also used to determine the relationship (association) between the perceived effect of the work environment on productivity and symptoms for each of the three lighting treatment conditions. The analysis was carried out on data sets CW and SW.

Statistically significant relationships were observed between perceived productivity and symptom severity for eyestrain, headache and lethargy symptoms in the Low Frequency Halophosphate (LF-Halo) treatment using data set CW, and for eyestrain and lethargy symptoms in the LF-Halo treatment using data set SW (Table 43). A significant relationship was also shown for headache symptoms severity in data set LF-Tri in data set CW.

Correspondence Analysis (CA) was used to interpret the significant relationships shown in Table 43 for the low frequency halophosphate treatment conditions in both complete and screened data sets. Figure 39 shows this relationship. Again the horizontal axis, Dimension One accounts for most of the inertia (93%). This graph is typical of the relationships shown for perceived productivity and symptom severity

for the headache and eyestrain analyses and shows that the variation was equally divided between mild symptoms (34%) and no symptoms (32%) and decreased perceived productivity (61%). Typical frequencies are shown in Table 44.

Table 43. Chi square analysis results - The relationship between lighting treatments and the perceived effect of the work environment on productivity

Lighting treatments and perceived productivity – Data set CW									
	Eyestrain			Headache			Lethargy		
	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value
HFTri	4	3.18	0.528	4	3.37	0.500	4	9.28	0.06
LFHalo	2	11.91	0.003	2	6.66	0.04	4	11.78	0.02
LFTri	2	1.00	0.61	2	6.39	0.04	4	5.32	0.26
Lighting treatments and perceived productivity – Data set SW									
	Eyestrain			Headache			Lethargy		
	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value
HFTri	2	4.04	0.132	2	0.164	0.921	2	2.78	0.25
LFHalo	2	9.06	0.01	2	2.77	0.25	2	8.27	0.02
LFTri	2	3.04	0.218	2	1.99	0.38	2	1.58	0.45

Direction vectors show that decreased productivity was related to both mild symptoms and severe symptoms and opposed by (furtherest away from) no symptoms, but that the relationship was much weaker than the one shown in Figure 38.

Figure 39. The relationship between the perceived effect of the work environment on productivity and lethargy symptoms for the Low Frequency Halophosphate lighting treatment.

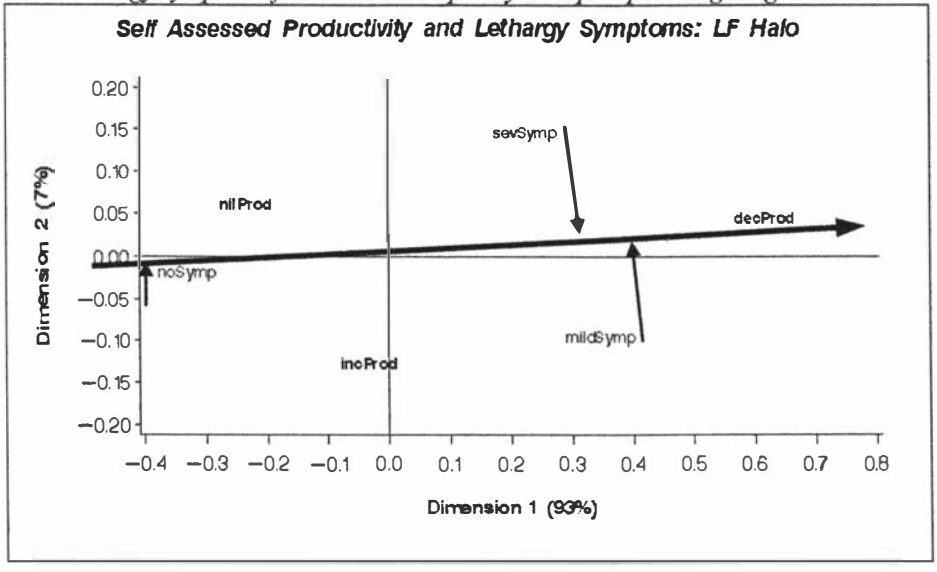


Table 44. Frequency data for lethargy symptoms: lighting treatments and perceived productivity(CW)

	HFTri			**LFHalo**			**LFTri**		
	MildS	NoS	IncS	MildS	NoS	IncS	MildS	NoS	IncS
Decprod	8	5	6	10	2	5	6	6	5
Incprod	17	21	3	11	13	6	12	20	2
Nilprod	17	24	4	9	25	11	16	21	4
	42	50	13	30	40	22	34	47	11

The relationship between perceived productivity and eyestrain, headache and lethargy symptoms in Offices

The Chi Square analyses revealed that significant relationships were present between all Office Two and Three variables for both the complete and screened data sets (Table 45). In Office One only headache symptoms were consistently related to perceived productivity. Office Two had much higher chi square values ($p>0.001$) for all symptoms. The correspondence analysis revealed that decreased productivity was related to severe symptoms and mild symptoms in the analyses undertaken.

Table 45. Chi-square statistic values for workplace symptoms and self assessed productivity in offices.

		Complete data			**Screened data**		
Symptoms	Office	DF	Chi-square stat.	p-value	DF	Chi-square stat.	p-value
Eyestrain symptoms	Office One	2	5.13	0.275	2	6.77	0.15
	Office Two	4	26.74	0.001	4	28.01	0.001
	Office Three	4	17.54	0.002	4	9.61	0.05
Headache symptoms	Office One	2	15.97	0.003	2	9.58	0.05
	Office Two	4	36.10	0.001	4	39.25	0.001
	Office Three	4	12.68	0.013	2	10.93	0.03
Lethargy Symptoms	Office One	4	10.93	0.027	4	4.72	0.32
	Office Two	4	45.43	0.001	4	44.80	0.001
	Office Three	4	23.89	0.001	4	16.67	0.002

Satisfaction with Lighting and Symptoms

The chi-square analysis considered the relationship between satisfaction with the lighting and each of eyestrain, headache and lethargy symptom severity. All three

symptoms (eyestrain, headache and lethargy) were strongly associated with satisfaction with the lighting conditions for data sets CW and SW (Table 46).

The correspondence analyses showed comparable trends to those discussed between self assessed productivity and lethargy (Figure 38) revealing that severe symptoms (eyestrain, headache and lethargy) were most strongly associated with decreased productivity.

Table 46. Chi square statistic values for workplace symptoms and satisfaction with the lighting

		Complete data		**Screened data**	
		Chi-square Stat.	p-value	Chi-Square Stat.	p-value
Satisfaction with Lighting	Eyestrain Symptoms	60.81	0.001	12.95	0.012
	Headache Symptoms	20.18	0.001	17.31	0.002
	Lethargy Symptoms	16.25	0.003	23.29	0.001

Satisfaction with the Lighting and Lighting Treatments

When satisfaction with the lighting and symptom severity was considered by individual treatment conditions (with a one week washout period), the results again showed similar trends to that of perceived productivity and symptoms (Table 47).

Table 47. Chi-square statistic values for lighting treatments and satisfaction with the lighting including one week washout

	Eyestrain			**Headache**			**Lethargy**		
	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value	DF	Chi-square Stat.	p-value
HF-Tri	4	9.45	0.05	2	0.477	0.788	4	7.88	0.58
LF-Halo	4	16.96	0.002	2	1.38	0.50	4	8.89	0.06
LF-Tri	2	0.57	0.78	2	15.24	0.004	2	5.50	0.24

Statistically significant relationships were observed between satisfaction with the lighting and symptom severity for the eyestrain and lethargy analyses in the low frequency halophosphate treatment (LF-Halo), for the eyestrain symptom severity in

the high frequency triphosphor (HF-Tri) and headache symptom severity in the low frequency triphosphor (LF-Tri) analyses. The Correspondence Analysis revealed that severe and mild symptoms were associated with dissatisfaction with the lighting.

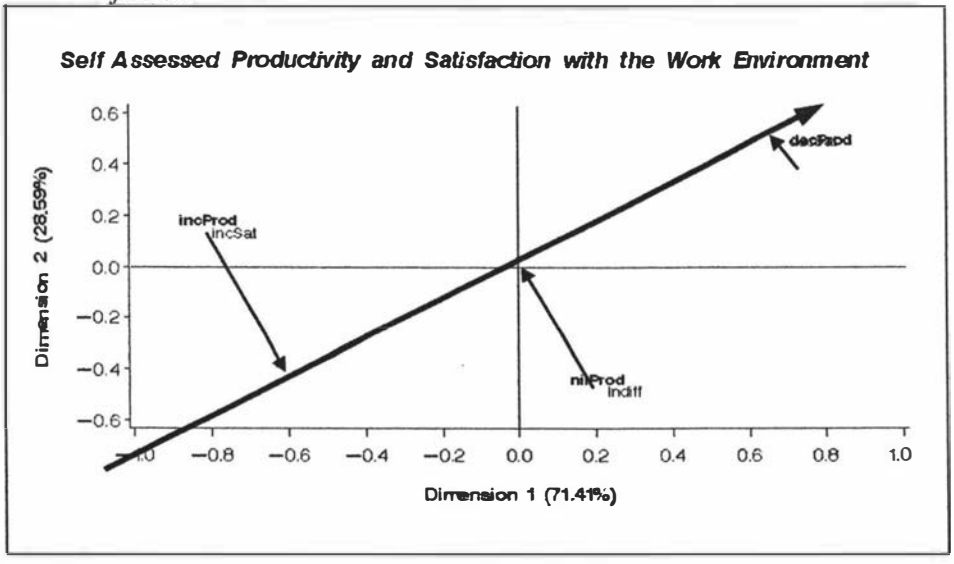
Perceived Productivity and Satisfaction with Lighting, Air circulation, Temperature, Job satisfaction and the Overall Work Environment

The chi square statistic showed clear evidence of an association between the perception of the work environment on productivity and all satisfaction measures (Table 48)[68]. This relationship remained present when a washout period and the baseline conditions were removed from the data set.

Table 48. Chi-square statistic values for satisfaction with the workplace and the effect of the work environment on productivity.

Questionnaire Measure	D.F.	Value	Prob.
Job satisfaction	4	222	<0.001
Satisfaction with air circulation	4	164	<0.001
Satisfaction with temperature	4	173	<0.001
Satisfaction with lighting	4	147	<0.001
Satisfaction with work environment	4	292	<0.001

Figure 40. The relationship between the perceived effect of the work environment on productivity and satisfaction with the work environment



[68] All satisfaction measures utilised the complete data set for analysis.

The close grouping of the measures in the Correspondence Analysis reveals the strength of the relationships between them (Figure 40). Increased productivity (incProd) was associated with satisfaction with the work environment (incSat); Decreased productivity (decProd) was associated with dissatisfaction with the work environment (disSat); No effect on productivity (nilProd) was associated with indifference about the work environment (Indiff).

The relationship between perceived productivity and satisfaction with the work environment in differing offices

The Chi Square analysis revealed that Office Two had a significantly stronger relationship (larger chi-square statistic) between all satisfaction measures and the effect of the work environment on productivity when compared to Offices One and Three (Table 49). The specific direction of the relationships between satisfaction measures and chi square values were not further analysed as it was anticipated that these would be comparable to the other analyses.

Table 49. Chi-square statistic values for satisfaction with the workplace and the effect of the work environment on productivity in differing offices

Questionnaire Measure by Bank		F	Value	Prob.
Job satisfaction	Office One	4	57	<0.001
	Office Two	4	183	<0.001
	Office Three	4	75	<0.001
Satisfaction with work environment	Office One	4	42	<0.001
	Office Two	4	139	<0.001
	Office Three	4	64	<0.001
Satisfaction with air circulation	Office One	4	30	<0.001
	Office Two	4	106	<0.001
	Office Three	4	41	<0.001
Satisfaction with lighting	Office One	2	47	<0.001
	Office Two	2	121	<0.001
	Office Three	2	30	<0.004
Satisfaction with temperature	Office One	2	44	<0.001
	Office Two	2	100	<0.001
	Office Three	2	51	<0.001

Discussion: Perception of the Work Environment, Lighting Treatments and Symptom Severity

The analyses undertaken showed a strong association between the participants assessment of the effect of the work environment on productivity and the symptoms experienced in the workplace. In all cases, severe eyestrain, headache and lethargy symptoms were highly associated with decreases in perceived productivity. Mild symptoms were less strongly associated with decreased perceived productivity. Clearly when participants experienced symptoms they also felt that their productivity was decreased and that this was attributable to the work environment.

When this relationship was examined by lighting treatments, decreased productivity remained associated with severe symptoms, but was equally or in some cases more strongly associated with mild symptoms. Statistically significant relationships were stronger and more systematic in the low frequency halophosphate treatment. Therefore, participants working in this lighting treatment were more likely to consider that their symptoms affected their productivity.

When the relationship between symptoms and perceived productivity was examined within each office, Offices Two and Three reflected the relationships discussed above, but this was not consistent in Office One. This office was undergoing restructuring in the course of the study and the participants had a low participation and response rate when compared to Offices Two and Three, which is likely to explain this outcome.

A strong relationship was also present between satisfaction with the lighting and symptoms, revealing that severe symptoms were also associated with dissatisfaction with the lighting. When this relationship was examined by lighting treatments, statistically significant relationships were again stronger and more systematic in the low frequency halophosphate treatment, indicating that in this treatment condition, symptoms clearly influenced satisfaction with lighting conditions.

Perceived productivity was strongly associated with satisfaction with lighting, air circulation, temperature, job satisfaction and overall satisfaction with the work environment. The strength of these relationships indicate not only that participants

attributed symptoms to their work environment, but also that they felt that these symptoms affected their productivity. These relationships overwhelmingly demonstrate the importance of ensuring that the work environment is satisfactory. Between 30-40% of participants experienced symptoms during their work shift, which is a significant proportion of staff in the work environment. Job satisfaction was also highly related to an individual's perceived productivity, indicating its importance in the overall well-being of office personnel.

The trend towards significant relationships between symptoms and the assessment of the effect of the work environment on productivity in the low frequency halophosphate condition suggests that office personnel felt that symptoms experienced in this lighting treatment influenced their productivity. Further, the data also suggests that participants attributed these symptoms to lighting conditions. This supports the previous findings that participants experienced more severe symptoms in the low frequency halophosphate lighting treatment.

There was no evidence to suggest that alterations in flicker frequency or modulation depth influenced these relationships. Neither perceived productivity nor satisfaction with the lighting were shown to be systematically related to symptoms in the high frequency triphosphor or low frequency triphosphor lighting treatments. This may indicate that participants did not feel that symptoms significantly influenced productivity or were strongly related to the lighting conditions in these treatment periods.

4 *Environmental Monitoring*

Introduction

In this study, the variables of interest were the flicker frequency and modulation depth of the lighting system. Ideally, all other aspects of the office environment that may influence the response variables of interest should be held constant. However, as an interventional study in three different office spaces, it was not possible to ensure constancy of other environmental variables.

Therefore these factors may influence the symptom reporting. If the nuisance variables were constant (such as high noise levels due to the machinery operating) throughout the study period, they may increase the overall level of reporting. This should not affect the study outcome, as the study measured differences in symptom reporting between lighting treatments, not absolute levels of symptoms. However, if the nuisance variable affected responses to a large extent, then the variables of interest may have been overwhelmed. This effect would not be statistically removed from the data set, but may assist in explaining the level of reporting. Alternatively, if the level of nuisance variable fluctuated throughout the study and it was at levels that may affect symptoms experienced by the participants, then it may have confounded the study data. In this case, it was appropriate to treat the variable as a covariate in the analysis. In addition, this information was used to explain differences in symptom reporting between the offices, and other factors that may have influenced the relationship between symptom severity, productivity and satisfaction with the work environment.

Since it was not possible to control all variables, assumptions were made. Aspects including workstation locations, proximity to windows and air conditioning diffusers were assumed to be randomised. Other variables were monitored throughout the study.

Environmental Parameters Monitored

The environmental parameters measured throughout the study included:

- Lighting - Illuminance and Luminance;
- Colour and Reflectance of surfaces;
- Thermal Comfort – Temperature and Humidity;
- Ventilation effectiveness (Carbon dioxide levels);
- Particulates;
- Noise.

Illuminance was measured during each lighting treatment at individual workstations. Temperature, humidity and carbon dioxide were continuously datalogged throughout the study period, with the monitoring equipment located centrally away from draughts, still air cavities and heat generating equipment, and moved periodically to capture a range of operating conditions. Spot measurements were used to confirm that the data was representative of conditions at individual workstations. The equipment was checked fortnightly to ensure that it was working correctly.

Luminance, colour and reflectance of surfaces, particulate counts and noise measurements were taken after the study was completed in Offices Two and Three. The staff levels and work tasks had not changed appreciably in these offices since the conclusion of the study and therefore the conditions were assumed to be the same as those at the time of the study. It was not possible to get access to Office One after the conclusion of the study. This office space is discussed based upon the photographs and observations of this office taken throughout the study period.

Detailed specifications of the monitoring equipment utilised are listed in Appendix H.

Lighting

The lighting conditions within the offices have been recorded in detail, as this was the focus of the study. Lighting conditions prior to the study are outlined in Table 50.

Table 50. Lighting conditions in the three host offices prior to the study.

Existing Office Lighting Conditions	**Office One**	**Office Two**	**Office Three**
Luminaires	Recessed three lamp	Recessed four lamp	Recessed three lamp
Diffusers	Prismatic	Prismatic	Prismatic
Fluorescent lamps	Cool white triphosphor and halophosphate	Cool white halophosphate	Cool white triphosphor
Control gear	Low frequency ballasts	Low frequency ballasts	Low frequency ballasts
Horizontal workplane illuminance[69]	430-650 lux	370-565 lux inside rm 700 lux outside rm	470 lux
Ceiling height	2.6m	2.7m	2.6m
Wall colour	white	White	light blue or white
Ceiling colour	white	White	White
Floor colour	medium gray	medium blue	medium gray

The desktop illuminance was measured during each experimental treatment and during the baseline period using a 'Hagner Luminance Meter'. The illumination was measured on the horizontal desk surface and in the depression in the desk where the cheques were placed. The light sensor was placed on top of cheques if they were present in the desk for expediency, as access to the building was only possible during normal working hours. If the desk was occupied, then the occupant remained in their normal working position with the researcher crouched beside the desk to prevent shadowing. If the desk was unoccupied then the researcher sat at the chair in an assumed work position when taking the measurement. The illumination was also datalogged using a light meter that was permanently positioned at one metre in height in each of the three offices using an Extech 'Light Adapter'. However, this stand was accidentally moved by staff in the offices, and failed to give consistent results, therefore the results are not included as part of this document.

The task luminance and luminance of surfaces within Office Two and Three were measured at the conclusion of the lighting study and luminance ratios were calculated. The luminance of the task was estimated by placing a sheet of white photocopy paper in the depression in the desk where the cheques were placed. Luminance measurements were taken for other work surfaces, walls, ceilings, floors and

[69] Average workplane value.

luminaires. The reflectance of the white photocopy paper and the work tasks (a range of cheques from differing banks) was subsequently measured and this enabled the range of luminance ratios to be estimated.

Colour and Reflectance

The colour and reflectance of the cheques used in the study and the surfaces in Offices Two and Three were measured after the conclusion of the study using a Minolta Chroma Meter. The colour was measured using Yxy co-ordinates with x and y representing the horizontal and vertical axes on the CIE chromaticity chart and Y representing the reflectance from the surface.

Thermal Comfort

The thermal comfort of the occupants was monitored by measurement of the temperature and humidity throughout the study. Temperature and humidity were continuously monitored with wet and dry bulb semiconductor transducers to determine the range of operating temperatures and humidity within the three office spaces. Spot measurements were taken at regular intervals throughout the study to check the calibration of the continuous readings and ensure that the transducers were reflecting the range of environmental conditions in the space.

Ventilation Effectiveness

The ventilation effectiveness was estimated by measurement of the carbon dioxide (CO_2) levels within the space. Carbon dioxide is a by-product of the human respiratory system and therefore increased levels of carbon dioxide indicate that the ventilation in the space is insufficient to remove bioeffluents and other indoor air pollutants. The carbon dioxide levels were continuously monitored within the spaces, with the CO_2 meter moved around the offices throughout the study. Spot measurements were taken at regular intervals throughout the study to check the calibration of the continuous readings and ensure that they were representative of the range of conditions within the space.

Particulates

The number of particles per cubic metre was recorded using a Met One laser particle meter at the conclusion of the study in Offices Two and Three.

Noise

The Equivalent Continuous A weighted sound pressure level was measured using a Rion integrating sound level meter giving an average and peak decibel value as well as decibel readings at each octave band. The measurements were taken at the conclusion of the study in Offices Two and Three, and ambient sound levels were measured in each of the individual rooms in Offices Two and Three as well as spot measurements taken at ear level beside the machining work stations.

4.1 Results and Discussion

The results below summarise the readings taken in the three offices during and subsequent to the study period. The national and international standards that were used to determine that the measurements taken were acceptable included:

- The New Zealand Code of Practice for Interior Lighting Design (NZS 6703-1984);
- The Australian Standard for Interior Lighting (AS 1680 – 1990);
- The IESNA Lighting Handbook (IESNA – 2000);
- The New Zealand Standard for Acceptable Indoor Air Quality (NZS4304 - 1990);
- ASHRAE Standard 55/1992;
- ASHRAE Standard 62/1989.

Appendix G lists the acceptable parameters for the environmental conditions monitored based on New Zealand and International standards, and gives detailed information on the variables measured.

Lighting

Illuminance

The illumination levels on the horizontal desktop and inclined work plane are shown in Table 51 and Figure 41. The work task of reading handwritten numbers is of high contrast (black or blue pen on a white or lightly coloured background[70]) and is a moderately easy task. The lighting configuration within the three offices (recessed lamps with prismatic diffusers) during the lighting treatments gave average illuminance levels of between 585 and 889 lux on the horizontal work plane, reducing considerably to 389 to 589 lux on the inclined work plane.

The recommended illuminance levels for this work task were assessed using the New Zealand (NZS 6703:1984[71]), Australian (AS 1680:1990) and North American (IESNA:2000) recommended standards. The Australian and North American standards stated base the recommended levels upon the contrast and task size/difficulty to a greater extent than the older New Zealand standard. The three standards gave levels of 500[72] lux, 240[73] lux and 300[74] or 500[75] lux respectively on the work plane (See Appendix G for further details).

Overall, the illuminance levels are high for the horizontal work surface, which is where the keyboard is located. On the sloped work surface, (the position of the primary work task), the work task, task difficulty and task contrast identified in the Australian Standard (AS1680: 1990) and the North American Standard (IESNA: 2000) gives recommended illuminance levels of 240 lux and 300 lux respectively to meet visual stimulus requirements. However, the speed at which the task was required to be completed and the lack of contributing daylight may suggest more

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[70] Background reflectance = 0.61 - 0.80 (See Appendix G for further details). High contrast is rated as above 0.3 (IESNA, 2000).

[71] In New Zealand, the Australian standard is also widely accepted and it is likely to form the basis for, or adopted with amendments as a joint Australian/New Zealand standard in the foreseeable future.

[72] General offices with mainly clerical tasks and occasional typing.

[73] Ordinary or moderately easy task with high contrast.

[74] Handwritten ballpoint pen.

[75] Open plan office – intermittent VDU use.

conservative levels of up to 500 lux as recommended by the New Zealand Standard (NZS6703:1984).

Table 51. Average illuminance levels (lux) in the data entry offices during the lighting treatments and baseline period.

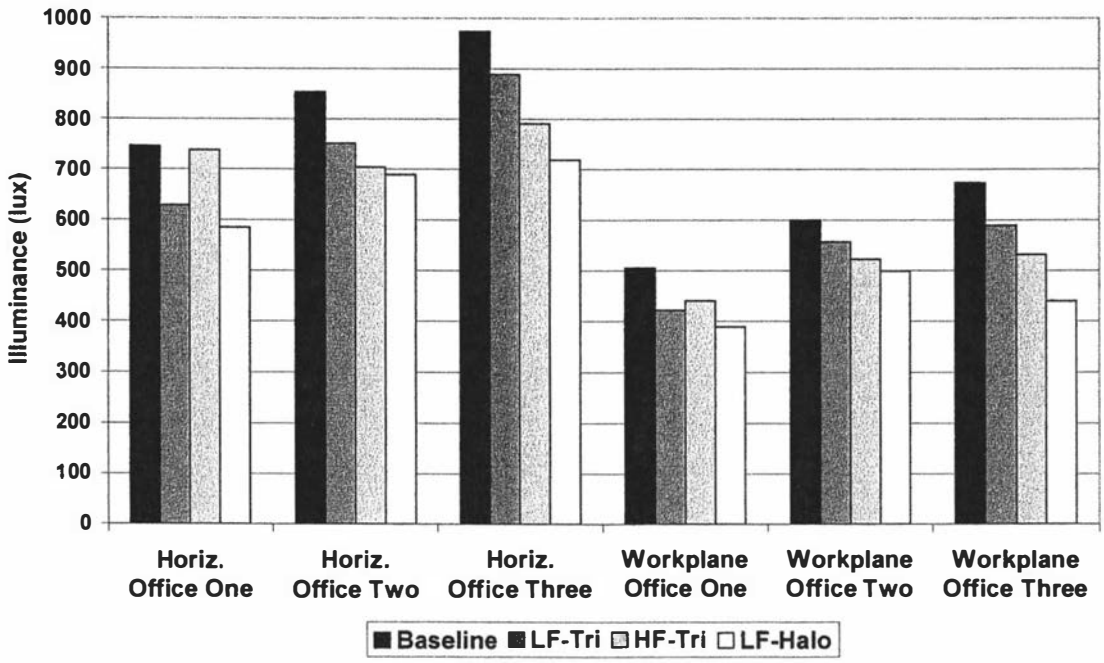
		Baseline		LF-Tri		HF-Tri		LF-Halo	
		Horiz.	Sloped	Horiz.	Sloped	Horiz.	Sloped	Horiz.	Sloped
Office One	Illum.	746	505	628	422	738	441	585	389
Office Two	Illum.	853	600	751	557	704	523	689	499
Office Three	Illum.	974	673	889	589	791	532	719	440

The baseline fluorescent lamps have the highest illuminance levels as these triphosphor fluorescent lamps were used without a tape backing to reduce the luminance, in contrast to the triphosphor lamps used for the lighting treatments. The LF-Tri lighting treatment gave the highest illuminance levels, followed by the HF-Tri and LF-Halo lighting treatment in Offices Two and Three. This outcome differed for Office One, and is likely to be due to changes in office configuration during lighting treatment one (HF-Tri). The difference between illuminance levels across the lighting treatments is most pronounced in Office Three. This may be in part due to the researcher[76] who measured the illuminance in this office during the LF-Halo lighting treatment. The researcher was inexperienced and when queried later, it appears that he may have leaned over the light meter as the measurements were taken, shading the sensor, resulting in lower readings for this treatment.

The illuminance measurements taken in the office spaces showed that the luminous output from the three lighting treatments differed despite the initial experiment which was used to match the brightness of the different fluorescent lamps. The possible reasons why the lighting treatments differed with respect to illuminance, and actions that future researchers should consider are discussed in Appendix I.

[76] A researcher assisted with the illuminance measurements to enable all three offices to be visited in the same evening.

Figure 41. Horizontal Desktop and Workplane Illuminance in Offices One, Two and Three



Luminance Measurements

In Offices Two and Three the majority of surfaces in the spaces achieved the recommended brightness (luminance) ratios (See Appendix G for the recommended and measured range of task and background luminance ratios). Exceptions to this include the surface of the data processing machines immediately adjacent to the work surface, the exterior windows in both offices and the tinted glass partitions in Office Three.

The surface of the data processing machines immediately adjacent to the work surface had low reflectance values on up to half of the machines. These surfaces did not meet the recommended 1:3 brightness ratio from task to the immediately surrounding surfaces for light coloured task surfaces (IESNA, 2000). This contrast may have been a contributor to eyestrain, headache and lethargy symptoms if the cheques being entered were of a light colour. The contrast with darker coloured cheques in those desks was likely to have been more acceptable.

The exterior windows and tinted glass partitions exceeded the recommended 1:10 ratio for task to immediate surrounds. However, in both these instances, these elements were perpendicular to the participants' workstations and thus were not in the direct field of view. In addition, Office Two had lightweight white curtains that

increased the luminance of the windows when drawn (the curtains were usually partially drawn). Therefore the contrast between the work task and these elements were unlikely to contribute to symptoms experienced by the office personnel.

There was minimal glare from veiling reflections in the two office spaces. Light was reflected from specular surfaces including the glazed partitions and the windows. However, as previously discussed, these were not in the direct field of view. The VDU's were dark in comparison to the work task, and veiling reflections were present in some cases, but the VDU's were only used intermittently to check that numbers had been entered correctly and were not positioned in the line of view.

The recessed luminaires with prismatic diffusers had luminance values of between 1000 and 4000 cd/m^2 for viewing angles of 15-70^o in Offices Two and Three. This type of luminaire can present a significant glare source, particularly if used with Visual Display Units. The glare index was estimated from AS1680:1990 (based upon the size of the room and type of luminaire) as 19-22 for Offices One and Two and 13-16 for Office Three. This was slightly high for Offices One and Two, but acceptable for Office Three. However, the position of work task in these three offices meant that the field of view was unlikely to include the luminaires and thus these were not considered to be a significant glare source.

The luminance measurements were taken after the study was completed. In Office Two, the lamps did not appear to have been altered since the lighting study, and an examination of the lamps confirmed that this was probable. The illuminance measurements taken were comparable to those taken in the study, providing further evidence to verify that this was the case. In Office Three, a lamp had been removed from the luminaire, however the lamps appeared to be those used in the study, and the illuminance measurements confirmed a reduction in illuminance by approximately one third, verifying that this was likely to have been the case. In this office, the luminance values during the study can be approximated from those listed in Appendix G by increasing them by one third.

An examination of the photographs taken in Office One during the study show that the colour of surfaces in this office were comparable to those in Office Two. The

machines used in Office One featured a dark grey desktop surface with a light beige base. These were comparable to machines used in Offices One and Two as shown in Appendix A.

Based on these estimates, the results and conclusions drawn for Office Two equally apply to this office. That is, that the contrast between the work task and the surface of the desk may contribute to eyestrain, headache and lethargy symptoms if the cheques being entered are light coloured, but that other surfaces are within acceptable parameters.

Colour and Reflectance

The colour co-ordinates of the space were measured after the conclusion of the study (as previously discussed) in Offices Two and Three. The results were used to ensure that the brightness contrast was acceptable. Surfaces that do not meet these parameters have been discussed in the Luminance Measurements section. The results for a range of work tasks and work surfaces are presented in Appendix A and Appendix G.

The reflectance of work surfaces, furniture, wall, ceiling and floor surfaces in Offices Two and Three were measured after the conclusion of the study and are shown in Appendix G.

All surfaces with the exception of the carpeted floor fell within the recommended reflectance levels. The carpeted floor was only marginally below recommended levels and was not of relevance to the study findings.

The reflectance of work surfaces and furniture is usually considered appropriate if the brightness ratios (work task to immediate and background surrounds) are acceptable. In this case, the reflectance of the immediately adjacent work surface was very low, resulting in low luminance and unacceptable brightness ratios when compared to the work surface. As is discussed above, this may have increased the level of reporting of symptoms. Other work surfaces and furniture were not of relevance to the study findings. This outcome equally applies to Office One.

Thermal comfort

Temperature profiles of the three offices revealed that the temperature was maintained within 19-23°C during working hours. Appendix G shows the temperature profiles for a typical week of the study in each of the three offices. The average temperature in the offices was 21.7°C, 21.2°C and 21.5°C for Offices One, Two and Three respectively[77].

The levels of relative humidity recorded within each office were predominantly between 40-60%, but could range between 25% and 80%. This is because the office buildings monitored did not control the moisture content of the air entering the building (which is typical of buildings in the Wellington region of New Zealand). Appendix G shows the humidity profiles for a typical week of the study in each of the three offices. The humidity data may have been compromised due to the presence of iron oxide in the water as metal fixings within the water receptacle were found to have corroded during the course of the study. However, spot measurements taken at regular intervals throughout the study suggested that the readings corresponded to the range of relative humidity within the offices.

These temperature and humidity ranges fall slightly outside of those stated in the ASHRAE Standard 55:1992. However they were predominantly within the parameters that are widely accepted within New Zealand (temperature range 19-24 °C and relative humidity range 40-60%).

Air Circulation

The CO_2 levels were continuously data logged throughout the study period. Appendix G shows the typical values recorded in each of the three offices. The New Zealand Standard for Acceptable Indoor Air Quality (NZS4304:1990) and ASHRAE Standard 62/1989 recommends that CO_2 measurements are maintained at below 1000ppm ($1.8g/m^3$) to ensure adequate indoor air quality. A further, more stringent guideline is set by Public Works Canada who recommend a range of between 600-800 ppm for commercial office buildings (Public Works Canada, 1995).

[77] The average temperature recorded for each office during working hours for Trial One.

The daily Carbon Dioxide levels within Office One were maintained at less than 800 PPM at all times indicating that air circulation and supply to the space was satisfactory and that indoor air quality was maintained at acceptable levels. In Office Two, the daily CO_2 levels climbed to approximately 750 PPM during maximum daily occupancy with a maximum of 900 PPM in peak loading conditions suggesting that indoor air quality may be compromised during these times and may have contributed to symptoms experienced by occupants. In Office Three, the daily CO_2 levels within the space show that the recommended levels were exceeded on a regular basis, typically exceeding 1000 PPM, and reaching levels as high as 1600 PPM. Furthermore, when levels exceeded 1400 PPM, air circulation was not sufficient to reduce the CO_2 to ambient levels before the next working day. These levels are very likely to lead to levels of contaminants within the space that can influence symptoms experienced by office personnel. It is possible that the air conditioning system was not on during the evening shift or that there was a high proportion of re-circulated air. Typical plots of daily profiles are shown in Appendix G.

Particulates

The particulate measurements were measured after the conclusion of the study as previously discussed in Offices Two and Three. The staff levels and work tasks had not changed appreciably during this time. Therefore the measurements were assumed to be comparable to those taken at the time of the study. Both of these offices were within acceptable guidelines for particulate levels and given the comparable work task, building type and location, the conclusions are equally valid for Office One.

Noise

The primary sources of noise in all three offices were from the following sources:

- The data entry machines;
- The online machines;
- The radio;
- Personal tape or CD players with headphones.

The maximum equivalent continuous A weighted ambient sound pressure level ranged from 63-78 dB, and was within acceptable parameters. However, the octave band frequency measurements yielded a NC[78] rating of 70, which was well above recommended levels for mechanised offices (NC rating 40-50). There is no reason why this should differ for Office One.

These levels of noise may have contributed to headache and lethargy symptoms experienced in the workplace. However, despite the obviously loud noise levels, there were minimal comments about noise on the questionnaire throughout the course of the study. The only responses collected were from new staff members. However, several of the staff members verbally commented on the high noise levels and related the noise to symptoms. In Office One, foam ear plugs were available for the staff to use, but there was no evidence of staff wearing these throughout the course of the study. One possible explanation for the lack of comment about the noise was that it was accepted as 'being part of the job'.

Conclusions: Environmental Monitoring

Overall the environmental monitoring identified a number of environmental parameters that had the potential to affect the symptoms, productivity and satisfaction of office personnel. Of these, the difference in luminous output between the different lighting treatments was the only parameter that may have influenced symptom reporting in a systematic manner.

The other parameters which may have influenced symptom reporting included:

- Excessive contrast between adjacent work surfaces and the work task in all three offices and possibly inadequate illuminance on the workplane;
- Ventilation effectiveness in Offices Two and Three;
- Excessive noise levels all three offices.

All of these parameters were at consistent levels throughout the course of the study. If they had any influence on symptom reporting, this was in a consistent manner.

[78] Noise Criteria levels.

Therefore, these conditions did not confound the study result. However, it is possible that the magnitude of difference in eyestrain and lethargy symptoms found and the lack of effect on headaches due to the lighting treatments was influenced by these conditions. That is, that these conditions reduced the effect of the lighting treatments.

The study results indicated that participants exposed to the lighting treatment (low frequency halophosphate) with the lowest average illuminance on the inclined work plane (where the primary task was located) had the highest incidence of eyestrain and lethargy symptoms. Therefore it is possible that the lower illuminance levels in this lighting treatment were a significant contributor to symptoms. In this lighting treatment, the average work plane illuminance was between 5% and 12% lower than the other lighting treatments[79]. However, the difference in illuminance between the two lighting treatments that were not found to be statistically different was between 4% and 8%. The average illuminance levels in all three lighting treatments were appropriate for the task, task difficulty and contrast levels, meeting the Australian and North American recommended lighting standards, but in some lighting treatments did not meet the New Zealand workplace standards. Research exploring the effect of illuminance on health symptoms and positive affect does not suggest that such small differences between lighting conditions should influence symptom incidence (IESNA, 2000; personal communication P. Boyce, M. Donn and J. Veitch, 1997). Overall, the available research suggests that the difference in illuminance between the lighting treatments was unlikely to have been responsible for the study outcomes. However, this cannot be excluded as a possible or partial explanation for the study outcomes. This is discussed in further detail in the General Discussion.

[79] In Offices One and Two. The data from Office Three is not included due to measurement errors as discussed previously in this chapter.

5 *Medical Study*

The main study examined the relationship between building related symptoms that could be attributed to lighting conditions.

The medical study collected detailed information on the symptoms experienced by the participants. This information was used to determine the extent to which other workplace factors or physiological characteristics may have attributed to symptomatic responses.

The primary symptoms of interest: eyestrain, headache and lethargy can be triggered by a large range of workplace factors including indoor air quality, thermal conditions, lighting and noise. In addition, these symptoms can also be caused by physiological characteristics, external or internal stressors and malaise.

Self-administered questionnaires are typically used to identify the prevalence of symptoms within a population. Where aspects of the work environment are measured or modified, symptoms can be attributed to specific aspects of the work environment. Screening symptoms that do not reduce or disappear outside of work hours can segregate symptoms that are not related to the work environment. Specific questions can assist in attributing symptoms to causal factors within the workplace. For example, eyestrain is more likely to be attributed to lighting than chest irritation.

In the interventional study, occupants were asked to identify if they had experienced eye symptoms, headache or lethargy symptoms on a daily basis. It did not collect detailed information on the type of eye symptom that participants may have experienced or enable symptoms that may have been due to other factors to be differentiated.

A medical examination administered by an independent occupational health physician, in conjunction with a detailed questionnaire, was used to examine the nature of the symptoms experienced by office personnel, external or internal stressors,

malaise and aspects of the workplace that may have contributed symptoms. This methodology has been utilised in other research that has identified eye symptoms as work related (Burge et al., 1990; Burge et al., 1991; Kjaergaard, 1992; Kjaergaard et al., 1993). In addition, the medical interview was used to elicit the occupant's perception of the internal environment.

This section was based on the medical interview report provided by the occupational health physician, in combination with the questionnaires completed by the participants who took part the Medical Study[80]. Additional information has been drawn from the Main Study results to corroborate the findings. However, the Main Study was completed under different lighting conditions than in the Medical Study, and at a later time in the year, with differing seasonal conditions. Therefore, some caution must be applied in comparing the two results.

5.1 Objectives

1. To collect detailed information on the range of symptoms experienced by the office personnel in their work environment and determine if measures for the main study were appropriate;
2. To attribute symptoms experienced in the work environment to environmental, external and internal stressors or malaise;
3. To collect specific information on the factors that occupants perceive are causing the symptoms they experience in the workplace.

5.2 Methodology

Staff from the three host offices were invited to take part in the Medical Interview Study. The staff were given an information pack containing an introductory letter, information sheet and consent form (Appendix C). The pack outlined the intention of

[80] The questionnaire results were analysed and interpreted by M. Fleming. The occupational health physician provided guidance in the compilation of the questionnaire, but was not further involved with the analysis or interpretation of the results.

the study and details of the methodology. The study methodology and information pack was approved by the Massey University Human Ethics committee.

The information sheet informed the participants that if they chose to participate in the study they would receive a complimentary dinner for two at a local restaurant to the value of $30 as compensation for their time and the costs associated with attendance. The consent form asked staff to indicate their availability during the three days allocated for the interview and for contact details to confirm the interview time and date.

Thirty six staff from the three offices indicated that they were prepared to participate in the study, and of these, up to eleven participants were selected from each office, with preference given to those who had completed the main study. All staff that indicated their willingness to participate were contacted and interview times were confirmed.

The interview was conducted at the occupational health physician's office. When participants arrived at the office, they were asked to complete a self-administered questionnaire (Appendix C), which included three sections:

- Demographic information;
- Health symptoms experienced in the workplace;
- Perception of the office environment.

Demographic information included factors that may have influenced symptoms experienced in the work environment or the participants' perception of the work environment. Questions included: age, gender, time employed as a data entry operator, predisposing medical conditions such as high blood pressure, diabetes or migraines and visual history including the use of spectacles or contact lenses, presence of cataracts or eye infections.

Health symptoms experienced in the work environment were divided into five categories:

- Eye symptoms;
- Headache symptoms;
- Lethargy symptoms;
- Concentration difficulties;
- Flu like symptoms.

A number of questions were asked within each category (Table 55). The questions enabled the symptoms to be matched to environmental factors. Table 52 outlines each environmental factor and possible resultant symptoms if conditions are inadequate. An open ended question was included for any symptoms that were not included in the questionnaire.

Table 52. Symptoms experienced in the workplace and possible causal factors

Environmental factor	**Symptoms**
Lighting	Eye symptoms Headache symptoms Lethargy/tiredness Muscle strain[81]
Indoor Air Quality	Eye symptoms Headache symptoms Lethargy/tiredness Concentration difficulties Flu like symptoms
Thermal Comfort	Dry or irritated eyes Lethargy/tiredness Concentration difficulties
Noise	Headache symptoms Lethargy/tiredness Concentration difficulties
Ergonomics	Muscle strain or discomfort

[81] Caused by poor ergonomic positioning in order to see task clearly (i.e. without glare).

The final section asked participants to identify symptoms that they felt were due to the office environment and their perception of the effect that the work environment had on symptoms.

The participants were then interviewed by the medical health practitioner. The interview provided an opportunity for participants to discuss their personal health in relation to the work environment and included a brief physical examination (Table 53). The interview outline is included in Appendix C. The physical examination was used to identify physiological factors that may have influenced the incidence, frequency and severity of eyestrain, headache and lethargy symptoms that the participants experienced in the work environment as well as the participants general health.

Table 53. *Components of the physical examination*

Symptom	**Possible physiological cause**	**Physical examination**
Eyestrain	Uncorrected visual disorder	Evaluation of visual acuity for near and far vision and assessment of stereopis or focusing ability for near work
Headache	High blood pressure	Blood pressure test
	Cervical spine misalignment	Evaluation of the head and neck range of movements including the presence of muscle tenderness in the region of the neck.
Lethargy	Anaemia	Evaluation for the presence of anaemia.
General health	Ear infection	Ear examination
	Arthritis	Evaluation for the presence of arthritis if joint and muscle pains are present.
	Respiratory tract infection Lymph node abnormalities Asthma	Evaluation of the nose and throat and if necessary lower respiratory tract and lung function tests
		Height/weight ratios
		General mood and well-being

Immediately after the physical examination the physician discussed the results with the participant and within two weeks of the interview, the participant was mailed a standardised form that detailed the result. Where previously unidentified medical conditions were noted, the physician requested permission from the participant to contact their general practitioner regarding the consultation. In these cases, the results were also mailed to their general practitioner.

5.3 Results

Characteristics of Participants in the Research Study

Twenty five workers from three offices took place in the study, with eleven, six and eight participants from Offices One, Two and Three respectively (Table 54). More than 50% of the participants fell into each of the following categories respectively: female, aged between 20 and 30, non smokers, wore glasses or contact lenses. Of those who wore glasses, the majority were short sighted and had their eyes tested within the last two years. Five participants reported experiencing migraines, one reported high blood pressure, one was diabetic and one was suffering from depression.

Table 54. Demographic characteristics of participants.

Gender	Female	18
	Male	7
Age	< 20 years	1
	20-29 years	13
	30-39 years	6
	40+ years	4
Smoking status	Current smoker	7
	Former smoker	4
	Never smoked	14

Symptoms reported by participants in Medical Study Questionnaire

Eye symptoms were common, with tired or strained eyes reported the most frequently of all eye symptoms and also rated as the most severe symptom (Table 55, Figure 42). More than half of the participants experienced tired or strained eyes more than once a

week. Focussing difficulties and dry, irritated eyes were also frequently reported. More than 80% of symptoms reduced or disappeared outside of work hours.

Participants most commonly experienced dull headaches (68%), with throbbing (22%) and migraine (25%) headaches less reported. One third of participants reported headaches of some type more than once a week. 70% of headaches reduced or disappeared outside of work hours.

Tiredness was reported by almost 90% of participants, with the majority experiencing symptoms more than once a week. Four participants almost always felt tired. Drowsiness and lethargy were also experienced frequently. More than one third of participants continued to feel tired at the conclusion of their work shift, twice as many as those who felt lethargic or drowsy.

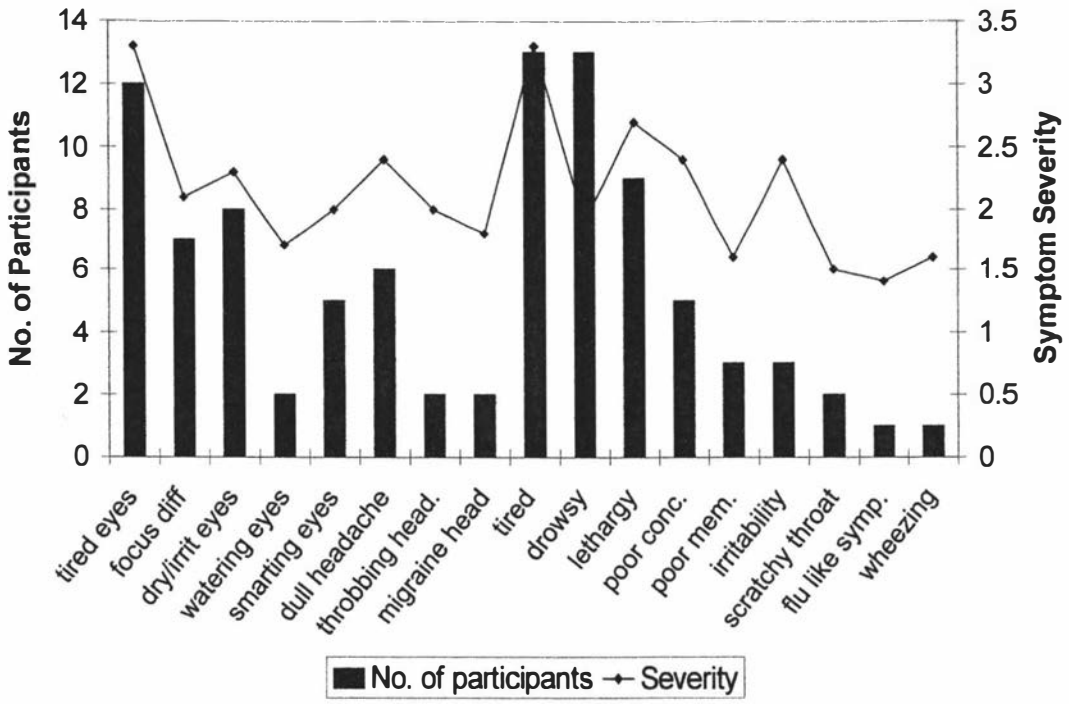
Table 55. Frequency and severity of symptoms experienced by participants

Questionnaire measure	**Symptom incidence**				**Average severity**	**Symptom reduced or disappears**	**Symptom remains**
	Never	>1 month	>1 week	Almost always			
Eye symptoms							
Tired or strained eyes	2	9	12	2	3.28	17	2
Focussing difficulties	14	2	7	-	2.10	7	3
Dry or irritated eyes	12	3	8	1	2.29	11	2
Watering eyes	17	2	2	1	1.68	4	2
Smart/ burn eyes	14	3	5	1	2.04	10	-
Headache symptoms							
Dull headache	8	10	6	1	2.38	14	3
Throbbing headache	17	3	2	-	2.00	3	3
Migraine headache	16	2	2	-	1.81	2	2
Lethargy symptoms							
Tiredness	2	6	13	4	3.32	14	8
Drowsiness	12	6	13	-	1.90	9	1
Lethargy	8	5	9	1	2.70	12	3
Conc. difficulties							
Poor concentration	10	9	5	1	2.44	11	4
Poor memory	16	3	3	-	1.60	4	2
Irritability	9	10	4	-	2.40	9	3

Respiratory							
Scratchy throat	18	1	2	-	1.50	3	1
Flu like symptoms	15	6	1	-	1.38	4	1
Chest tightness or wheezing	19	2	1	1	1.60	1	2
Muscular[82]							
Sore neck/back	-	-	-	3	5.30	2	1
Sore hand/elbow/arm	-	-	2	1	3.70	2	1

Poor concentration, poor memory or irritability were reported less frequently by participants. Flu-like symptoms were uncommon in this population and were typically not severe. Three participants self-identified severe muscular strain in response to the open-ended question.

Figure 42. Frequency and severity of symptoms experienced by participants more than once per week



The average symptom severity for tired eyes, dull headache and tiredness was compared to that of the main study to determine if the participants who took place in the medical study were representative of the larger population who took part in the main study (Table 56). Although the main study took place under differing lighting

[82] These responses were included in the open ended question.

and seasonal conditions, the average symptom severity of participants in the medical study were comparable to the larger main study population suggesting that these participants were likely to be representative of the main study group.

Table 56. Average symptom severity for symptoms reducing or disappearing after leaving the work environment.

Symptom	Office One	Office Two	Office Three	Medical study
Eyestrain	1.41	1.72	1.72	1.76[83]
Headache	1.36	1.57	1.49	1.43[84]
Lethargy	1.29	1.74	1.80	1.57[85]

Symptoms attributed to the Office Environment

Participants were asked if they attributed symptoms to the office environment or use of office equipment (Table 57). Almost 50% of participants who reported eye symptoms attributed them to the office environment with 35%, 17% and 27% of headaches, tiredness and concentration difficulties respectively considered due to the office environment. Over one third of participants attributed symptoms to the air conditioning system (Table 58). Lighting and noise were also identified as significant causal factors.

Table 57. Symptoms reported in the medical examination or attributed to the work environment.

Symptoms	Reported in Medical examination	Attributed to the work environment[86]
Eye symptoms	19	11
Headache	9	6
Tiredness	2	4
Concentration difficulties	2	4
Throat/nasal	3	2
Muscular pain	10	3

[83] Tired or strained eyes.

[84] Dull headache.

[85] Tiredness.

[86] Do you consider any of the health symptoms that you described in Section B to be related to the office environment or use of the office equipment? Yes/No Specify.

Table 58. Causal environmental factors reported in the medical examination or questionnaire..

Environmental Factor	Open ended questionnaire Responses	Medical examination
HVAC (temp and dry air)[87]	9	11
Lighting	5	1
Noise	4	1
None	2	14

Medical Examination

The medical examination highlighted a number of conditions that may have impacted on the symptoms experienced by the participants (Table 59). Four participants had poor vision, none of these had their eyes tested within the last two years (Table 60). A further two participants had glasses prescribed within the questionnaire period and had noted differences in their workplace symptoms[88]. Three participants had high blood pressure. Other medical conditions or malaise that may have influenced symptom incidence and severity included: insomnia, anaemia, asthma and hayfever. In addition, six participants worked very long hours, with either another job (full-time or part time) or tertiary study.

A significant number of participants experienced muscular pain or strain that was attributed to the work task by the occupational health physician. Three of these participants reported migraines.

The medical interview and questionnaire data was examined to identify factors that may have influenced symptoms. Table 61 shows the perceived severity of symptoms (eye symptoms, headache, tiredness, lethargy, poor concentration, irritability) experienced more than once a week alongside symptoms reported in the medical interview or attributed to the work environment. These are compared to the causal factors identified in the medical interview or questionnaire. The final column shows symptoms that are unlikely to be attributable to these factors.

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[87] Occupant responses did not sufficiently distinguish categories to enable these to be treated separately.

[88] These participants chose to base questionnaire responses on the period prior to receiving glasses.

Table 59. Medical condition or other causal factor identified in the medical examination and possible resultant symptom

Medical condition or other causal factor	**No. of participants**	**Possible resultant symptom**
Visual problem	6	Eye symptoms, headache, lethargy
Muscle strain or OOS[89]	9	Headache, lethargy
Working long hours	6	Eye symptoms, headache, lethargy
Low iron levels	1	Lethargy, poor conc., irritability
Perfume allergy, other allergen[90]	1	Eye symptoms, headache, lethargy, flu like symptoms
High blood pressure	3	Headache, eye symptoms
Lack of sleep	2	Eye symptoms, headache, lethargy, poor concentration, irritability

Table 60. Visual Acuity of Participants

Questionnaire Measure	**Response variables**	**Frequency**
Eyes last tested	Never had eyes tested	3
	Tested within last two years	13
	Tested more than two years ago	9
Visual acuity	Short sighted	11
	Far sighted	3

Table 61. Symptoms reported in the medical questionnaire and causal factors.

	Symptom severity[91,92]								
Oper.	Eye	Head.	Tired.	Leth.	Conc.	Irrit.	Other reported symptoms[93]	Possible causal factors	Unexplained symptoms
1-2	-[94]	-	-	-	-	-	None	None	None
1-4	N	N	M	M	N	N	None	None	None
1–5	S	N	M	M	N	S	Eyestrain, sore back/neck	Spinal injury	Eyestrain, irritability

[89] Thoracis (middle) spine, cervical (upper) spine, neck muscle.

[90] The symptoms described by the participant may be due to an allergic reaction. This participant also experienced hayfever and asthma suggesting a predisposition.

[91] Symptoms experienced more than once a week.

[92] S = Severe symptoms (rated ≥ 4); M = Mild symptoms, N = No symptoms.

[93] Reported in the medical interview or questionnaire.

[94] A dash (-) indicates that the participant did not complete that section of the questionnaire.

1-9	S	N	S	N	S	S	Headaches, poor concentration	Poor vision, insomnia	None
1-22	S	M	N	N	N	N	Tired eyes	Low iron levels	None
I-24	N	N	M	S	N	N	Tired, strained, irritated eyes, headache, flu like symptoms,	Asthma, work hours	None
1-25	N	N	S	S	N	N	Eye irritation, poor concentration	Low back strain, work hours, low job interest	None
1-50	N	S	N	N	N	N	Morning headaches	Blood pressure	None
1-31	N	N	N	N	N	N	Eye discomfort, tiredness, hand, finger, elbow soreness	OOS right arm	Eye discomfort
1-66	N	N	S	S	N	S	Tired eyes, difficulty focussing	Work hours	None
2-1	-	-	-	-	-	-	Irritated, dry eyes	Poor vision	None
2-2	-	-	-	-	-	-	Irritated, dry eyes,	Mild asthma	Irritated, dry eyes
2-4	M	N	N	N	N	N	Irritability, strained eyes	Glandular fever	None
2-5	S	S	S	S	S	N	Eye irritation, headaches	Asthma, neck strain	Eye strain/ irritation, poor concentratn
2-8	-	-	-	-	-	-	Occasional migraine, nasal irritation	Neck strain	Nasal irritation
2-9	N	N	N	N	N	N	Dry eyes, sneezing, tired	Sports neck injury	Dry eyes, sneezing, tired
2-11	S	N	M	N	N	N	Mild headaches, sore eyes	Poor vision	None
2-13	N	M	S	M	N	N	Headaches, sore neck, shoulders	Neck strain	None
2-24	S	S	S	S	S	S	Irritated eyes, headaches	Neck strain, work hours	None
2-54	M	N	S	S	N	N	Scratchy throat, sore eyes, drowsiness, lack of conc.	Asthma, work hours	Scratchy throat
3-2	S	N	S	N	N	N	Poor sleep, irritated eyes	Neck strain, insomnia	None

3- 11	N	N	M	N	N	N	Dry throat, irritated eyes, neck and low back pain	Arthritis, bronchitis	Irritated eyes
3-14	S	N	N	N	N	N	Headaches	Poor vision	None
3-17	N	N	N	N	N	N	Sore eyes, sneezing	Stress, neck strain, asthma	Sore eyes
3-20	S	N	S	N	N	N	Dry eyes, neck pains, hayfever symptoms	Blood pressure, allergy (perfume)	None
3-22	N	M	S	S	N	N	Tired eyes	Insomnia, poor vision, blood pressure	None
3-26	N	N	N	N	N	N	Tired	Neck pain	Tired
3-36	S	M	N	N	S	N	Headache, sore eyes	Poor vision	Poor concentratn

A large proportion of symptoms reported by participants could be explained by factors other than the work environment, with long work hours, poor vision and high blood pressure featuring prominently. Muscular strain was the most commonly experienced causal factor for symptoms experienced in the workplace. This incidence was unusually high and can be attributed to the work environment. *'....it should also be noted that the history of OOS type complaints or conditions in this group of workers is very high and is clearly a high risk for these workers....'* Whiteside (1997).

However, when all these factors were considered, there were still a number of symptoms that were apparent in either the medical interview or the questionnaire that could not be explained by other factors[95]. Eight participants experienced eye symptoms including eyestrain, dry eyes, sore eyes, eye discomfort and eye irritation. A number of other symptoms were also unexplained, including tiredness, nasal irritation, irritability, poor concentration, scratchy throat and sneezing. These participants typically experienced other symptoms that could be explained, for example, neck strain could explain headaches, but not eye symptoms.

[95] Interpretation of medical interview by occupational health physician, interpretation of questionnaire by M. Fleming.

5.4 Discussion

When asked to report on symptoms experienced in the workplace: eye symptoms, headache symptoms and tiredness or lethargy were the most frequently reported; the most frequently attributed to environmental conditions; amongst the most severe; and typically reduced or disappeared at the conclusion of the work shift. These results support the main study methodology, which asked participants to report eye symptoms, headache symptoms and lethargy symptoms.

Participants reported a high incidence of tiredness and drowsiness as well as lethargy and these were also rated as severe, suggesting that these may also have been appropriate measures for the main study.

The majority of symptoms that could not be adequately explained by other factors were eye symptoms. In addition, when participants were asked to attribute symptoms to the office environment, almost 50% of participants attributed eye symptoms, while only 35%, 17% and 27% of headache, tiredness and concentration difficulties were considered to be due to environmental conditions.

While participants most frequently attributed the symptoms they experienced to air conditioning within the space, the results suggest that visual conditions may also have been a significant culpable factor. This is supported by the incidence of visual complaints across the three offices, the eye symptoms that could not be explained by external factors and the environmental conditions in the offices studied (See Chapter 4). The high level of muscular strain experienced by this group may also be attributed to the lighting conditions in the office space as workers have been shown to assume uncomfortable or awkward conditions to improve visual conditions (Rea et al., 1985).

In addition, the primary work task of the occupants (reading hand written numbers) requires high levels of visual concentration that must be maintained over a long period. The visual task was not difficult, but staff were required to process a large number of cheques at speed (1000/hour). Lighting conditions that are not optimum could reasonably be expected to cause eye discomfort in this group of workers. This

finding is supported by the main study that found that differences in lamp type impacted upon eyestrain and lethargy symptoms experienced by the occupants.

It was clear that external factors had the potential to influence symptom severity significantly. While it is over simplistic to assume that all symptoms discussed above were caused by external factors, they were undoubtedly influential in many causes, possibly increasing the incidence or severity of a symptom which otherwise may not have been expressed. Poor vision and high blood pressure were surprisingly common and likely to be associated with eye discomfort and headache. This study supports the role that collecting a detailed medical history can provide in explaining symptoms experienced by the participants. However, aspects of health such as visual acuity that occupants may not be aware of, can also significantly affect reported symptoms. Regular physical examinations may be able to reduce the incidence or severity of symptoms experienced in the workplace that are due to these factors.

In the subject population, many participants worked long hours, due to tertiary study or other employment. It is probable that these participants experienced eye discomfort, headaches, tiredness, poor concentration and irritability, particularly as the work took place in the evening. In addition, muscle strain was identified as a risk factor for this occupation and was a probable contributor to symptoms. Therefore, further research on office personnel that have a wider range of work tasks, is necessary to determine the extent to which these results are applicable to other office personnel.

However, given the impossibility of ensuring that all people who work in office environments are in perfect health, it seems that we must accept that some factors may increase symptom severity. The primary target of researchers therefore remains to determine if by mitigating the environmental condition, the symptom is reduced, regardless of external influential factors.

6 General Discussion

This chapter considers the analyses that were undertaken in turn and outlines the relationship found between the factors in relation to the study aims and hypotheses. The strength of the relationships found is explored, including any limitations in the data set and alternative explanations.

The contribution that this study makes to the body of literature in this field is examined. This includes a discussion of how the study results compare to other findings in this field of literature. Finally the contribution that this study makes to office lighting design, management and energy use is discussed and recommendations for future research are made.

6.1 The effect of flicker frequency and modulation depth of fluorescent lighting on the health, productivity and satisfaction of office personnel

The relationship between lighting treatments was explored by evaluating the differences in lighting related health symptoms (eyestrain, headache, lethargy), the actual productivity and perceived productivity of the participants and satisfaction with the lighting. The perception of flicker during the study was also elicited.

Participants were found to report higher lethargy symptom severity and incidence in the low frequency halophosphate lighting treatment in comparison to the high frequency triphosphor and the low frequency triphosphor lighting treatments. There was some evidence to suggest that eyestrain symptom severity was also greater in this lighting treatment. Lethargy and eyestrain symptom severity was rated as 10-15% more severe, and participants experienced 5-10% more lethargy symptoms in this lighting treatment. The difference between lighting treatments was attributed to

increased reporting of severe symptoms, suggesting that participants who experienced symptoms rated them as more severe in the low frequency halophosphate lighting treatment.

Headache symptoms were not significantly different in any of the lighting treatments. No significant differences were observed between the high frequency triphosphor or low frequency triphosphor lighting treatments.

Participants experienced symptoms in approximately 30-40% of work shifts, with 70-90% of symptoms disappearing or reducing when the work environment was left. A smaller group of individuals (35%) reported severe symptoms, but there was no evidence to suggest that a few participants were responsible for the lighting treatment differences found. A small number of influential responses were excluded from the analyses. The participants reporting these responses were not identified as exceptional in relation to their medical history or other external factors.

The relationship between perceived productivity and symptom severity was undertaken for each of eyestrain, headache and lethargy symptoms for each lighting treatment. The analyses showed that eyestrain and lethargy symptoms experienced by the participants were related to their perception of the work environment in the low frequency halophosphate lighting treatment. In all cases, perceived decreases in productivity (due to the work environment) were strongly associated with increased symptom severity. No relationship was shown between perceived productivity and headache symptom severity in the low frequency halophosphate lighting treatment and while there were some statistically significant relationships present in the other lighting treatments, these were not consistent across all analyses. A similar trend was observed for the relationship between satisfaction with lighting and symptom severity.

The analyses did not suggest that the actual productivity of participants differed with lighting treatments. The variation in the data, along with the limited amount of data available, limited the ability of the analyses to detect any differences that may exist.

However, sufficient evidence was presented to show that if any difference was present, it was very small.

Taken together, the results provide evidence to suggest that the low frequency halophosphate lighting treatment differed from the high frequency triphosphor and low frequency triphosphor lighting treatments. Participants experienced more symptoms, rated symptoms as more severe, and felt that their productivity was affected negatively to a greater extent in this lighting treatment.

Limitations of this study include the small sample size and the minor violations of ANOVA assumptions.

The results from this study did not suggest that the flicker frequency or modulation depth of the fluorescent lamps influenced lighting related symptoms, productivity, perceived productivity or satisfaction with the work environment.

The high frequency lighting treatment (HF-Tri) was shown to be significantly different to one of the low frequency lighting treatments (LF-Halo), but it did not differ from the other low frequency lighting treatment (LF-Tri). Therefore increasing the flicker frequency of the control gear in fluorescent light lamps from low frequency operation (100Hz) to high frequency operation (20-60 kHz) was not shown to decrease lighting related symptoms.

Participants reported significantly more severe eyestrain and lethargy in the low modulation lighting treatment (LF-Halo) than the high modulation lighting treatment (LF-Tri). Therefore utilising low modulation fluorescent lamps was not shown to decrease lighting related symptoms.

Visible flickering of fluorescent lamps was observed more frequently in the low frequency, high modulation lighting treatments (LF-Tri and baseline lighting). However, it was perceived infrequently in all lighting treatments and was not found to influence symptom incidence, symptom severity or satisfaction with the lighting.

Overall, neither flicker frequency or modulation depth was shown to reduce the incidence or severity of eyestrain, headache or lethargy symptoms in the office environment. Further, this study found no evidence to suggest that flicker frequency or modulation depth affected productivity or satisfaction with the lighting.

These findings need to be considered carefully alongside other research. Previous studies have shown that components of the visual pathway respond to low frequency flicker at frequencies above the perceptual CFF (Brundrett, 1974; Eysel & Burandt, 1984; Berman et al., 1991). This nuerological activity has been interpreted as 'noise' that has been hypothesised to impede stimulus recognition for tasks that have a high visual difficulty, and to contribute to asthenopic symptoms reported by subjects working under fluorescent lighting (Veitch & McColl, 1995). These conclusions are based on research that has shown that visual processing, task performance and asthenopic symptoms are improved when spaces are illuminated by high frequency fluorescent lighting. However, much of this research is based on performance tasks which are not representative of those found in the workplace. In the majority of studies the effect sizes were small, therefore the relevance of these findings has not been quantified in relation to the work environment. This study attempted to assess the effects of fluorescent light flicker and modulation depth on the task performance, asthenopic symptoms and satisfaction of participants in an office environment.

Research has shown that visual saccade response is less accurate under low frequency lighting in comparison to high frequency lighting (West & Boyce, 1968; Wilkins, 1986; Kennedy & Murray, 1991). These effects were found for visual tasks that required participants to fixate on moving or widely spaced targets. Where the visual targets were static or more closely spaced, the flicker frequency effects were not significant. In this study, participants were fixated on a static target, therefore it is unlikely that visual saccade response contributed to the findings.

Laboratory research supports flicker effects on visual processing, showing that visual performance improved under high frequency lighting as compared to low frequency lighting (Veitch & McColl, 1995; Veitch & Newsham, 1998a). In these studies the performance task had a high degree of visual difficulty and despite the isolation of the

variables of interest and the task difficulty, the results did not show large differences between lighting treatments. Veitch and McColl (1995) found that only one of the six rows tested using VaLID in a visual performance task was significantly different with respect to flicker frequency. The other rows, which had both higher and lower contrast, did not differ, and the fitted model only explained a small amount of the variation. A similar result was found by Veitch & Newsham (1998a). Start et al., 1995[96] attempted to replicate Veitch & McColl (1995) and did not find a statistically significant effect, although similar trends were observed. Laboratory studies have not found effects on tasks with visual components including proof reading, reading comprehension and computerised reading tasks (Nelson et.al., 1983[97], Veitch & Newsham, 1998a). None of these studies have found differences in visual comfort.

In this study, data was only collected from two offices, limiting the amount of analysis undertaken. However, it was clear from the data presented that if any difference between the lighting treatments was present, it was extremely small. While the manner in which the productivity data was collected introduced variability, the small difference between the lighting treatments suggests that this was minimised over time. This is supported by Zyla-Wisendale & Stolwijk (1990) who found that while daily productivity output varied considerably, the productivity over a six month period was consistent.

The null result found and the absence of any trend in this study, confirms previous research that has suggested that effects on performance are limited to tasks that have a high level of visual difficulty, with minimal cognitive or motor components. The performance task in this study fitted these criteria, but in addition, participants were required to identify the hand written figure on the cheque. This may have introduced cognitive elements that impacted on the visual processing component.

The interventional field study by Wilkins et al. (1989) found that headaches and eyestrain were more than halved in their interventional study. Wilkins et al. (1989)

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[96] Cited from Veitch & Newsham, 1996.

[97] Cited from Veitch & Newsham, 1996.

had a small group of participants (42) who took part in a crossover design. While the incidence of headache and lethargy symptoms was markedly reduced in the high frequency lighting treatment, the Mann-Whitney U-tests did not return statistically significant results consistently for the analyses undertaken. The headache incidence was significant for the group experiencing the conventional lighting first (paired-t(19) = 2.31, p=0.02, one tailed), but not for the reverse group (paired-t(21) = 0.35, p=0.36, one tailed) giving an aggregate difference of t(40) = 1.60, p=0.059, one tailed. Eyestrain incidence was provided for the total group (those who crossed over and those who remained in the same lighting conditions) and again showed that the difference before the changeover was significant (z=2.09, p=0.018, one tailed) but not afterwards (z=1.24, p=0.11, one tailed), with a significant aggregate difference for the crossover group t(38) = 1.83, p=0.037, one tailed). Wilkins et al. (1989) has not been successfully repeated and this study attempted to verify their findings.

In this study, the incidence of symptoms was markedly higher than those found in Wilkins et al. (1989). Wilkins et al. (1989) reported a weekly headache incidence of 0.06-0.47 and a weekly eyestrain incidence of 0.01-0.36. In comparison, this study found that participants experienced eyestrain, headache or lethargy symptoms in 30-40% of all work shifts.

The difference in reporting may be due to the populations studied. Wilkins et al., (1989) utilised the staff of a government legal department, who are likely to have worked an eight hour day shift, five days a week (this information was not provided in the paper cited). In this study (the subject of this thesis), the participants had other commitments including tertiary study, child care, and other employment, which were typically undertaken before their evening shift was commenced. Further, their position was typically part time and casual, requiring minimal prior training. The participants may not have had the commitment to the job that a full time position would entail, which may have influenced their symptom reporting.

The participants who took part in this study may have been fatigued, possibly experiencing symptoms before the work shift commenced. Further, as it was an evening shift, participants were likely to experience increased fatigue and/or

symptoms in comparison to day shifts. Perhaps participants did not report a higher incidence of symptoms in the low frequency and/or low modulation lighting treatments because they were less sensitive to the lighting conditions due to their increased fatigue.

This result suggests that flicker effects on asthenopic symptoms may have a similar level of sensitivity to those found on task performance. Neither Veitch & McColl (1995), or Veitch & Newsham (1998) found that the visual comfort of participants differed under high or low frequency lighting. Wilkins et al. (1989) observed that symptom incidence was markedly reduced under high frequency lighting, but overall the symptom incidence was not high and these findings did not all translate to statistically significant differences between lighting treatments. Perhaps differences in asthenopic symptoms that can be attributed to lighting are primarily due to sensitive populations. Wilkins et al. (1989) noted that symptoms were reported by a small group of participants, and Lindner & Kropf (1993) observed that only 200 participants in a sample of 3030 (6.7%) experienced symptoms that were attributable to the fluorescent lighting. This study found that the differences in lighting treatments observed was due to increased reporting of severe symptoms, with a smaller subset of the participants contributing to this result.

The low incidence of flicker detection supports the findings of Collins & Hopkinson (1954) and Brundrett (1974) who suggested that complaints of visible flicker could be attributed to 50 Hz flicker from poorly maintained or malfunctioning lamps.

Taken together, the study supports previous findings that suggest that differences in task performance due to flicker frequency are only present on performance tasks with a high level of visual difficulty and minimal cognitive or motor components. Further, the findings also suggest that affects on asthenopic symptoms may be small and possibly limited to sensitive populations. This study may not have been sensitive enough to detect differences in the health, productivity and satisfaction of office personnel due to fluorescent light flicker.

6.2 *Lighting Treatment Differences*

The results from this study did not verify the findings of previous research (Wilkins et al., 1989; Veitch & McColl, 1995). Thus the primary research hypothesis was not confirmed and alternative explanations need to be explored. The following section examines the low frequency halophosphate lighting treatment in relation to the low frequency triphosphor and high frequency triphosphor lighting treatments. It describes how this lighting treatment differs from the other two and discusses the possibility that these differences may have been responsible for the study findings.

Spectral Distribution

The differences between the low frequency halophosphate lighting treatment and the two triphosphor lighting treatments may be due to differences in the spectral distribution of the two fluorescent lamps. The spectral distribution of lamps can be described by various parameters including colour rendering, colour temperature, modulation depth and scotopic/photopic illuminance.

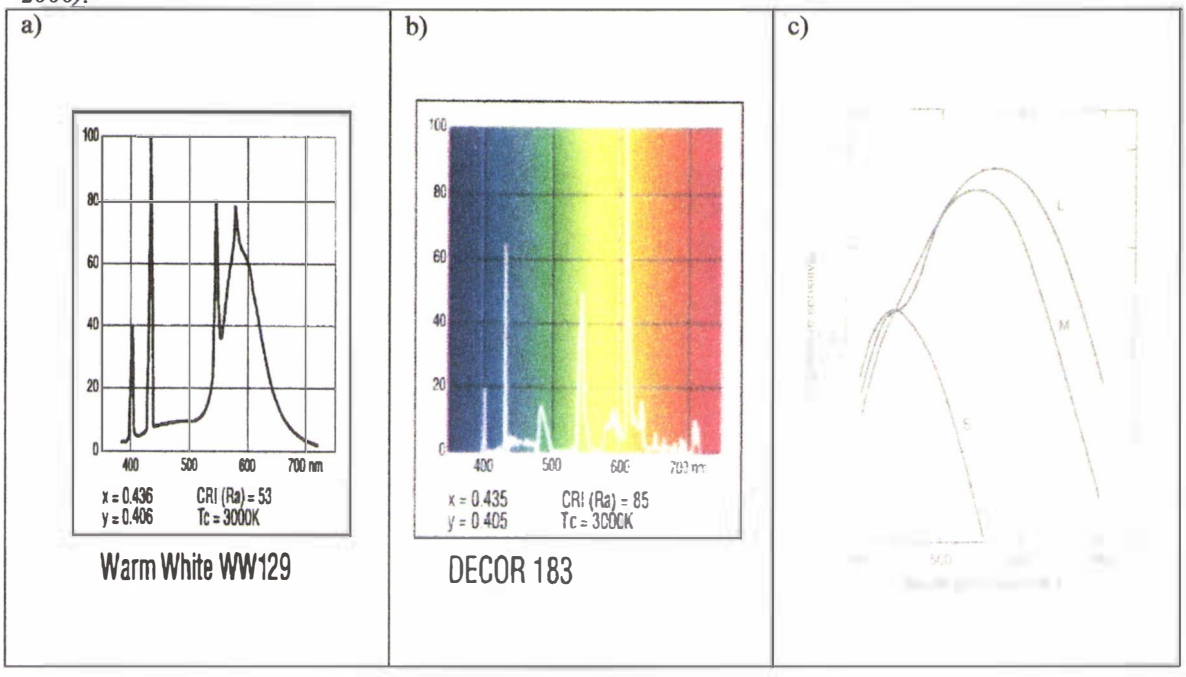
Halophosphate lamps have broad waveband emissions across the entire visible spectrum (Figure 44a), whereas triphosphor lamps emit in three narrow bands with peaks that correspond to the three cone photoreceptors within the retina (Figure 44b and Figure 44c). Thornton (1972)[98], suggested that for maximum visual performance and clarity, lamps should generate radiation to correspond with the three cone photoreceptors. This is supported by a body of literature that has shown that coloured scenes illuminated by triphosphor lamps are perceived to have increased brightness perception and visual clarity in comparison to halophosphate lamps (Bellchambers & Godby, 1972; Lemons & Robinson, 1976; Boyce, 1977).

However, research comparing high colour rendering halophosphate lamps with high colour rendering triphosphor lamps has not shown significant differences between

[98] Cited from Vrabel et al., 1998.

lamp types. In all cases these lamps were ranked higher than the low colour rendering halophosphate lamps (Worthey, 1985; McNelis et al., 1985; Vrabel et al., 1998).

Figure 43. Spectral distribution of the a) halophosphate (Warm White WW129), and b) triphosphor (Décor 183) fluorescent lamps used in the study (from Sylvania Lamp Catalogue), and c) The relative spectral sensitivity curves of the three cone photoreceptors: long (L), middle (M) and short (S) (Rea, 2000).



Therefore the difference in colour rendering between the fluorescent lamps may be a better measure of this difference. The halophosphate fluorescent lamps used in this research study had poor colour rendering characteristics (CRI = 51) when compared to the triphosphor fluorescent lamps (CRI = 85). Lamps with high colour rendering indices have been shown to improve visual clarity[99] (Aston & Bellchambers, 1969; Worthey, 1985; McNelis et al., 1985; Vrabel et al., 1998). When the task has involved colour discrimination[100], lamps with a high CRI have been shown to improve performance, however, the lamps are not ranked differently for monochromatic tasks (Boyce & Rea, 1994; Vrabel, 1995).

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[99] The concept of "visual clarity" has been used in several studies to indicate a preferred appearance of scenes containing coloured objects when illuminated by certain sources. '"Visual clarity" seems to be a combination of various factors included perceived colour and contrast, colour rendering, colour discrimination, colour preference and border sharpness, but is not a well understood notion.' (Rea, 2000)

[100] Such as colour matching.

The Colour Discrimination Index (based upon the Gamut area of the lamp) may also be a predictor of these results. The CDI is based on the eight CIE test colours, but does not involve a reference source and is an estimate of the colour differences between a range of colour surfaces lit by a specific light source. Lamps with high CDI values appear to have greater clarity as the colours appear more saturated and hence clearer (Boyce, 1977; Boyce & Simons, 1977; Thornton, 1998).

In this study, participants were required to visually identify hand written numbers at a rate of 1000 per hour. Any factor that increased visibility, and thus made numbers easier to distinguish, could impact on visual comfort with follow-on effects on asthenopic symptoms, satisfaction and productivity. In addition, the subjects were reading cheques that were hand written with differing pen colours (primarily blue and black) and up to one third of the cheques were lightly coloured. Therefore there was a colour component that may have contributed to this outcome.

Further, the participants' perception of the lighting treatments suggests that the lamps may have been perceived differently. A large number of participants in Office Two reported that the newly installed triphosphor lighting was very bright when the existing halophosphate lighting was replaced at the beginning of the baseline period. In comparison, Office Three participants did not report increased brightness to the same extent when their existing triphosphor lighting was replaced, even though the largest increase in luminance occurred in this office. The glare index was higher in Office Two as it was open plan and hence the perceived glare in this offices may also have increased, but this does not fully explain the difference in perception which may be attributable to the difference in perceived brightness, as distinct from measured luminance between the two types of fluorescent lamps. Current research on visual perception suggests that light signals are processed via chromatic and achromatic channels in ways that are not yet fully understood, but may explain increased brightness perception under lamps with differing spectral distributions (Vrabel, 1998; Rea, 2000).

The lamps were matched for colour temperature; therefore the scotopic illuminance is unlikely to differ substantially between treatments (Berman et al., 1995).

The collection of studies that have specifically examined colour rendering have primarily examined scenes or pictures, which are brightly coloured, not physical spaces. Limited studies have been conducted using performance tasks, both coloured and achromatic. Visual comfort has received minimal research attention. Overall the research to date suggests that when coloured scenes are compared directly that higher colour rendering lamps are the preferred illuminant and that these lamps give better performance for tasks in which colour discrimination is important. These effects have not been demonstrated for achromatic scenes (Boyce, 1977; Boyce & Rea 1994). However limited research has considered long term studies in workspaces, despite anecdotal evidence that occupants of spaces prefer high colour rendering sources. Effects on health (eyestrain, headache, lethargy) have not been sufficiently explored.

A significant body of research has examined the effect of full spectrum lamps on behaviour and performance, mental well being, physiology and health (Boyce et al., 1992; Veitch, 1994). These lamps feature high colour rendering indices (95+), high colour temperature (5000+ K) and typically have an ultraviolet component. Unfortunately the quality of this research has been poor and has not enabled clear effects to be attributed to these lamps *'In general, poor quality research has resulted in an absence of simple deterministic effects that can be confidently attributed to fluorescent lamps'* (Veitch & McColl, 1994). However, the following conclusions have been drawn from extensive critiques of this research (Boyce et al., 1992; Veitch, 1994):

- There is no evidence to show that full spectrum lamps can be used with lower illuminance in comparison to other lamp types without detriment to visual performance or impression;
- There is an improvement in the accuracy of colour sorting or other tasks that are reliant on colour discrimination due to the high colour rendering index of the lamp;
- Claims that full spectrum lighting markedly improves health, performance and user perception are not supported by the laboratory research that has been conducted.

The majority of this research does not adequately address the long term effects of the lighting on health, performance and user perception in the work environment. Health effects in particular are not captured well by laboratory research. However, while the research that has been conducted does not exclude a relationship between spectral distribution and the health and satisfaction of office personnel in the work environment, it suggests that any effects are likely to be small.

In this study, the size effect was small. However the range of previous research suggests that the utmost caution must be applied in attributing this result to spectral differences, particularly as the study was not designed to isolate this effect. Nonetheless, this remains a plausible explanation for the result found and there is some evidence in the literature that supports this finding. Therefore, further exploration of this hypothesis is warranted. Future research should initially attempt to determine which aspects of spectral distribution are important. The Principal Components Analysis approach suggested by J. Veitch[101] would provide such a descriptive basis and lead to field research that is able to explore perceptual and health effects in the work environment.

Luminance and Illuminance

The difference in efficacy between the halophosphate and triphosphor fluorescent lamps resulted in a 15% difference in light emission. This was corrected by placing black tape along the rear of the triphosphor fluorescent lamps, but all three lighting treatments still differed with respect to illuminance on the horizontal desktop and work plane and luminance levels in the Offices (Chapter Four: Environmental Monitoring). The low frequency triphosphor lighting treatment was the brightest, followed by the high frequency triphosphor and the low frequency halophosphate lighting treatments.

Differences in luminance and illuminance have been shown to influence visual performance and positive affect (Boyce, 1977; Boyce & Rea, 1994; Boyce & Cuttle, 1990). These studies do not show significant differences for smaller increments at

[101] Cited from the discussion papers, Vrabel et al., 1998.

higher illuminance such as those found in this study. In addition, all three lighting treatments differed with respect to illuminance, and this was not reflected in significant differences between all three lighting treatments. Therefore, it seems unlikely that this difference contributed to the study findings.

However, although the illuminance levels were appropriate for the task, task difficulty and contrast levels, meeting visual stimulus requirements and the Australian and North American recommended lighting standards, they fell below the New Zealand and North American recommended standards of 500 lux for '*general offices with mainly clerical tasks and occasional typing*' and *'open plan office – intermittent VDU use'*. As lighting affects the speed and accuracy with which visual information can be extracted and processed (Rea, 2000), it is possible that the lower illuminance levels in the low frequency halophosphate lighting treatments may have contributed to the significant difference found between lighting treatments.

Luminance Distribution

The halophosphate and the triphosphor lighting treatments may have differed with respect to luminance distribution as the triphosphor fluorescent lamps had black tape along the rear of the lamp to reduce the luminance from the lamps. However, any difference between the luminaires was most unlikely to be detected by the participants as the luminaires had prismatic diffusers and it is unlikely that this difference could contribute to changes in the symptoms or perception of the work environment.

6.3 The Relationship between Study Measures: Symptom Severity, Actual Productivity, Satisfaction and Perceived Productivity

The analyses revealed a number of relationships between study measures. These included:

- Symptom severity and perceived productivity;
- Symptom severity and satisfaction with the lighting;

- Satisfaction with the office environment and perceived productivity;
- Symptom severity and actual productivity.

There are a number of studies that have shown that the office occupants perceive that their productivity is adversely affected by the work environment (Burge et al., 1987; Hall et al., 1991; Whitley et al., 1996; Raw et al, 1990). This study supported the relationships that have previously been identified between perceived productivity and satisfaction with the work environment. Perceived productivity was shown to be strongly associated with reported symptom severity and satisfaction with the office environment. This relationship was present when satisfaction with lighting, temperature, air conditioning or the overall work environment was considered.

Research has also shown that task performance can be affected by changes in environmental conditions. However, there is very little research that has shown that the actual productivity of office occupants can be affected by the work environment. Productivity is influenced by a large number of factors and therefore the effects due to any one variable are readily overwhelmed by the variation introduced by other factors.

This study found that symptom severity and actual productivity was related in one of the offices studied. The results showed that when participants rated their symptoms as more severe, their actual productivity declined. For each increment of symptom severity reported, a corresponding decrease in productivity of 2-3% (equivalent to 28-39 cheques/hour) was observed.

No relationship was demonstrated between actual productivity and other measures including perceived productivity and satisfaction with the work environment (including lighting, temperature, air conditioning and overall work environment). However, participants were asked to describe the effect that they felt the work environment had on their productivity. Therefore, other factors that may have affected symptoms and/or productivity were not collected by this questionnaire measure. This may explain the lack of relationship between these variables.

In summation, this study lends support to previous research that has explored the relationships between satisfaction with the work environment, symptoms experienced in the work place and the perceived effect of the work environment on productivity. In addition, the relationship observed between actual productivity and symptom severity forms an important contribution to international research by showing that symptoms experienced in the workplace can influence the productivity of the occupants. Although the study could not show conclusively that the work environment induced these symptoms, the relationship is suggestive and this methodology may be of use in future field studies.

6.4 The Role of Environmental Factors and Personal Characteristics in Symptom Incidence and Severity

The environmental conditions monitored in the main study and the medical history identified in the medical study isolated factors that might have influenced symptom incidence and severity in the participants studied.

Environmental conditions that may have increased the overall level of symptom reporting in the three offices included luminance contrast, air conditioning and noise[102]. Participants most frequently attributed symptoms to the air conditioning, lighting and noise in the offices with 50% of eye symptoms, 17% of tiredness and 27% of concentration difficulties attributed to the work environment or use of office equipment. Despite this, the majority of participants reported that they were not significantly satisfied or dissatisfied with the office environment. Therefore, while a number of participants' specifically highlighted aspects of the environment that they were unhappy with and attributed symptoms to these, dissatisfaction was not endemic.

[102] These conditions remained constant throughout the study period and therefore they did not confound the differences between lighting treatments.

The medical study provided detailed information on individuals and enabled a number of factors that were potentially significant contributors to symptoms to be identified. Medical conditions included poor vision and high blood pressure, which were surprisingly common in the staff examined. Muscular strain and working long hours were also highlighted. However, there was no evidence to suggest that participants who experienced very severe symptoms[103] in the main study differed with respect to their medical history or other factors.

There was insufficient evidence to suggest that age and gender impacted on symptoms. In contrast, studies have suggested that females and occupants aged under 30 have a higher incidence of symptoms (Hedge, 1988; Skov et al., 1989, Godish, 1994).

A number of studies have found that the medical history of study participants can predispose or increase the severity of symptoms experienced by office workers. Most of these studies have been large-scale epidemiological research programmes. Other laboratory and interventional studies have not shown that medical history influenced symptoms suggesting that the effects may not be easily detected by studies of this nature. Regardless, collection of this history is critical in ensuring that participants with specific medical conditions are not influential.

6.5 The Contribution of this Study to Lighting Research and Recommendations for Future Research

Flicker Frequency and Modulation Depth

As discussed in Chapter Two, previous studies have demonstrated that flicker frequency can influence the visual performance, comfort and satisfaction of research participants. This research programme suggests that these effects may be small and easily overwhelmed by other factors in an office environment. However, the relatively specialised population and the limitations of the study justify further field

[103] Identified as outlying values in the ANOVA.

research. If a sufficiently large population were available, then further research could be attempted with a control group, thus limiting the duration and cost of the research. Alternatively, an epidemiological study of several office buildings may be feasible. However, it would be inadvisable to examine the effect of the lighting treatments on productivity alone as this study suggests that if any effect was present it was very small. Further field research examining the relationship between symptoms and productivity should be undertaken where a strong relationship has been demonstrated between a causal environmental factor and symptoms.

This study did not find any effect due to modulation depth. Further laboratory research should be undertaken to assess the size of any effect that may be present.

The literature review reports upon studies that have described occupant's responses to flicker from fluorescent lighting as directly causing asthenopic symptoms including eyestrain and headaches, as well as being annoying and irritating. However, this study was not able to verify these findings. This is unsurprising, as our knowledge of the eye's physiology shows that the vast majority of office occupants will be unable to detect flickering from lamps under low or high frequency operation unless the lamp is malfunctioning. In this study, all the lamps used were new and therefore malfunction was unlikely, as most failures occur in lamps at the end of their rated life. In aged lamps, it is common for the electric discharge occurring between electrodes to become uneven, resulting in a perceptible 50 or 60 Hz flicker.

The finding from this study confirms previous research that has suggested that perceptible flicker only occurs in lighting installations that have been poorly maintained, with lamp replacement taking place at lamp failure or when occupants complain of flicker or poor light levels. Future studies examining lighting conditions in buildings should ensure that information on the maintenance and age of installation is collected. An appropriately designed field study, that critiques a range of office spaces with differing levels of maintenance and age of installation would conclusively verify that the primary cause of occupant complaints relating to flicker in lighting is only significant in poorly maintained installations.

Actual Productivity

The actual productivity of the participants was collected by office management to appraise individual staff performance, and was thus readily available. Checks had already been undertaken on the data to ensure that it was accurate, and the data was collected as part of the work task, thus avoiding increased performance due to positive effect[104]. Personnel were required to undertake regular productivity assessments by office management; therefore a significant pool of data was available. This represented an ideal situation as the costs associated with collecting the productivity data and the ethical difficulties that may have arisen were avoided. Inaccuracies in the data were imposed by the time taken to load the machines, cheque collection and machine jamming. In addition, in Office One, all machining staff participated in a short stretching session to reduce or prevent the incidence of Occupational Overuse Syndrome (OOS) on an hourly basis. This stretching session was lead by differing staff and therefore was of variable duration.

While these limitations decreased the accuracy of the data, research suggests that this is minimised when data is collected over a long time period (Zyla-Wisendale & Stolwijk, 1990). In addition, a larger pool of data was available in the offices because office management collected the data. Other methods of data collection inevitably would face similar restraints if collected in an interventional study.

On balance, this methodology was successful. However, further analysis of the data available, which included the number of errors made by the participants, may confirm the findings to date. In addition, other measures of productivity such as absenteeism and staff turnover can be used. These both have significant methodological difficulties, but if taken alongside other results and appropriately screened, can be worth attempting. However, neither of these were appropriate methods for this study.

[104] If the task took place intermittently and was monitored by the researchers, staff may optimise their performance.

The significant relationship found between symptoms experienced by office personnel and their productivity makes an important contribution to the research arena. This finding suggests a methodology that warrants further investigation.

Study Methodology and Design

An interventional study is typically undertaken when laboratory research has shown a robust relationship between variables. The study design enables the magnitude of effect to be evaluated in the work environment, without isolation from other influential variables. This type of research can be very expensive and time consuming as the study is typically longitudinal, requires a relatively large population, and introduces significant changes to the office environment.

This study provided the opportunity to investigate the effect of fluorescent light flicker and modulation depth on the health, productivity and satisfaction of office personnel, and to investigate the relationship between these variables in an office environment over a long time frame.

Overall, the study methods and design were successful, meeting the research objectives and contributing to the body of research in this field. However, future studies could benefit from the experience of this research.

In particular, the baseline period enabled initial information to be collected and familiarity with the study conditions and questionnaire design. This baseline data was then utilised as a covariate in the analyses to enable initial differences between offices to be quantified. In this study, the lighting conditions between host offices differed sufficiently that it was necessary to install a new lighting regime in the three offices, and initial questionnaire data had to be discarded to exclude any carryover effect that may have been present. This resulted in a smaller dataset than was desirable. If the baseline lighting was installed for a longer period of time then participants could become accustomed to the new regime before questionnaire data was collected. Alternatively, if lighting conditions in the host offices were comparable, collecting baseline data before any changes to the lighting took place would also be feasible.

The crossover design enabled the study to be completed with a smaller number of participants and no control group was necessary, due to the repeated measures nature of the design. The between subject variability was also greatly reduced. This was important as it would be extremely difficult to identify a control group with comparable conditions, and previous research had suggested that the effect, if present, would be relatively small, so that a very large number of participants would be required. The primary disadvantage of a study of this nature is the long duration, as each participant is exposed to all of the lighting treatments. In addition, the costs associated with changing the lighting installation escalate. In this study, there was some evidence to suggest that response fatigue occurred and the attrition rate was undesirable[105]. A shorter questionnaire may have minimised this effect, and influenced the study findings. If a larger population of participants was available, a between subjects study with a control group may have been feasible. However, within New Zealand, this was difficult if not impossible to achieve, when considering a task in which the productivity could be measured and in which daylight penetration was minimised. A larger population base and a study in which productivity was not measured would be necessary.

The use of the pilot study (Appendix D) and subsequent power analysis (Appendices E & F) enabled estimates of the number of participants required for the main study to be calculated and gave an indication of the probable response rates and symptom incidence in this subject population. Unfortunately, differences between the office in which the pilot study was undertaken and the main study offices resulted in fewer numbers of participants than was previously estimated[106]. As few offices were available in which this study could be undertaken, the study continued nonetheless with a participant rate that was acceptable, but had little margin for attrition. Future research of this nature should ensure that estimates of the number of participants required have a substantial margin of error to avoid such occurrences.

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[105] This was primarily due to participants leaving the place of employment. The nature of the work contributed to a higher attrition rate than may have occurred in other organisations.

[106] The main study had a lower participation rate and fewer participants exposed to the experimental lighting conditions for the duration of the work shift.

Questionnaire Design

The data collected in the study enabled accurate and concise information to be collected on the incidence of symptoms that could be attributed to the changes in the lighting treatments. In addition, participants were provided with an opportunity to discuss any aspect of the work environment that they liked or disliked. This did not specifically isolate lighting conditions. These questions were deliberately excluded to prevent participants focussing on lighting conditions to the exclusion of other, possibly more influential environmental conditions. However, it would have been beneficial to collect further information on the response to the lighting, including perception of glare, colour of lighting and how natural the lighting appeared. The answers to these questions may have indicated more specifically which aspects of the lighting participants preferred or felt resulted in symptoms.

Participants outlined whether their symptoms had disappeared, reduced or remained at the conclusion of their work shift. The findings in this study suggest that screening symptoms to remove those that continued outside of work hours may not be valid for this group of participants (see Chapter 3: Results and Discussion). This may be due to the type of study population. Evening shift workers typically allow little time after their shift for symptoms to abate before retiring to bed, and so they are more likely to believe the symptoms persisted. Alternatively, symptoms influenced by the lighting conditions in this study may not abate until the eye is rested.

The questionnaire was based on previous research studies, and aimed to collect accurate and precise data. However, the attrition rates and reduction in responses to the open ended questions suggested that some response fatigue was occurring. This may have reduced the validity of the results. The questionnaire for the second section of the methodology was based upon Wilkins et al. (1989). In their study, eyestrain and headache symptoms were classified by participants as none, mild or severe symptoms. In this study (the subject of this thesis), symptom incidence and severity was collected on a seven point Likert scale to enable small differences in perceived severity to be detected. This method enabled the participants to classify their symptoms more precisely, but gave sufficient flexibility for symptoms to be grouped and analysed in a number of ways. The results showed that the sensitive scale was

useful, as the average difference in perceived symptom severity that was statistically significant was less than one point on the Likert scale. In addition, participants were asked to identify whether their symptoms remained or reduced after their work shift and to complete a weekly questionnaire. It is possible that collecting this additional information influenced response fatigue.

Study Population

This study was conducted on a relatively specialised population. The participants in this study were from a population of evening shift workers. These personnel have an increased incidence of mental illness, sleep problems and health problems, which are associated with their inability to socialise, sleep or eat at normal times (Mellor, 1986). This may be reflected in increased symptoms reported by these staff. However as these workers were typically part time and worked at times that would enable them to maintain normal sleep and eating patterns, these factors may not be as influential as they would be for other shift workers. Many of the staff had other primary activities including jobs, study and parenting. The results from the medical study strongly suggest that these influenced lethargy, tiredness, concentration difficulties, and may have contributed to eye symptoms and headaches.

The specialised nature of this occupation may impact upon this study's comparability to other research. The hours of work, external activities and type of work task completed by the participants are atypical of many occupations. It is recommended that this study be extended in a more 'typical' office environment.

Environmental Monitoring

Collecting environmental data was important in isolating possible differences in the symptomatic responses of participants where other environmental conditions may have contributed (such as poor thermal conditions). In addition, this data played a critical role in corroborating participant's perception of the office spaces, their satisfaction with environmental conditions and the contribution of other factors. In this study, the environmental variables remained constant throughout the study, but in

offices where these variables vary, it is critical to consider these in the statistical analyses. Therefore, this information should be collected in all studies of this nature.

Medical Study

The medical study made a valuable contribution to our understanding of the role that medical conditions and other factors can play in symptom incidence and severity. The findings of this research warrant further study to give a body of research that will enable generalisation across a range of office spaces. The data collected in the medical study was probably far more thorough than warranted in studies that address the role of the environment or other variables in office design. However, collecting the medical history of participants can highlight medical conditions that may contribute to symptom incidence or severity.

6.6 The Contribution of this Study to Office Lighting Design, Management and Energy Use

The study results support the use of triphosphor fluorescent lamps over halophosphate fluorescent lamps in the workplace. Participants were shown to experience less severe eyestrain and lethargy when working under this lighting. Triphosphor fluorescent lamps are also recommended as they have better colour rendering, are more energy efficient, last longer and have lower depreciation than halophosphate fluorescent lamps. The study results do not show that high frequency electronic ballasts influenced the incidence or severity of symptoms experienced by participants. These ballasts are more energy efficient than magnetic ballasts and increase the life of the fluorescent lamps.

This study clearly demonstrates the relationship between staff satisfaction and symptoms experienced in the workplace. In addition, the results suggest that the symptoms experienced by occupants affected their actual productivity. Therefore,

this study presents a strong argument for providing a work environment that promotes high staff satisfaction.

The medical study suggested that symptoms experienced in the workplace could be significantly influenced by factors including medical conditions and external commitments. However, the work environment was shown to be a significant contributor to symptoms and one that the office management could control. While the results from the study show relatively small improvements in productivity, taken across an entire organisation over a length of time, these would be significant. In addition, the costs associated with changes to the office environment are negligible in comparison to the cost of wages, or replacement and training of staff that choose to leave their place of employment due to unsatisfactory conditions.

7 *Final Conclusions*

The primary aim of the study was to examine the relationship between flicker frequency and modulation depth in relation to the health, productivity and satisfaction of office personnel. The analyses specifically investigated the effect of the lighting treatments on:

- Symptom severity;
- Actual productivity;
- Perception of the effect of the work environment on productivity;
- Satisfaction with the lighting;
- Perception of flicker.

In addition, the relationship between these measures was explored.

Finally, the role of personal characteristics and environmental factors that may have influenced symptoms, productivity and satisfaction were examined.

The study did not show that increased flicker frequency or reduced modulation depth of fluorescent lighting decreased the incidence or severity of eyestrain, headache and lethargy symptoms. Nor did changes in flicker frequency or modulation depth influence participants' perceived or actual productivity or satisfaction with the work environment. Fluorescent light flicker was perceived infrequently and was not identified as detrimental to participants' health, satisfaction or well being. Overall, this study supports previous findings that suggest that low frequency flicker effects on task performance are limited to difficult visual tasks with minimal cognitive or motor components. Further, the study suggests that asthenopic symptoms may have a similar level of sensitivity.

The perceived productivity of the occupants was related to the symptoms they experienced and their satisfaction with the workplace. In addition, the results showed a small but significant relationship between actual productivity and symptoms in one of the offices studied.

The medical study identified a number of physiological characteristics that may have influenced lighting related symptoms. In particular, visual aberrations and high blood pressure were common. In addition, the additional hours that many participants worked are likely to have influenced symptoms.

This study provided some evidence to suggest that office personnel experience a lower incidence of lethargy symptoms and less severe eyestrain and lethargy symptoms in office spaces lit by energy efficient triphosphor fluorescent lamps instead of halophosphate fluorescent lamps.

One plausible explanation for the study outcome is the difference in spectral distribution between the fluorescent lamps. This effect may have been exacerbated by a small colour component in the work task and an equally small difference in luminance between the lighting conditions, resulting in increased symptom incidence in the low frequency halophosphate lighting treatment.

Given the small size of the effect found and the limitations of the study, these results should be considered as exploratory. The study raises a number of questions that should be explored in future research examining the effects of lighting on office personnel.

Glossary[107]

Actual Productivity describes the measurable and quantifiable work completed by an individual in the work environment. For example, the number of data units entered per hour.

Asthenopia or **Asthenopic symptoms** describes eyestrain, symptoms of eye fatigue or tiredness, including headaches arising from the use of the eyes.

Brightness see Luminance

Building Related Illness (BRI) is typically identified by a unique set of symptoms that have been confirmed by clinical signs or laboratory findings, and can be attributed to a specific causal factor in the workplace. It is generally limited to airborne contaminants or pollutants such as Legionnaires Disease or formaldehyde.

Chromatic Adaptation occurs as the colour channels within the eye respond to the chromaticity and luminance of a light source resulting in changes in the perceived sensation. This enables the eye to adapt to wide variations in colour on surfaces within a space. For example, a white wall lit by an incandescent bulb when compared to the same wall lit by daylight is identified as the same colour, despite significant differences in actual appearance.

Chromatic Variation the variation in wavelength between each discharge of a phosphor lined lamp due to the differing decay rates of the phosphors used in the lamp.

Colour Discrimination Index (CDI) describes the Gamut Area which is enclosed by the eight CIE test colours used in the CRI calculations (Boyce, 1977).

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[107] Glossary terms have been based upon those described in the IESNA Lighting Handbook - Reference and Application unless otherwise referenced.

Colour Rendering describes the effect that a light source has on the appearance of objects. Lamps with good colour rendering typically have high colour rendering indices with objects appearing 'natural' or resembling the appearance of the object under daylighting.

Colour Rendering Index (CRI) is a measure of the colour shift of an object illuminated by a test lamp in comparison to a reference source of comparable colour temperature. The most widely recognised and acceptable benchmark is natural daylight, and this is the reference illuminant for lamps with colour temperatures of greater than 5000 K. Lamps with colour temperatures below 5000 K use a colour temperature matched reference illuminant.

Contrast see Luminance Contrast.

Correlated Colour Temperature (CCT) describes the absolute temperature of a Plankian (black body) radiator whose chromaticity most nearly resembles that of the light source. CCT is defined in kelvin, with 'warm lamps' (CCT < 3500 K) emphasising the yellow/red section of the visible spectrum and having a greater proportion of their energy emitted in this range. 'Cool lamps' (CCT > 5000 K) emit more energy in the blue/violet range of the spectrum. 'Intermediate lamps' fall between the two.

Critical Fusion Frequency, Critical Flicker Frequency (CFF) or **Flicker Fusion Frequency** is the frequency at which a flickering or modulating light source is no longer perceptible as intermittent, and appears as a steady light. The CFF peaks at approximately 60 Hz with an upper limit of 80 Hz for human vision.

Discharge lamps include low pressure sources (fluorescent lamps and low pressure sodium lamps) and high pressure sources (metal halide, high pressure sodium and mercury lamps). In these lamps, an electrical discharge arcs between the electrodes within the lamp emitting light in the visible or ultraviolet spectrum. Phosphors are frequently used to alter the spectral emission from the lamp.

Electroencephalogram (EEG) an instrument recording the electrical activity of the brain (Allen, 1990).

Electroretinogram (ERG) an instrument recording the electrical activity of the retina.

Flicker Index is a measure of the cyclic variation in the output of a light source, taking into account the waveform of the light output. It is the ratio of the area under the light output curve that is above the average light output level, to the total area under the light output curve for a single cycle.

Flicker Frequency describes the rate of cyclic variation in output of a light source. In discharge lamps with magnetic or wire wound ballasts (low frequency operation), the lamps discharge is synchronous with the power supply, and at twice the frequency. Lamps controlled by electronic ballasts (high frequency operation) have a discharge frequency of between 20 kHz – 100 kHz.

Filament lamps include incandescent filament and tungsten halogen lamps that generate visible light via incandescence of the lamp filament by heating action.

Full Spectrum lamps are fluorescent lamps that typically feature cool colour temperatures (5000+ K), high colour rendering indices (90+) and some emission in the ultraviolet spectrum.

Glare the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted, resulting in annoyance, discomfort, or loss in visual performance and visibility.

Modulation (luminous variation) the modulation or modulation depth of the light source. It describes the change in luminous flux emitted from discharge or filament lamps due to cyclic variation in light output or voltage fluctuation.

$$C = \frac{(L_{max} - L_{min})}{(L_{max} + L_{min})}$$

where: C = modulation[108]

L_{max} = maximum luminance

L_{min}=minimum luminance

In filament lamps the modulation depth is between 2 and 22%. In discharge lamps the modulation depth is dependent upon the phosphors utilised in the lamps. Lamps without a phosphor lining have modulation rates of between 83-100%, whereas in lamps with a phosphor lining the modulation varies between 19-98% dependent upon the phosphors selected (Andersonn et al., 1994).

Halophosphate phosphors are fluorescent powders which when excited by ultraviolet light, photoluminescence, emitting light in the visible spectrum. There are a range of halophosphate phosphors, all of which have broad spectral emissions across much of the visible spectrum.

Halophosphate lamps are fluorescent lamps that are lined with a blend of several halophosphate phosphors. Halophosphate lamps can be created with a range of colour temperatures and colour rendering indices, but have largely been superseded by triphosphor lamps, which achieve higher colour rendering indices with much greater luminous efficacies.

Indoor Air Quality (IAQ) describes the quality of the indoor air, typically in the breathing zone of the occupants. Inadequate fresh air (litres/person/hour), poor air circulation within the space, contaminants from building materials, microbials or exterior air can all contribute to poor indoor air quality and can contribute to a variety of SBS symptoms in building occupants.

[108] Also known as contrast, or Michelson contrast, but usually and more properly called modulation.

Illuminance (E) describes the luminous flux density on a surface. The unit of measure is lux (lumen/metre^2).

Lamp Flicker variation in the luminous flux from the lamp under normal operation. This can be due to changes in the frequency at which the lamp discharges (flicker frequency), variation in the luminous output (modulation), uneven firing of the electrodes at either end of the lamp and variation in the colour of the light (chromatic modulation).

Luminance is the luminous intensity per unit projected area, measured in candela/metre^2. The term **Brightness** is an impression of the appearance of a light source or an illuminated surface, described in terms of its perceived relative luminosity. This sensation is determined in part by the definitely measurable luminance defined above and in part by conditions of observation such as the state of adaptation of the eye.

(Relative) Luminance Contrast the relationship between the luminance of an object and its immediate background. The following equation is commonly used to determine the luminance contrast for task visibility of tasks (such as printed text).

$$C = \left| \frac{(L_t - L_b)}{L_b} \right|$$

where: C = luminance contrast

L_t = luminance of the target

L_b = luminance of the background

Luminous Efficacy describes the quotient of the total luminous flux emitted in relation to the total lamp power input emitted from a lamp. It is expressed in lumen per watt and is a measure of the efficiency of the lamp output.

Mesopic Vision describes visual response as the brightness of a scene is increased above the scotopic visual range including increased foveal detection and colour appreciation (Coaton & Marsden, 1997).

Productivity describes the output of an organisation or individual. Measures of productivity can include: actual productivity, perceived productivity, absenteeism, staff turnover, and frequency or duration of work breaks.

Perceived Productivity describes the workers perception of their individual work output.

Photopic Vision vision mediated essentially or exclusively by the cones. It is generally associated with adaptation to a luminance of at least 3.4 cd/m^2.

(Relative) Spectral Luminous Efficiency (V(λ)) the relative spectral luminous efficiency of the eye under photopic conditions is described by the V(λ) curve.

Saccades high velocity involuntary rapid eye movements, usually generated to move the line of sight from one target to another. Eye movements during reading characterize a series of alternate fixations and saccades, along a row of print.

Scotopic Vision vision mediated essentially or exclusively by the rods. It is generally assoicated with adaptation to a luminance below about 0.034 cd/m^2.

Scotopic/photopic ratio the relationship between scotopic and photopic visual responses for a light source is calculated from the spectral distribution of the lamp and expressed as the ratio of the scotopic visual response over the photopic visual response.

Sick Building Syndrome (SBS) describes health symptoms that are experienced in the work environment, improving or disappearing outside of work hours and for which no one specific causal factor can be identified. Symptoms include sensory irritation of eyes, nose and throat, headache, lethargy, fatigue and skin symptoms.

Sick Building a building in which a high proportion of occupants (more than 30%) experience typical SBS symptoms (World Health Organisation, 1984).

Spectral Power Distribution (SPD) describes the emission of electromagnetic light in the visible spectrum. Aspects of spectral distribution for any given lamp source are generally described by the colour rendering index and the correlated colour temperature.

Steriadan (unit of solid angle) the solid angle subtended at the centre of a sphere by an area on the surface of the sphere equal to the square of the sphere radius.

Suprathreshold visual performance describes the visual performance of tasks that are above threshold levels.

Task Performance describes the actual performance of a research participant when undertaking a measurable, defined activity. In lighting research, a Landolt ring test is commonly used as it gives clear increments of visual difficulty.

Triphosphors are rare earth fluorescent powders which when excited by ultraviolet light, photoluminescence, emitting light in the visible spectrum. Triphosphors typically have narrow spectral emissions.

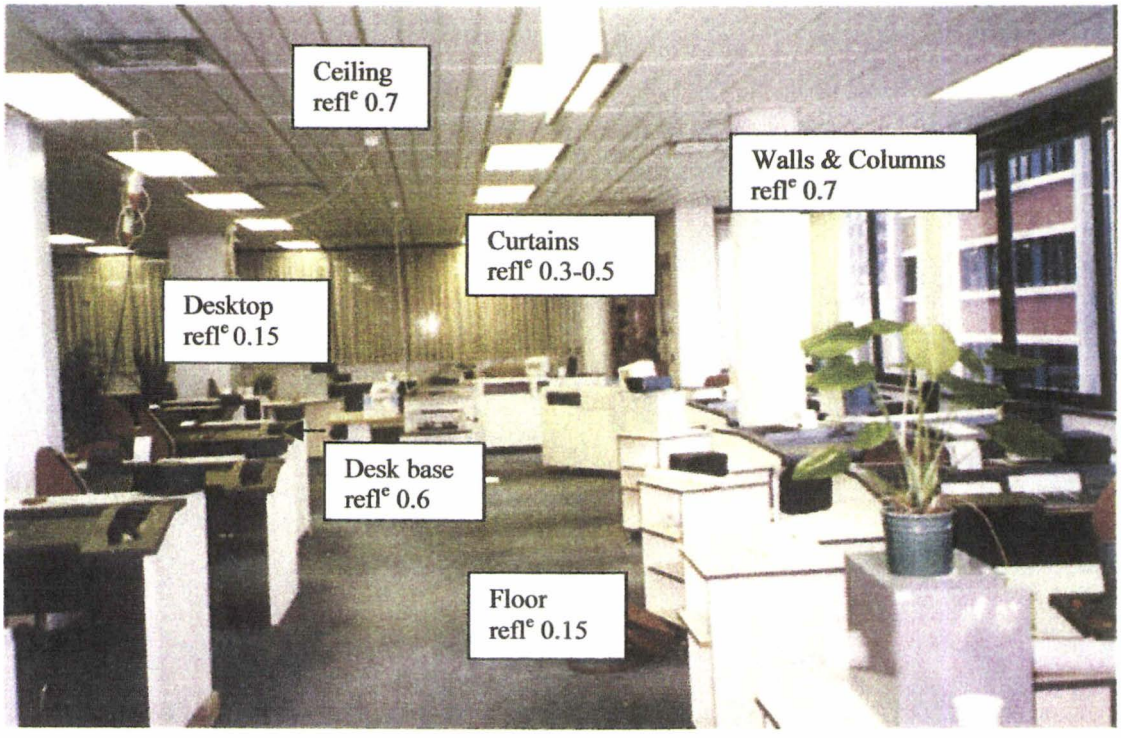
Triphosphor lamps are fluorescent lamps that typically contain three narrow band rare earth triphosphors with short, middle and long emission peaks that correspond to the spectral sensitivity of the short, middle and long wavelength cones in the eye. Triphosphor phosphors are much more efficient than halophosphate phosphors, but more expensive, therefore triphosphor lamps often have a thin halophosphate coating and less triphosphors to reduce the production costs. Triphosphor lamps can be created with a range of colour temperatures and colour rendering indices and typically have higher colour rendering indices and luminous efficacies when compared to halophosphate lamps.

Visual Clarity the concept of "visual clarity" has been used in several studies to indicate a preferred appearance of scenes containing coloured objects when illuminated by certain sources. '"Visual clarity" seems to be a combination of various factors included perceived colour and contrast, colour rendering, colour discrimination, colour preference and border sharpness, but is not a well understood notion.' (Rea, 2000).

Appendices

Appendix A: Office Photos

Figure 44. Office One



Refl[e]= Estimated Reflectance based on office visits and values in Offices Two and Three

Figure 45. Exterior Room, Office Two

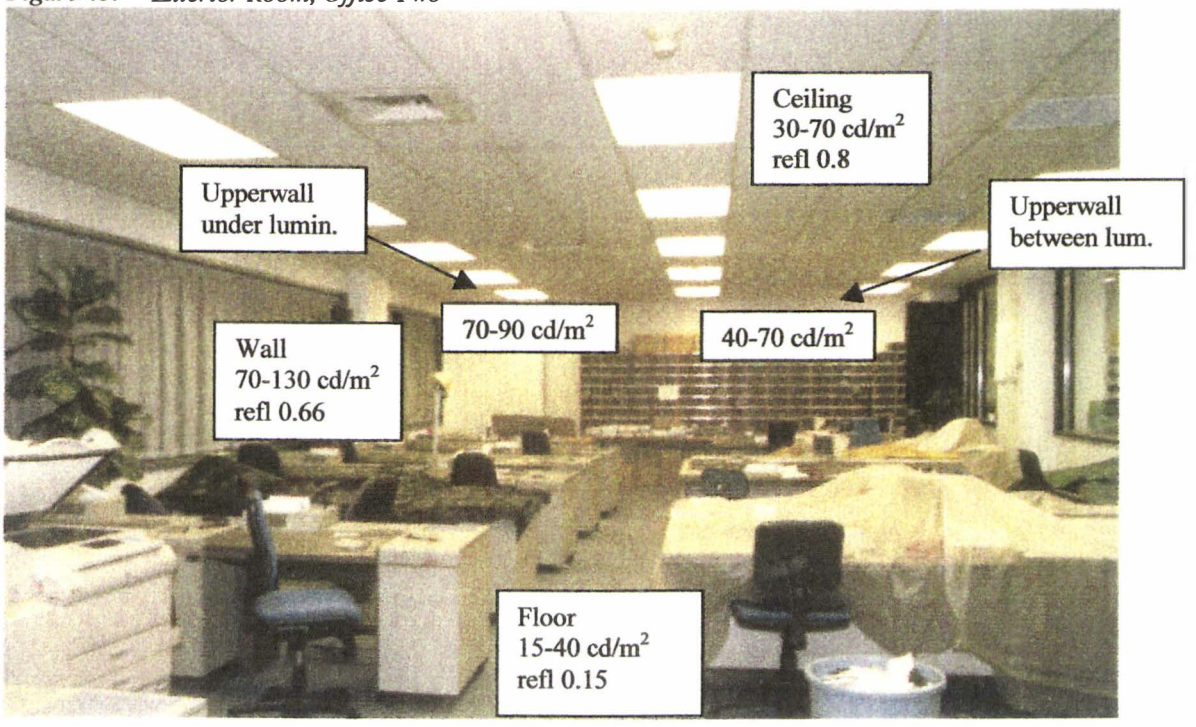


Figure 46. Interior Room, Office Two

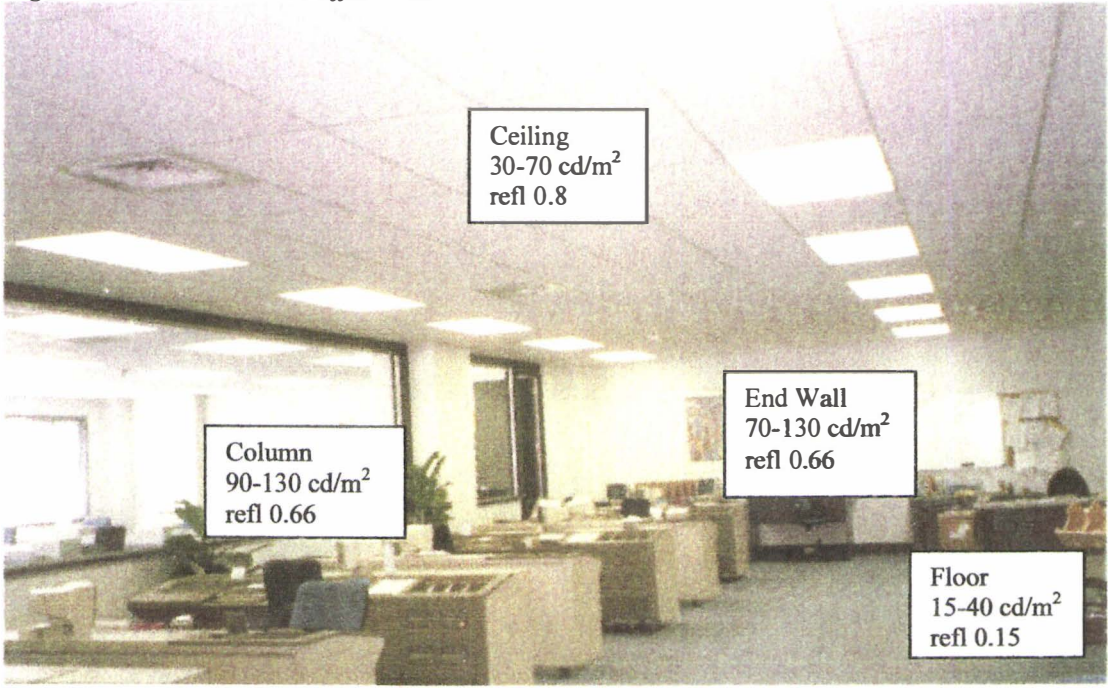


Figure 47. Room One, Office Three

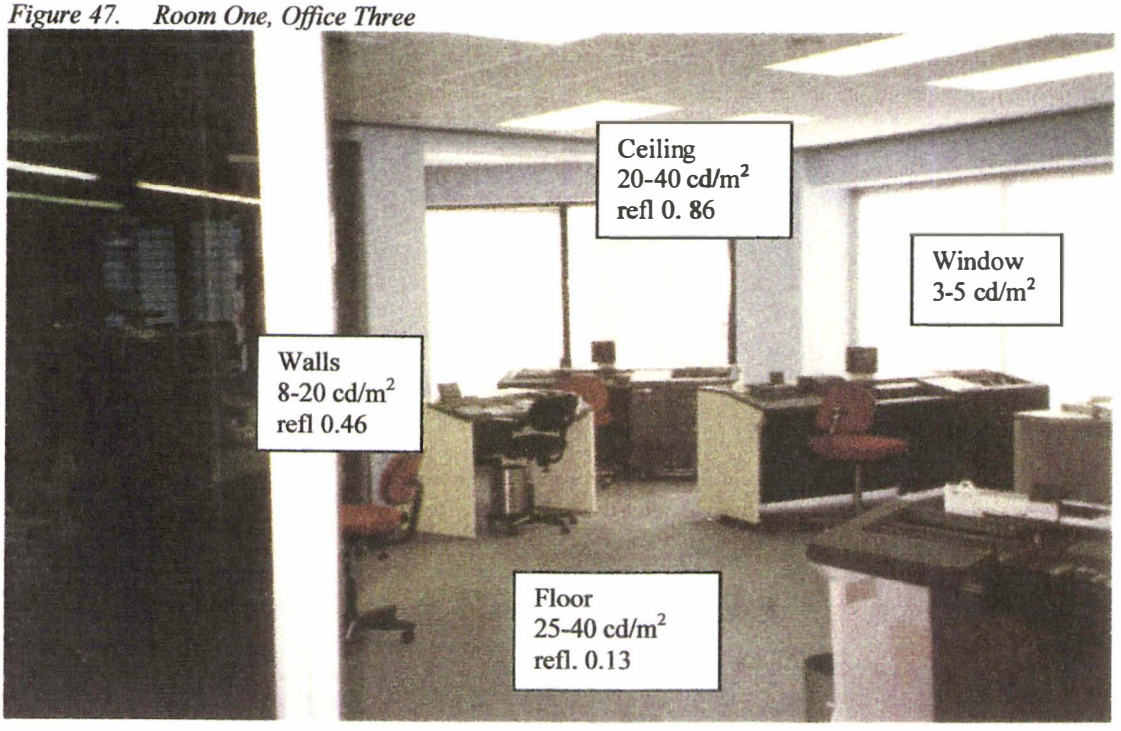


Figure 48. Room Three, Office Three

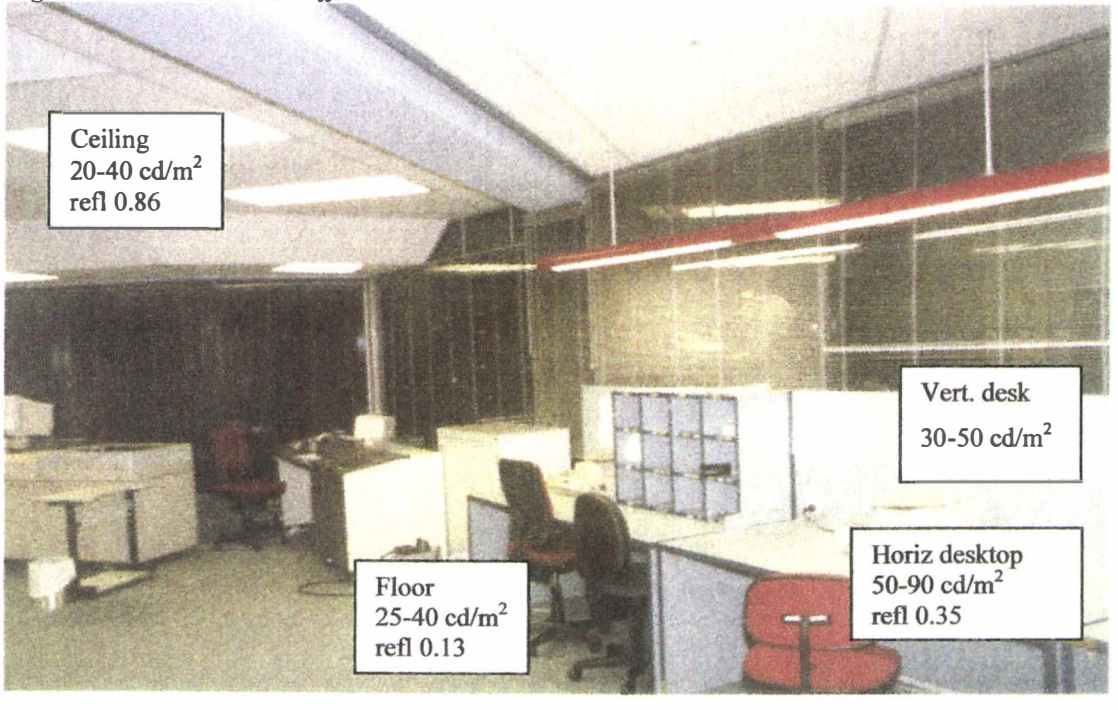


Figure 49. Beige machining desk, Office Two

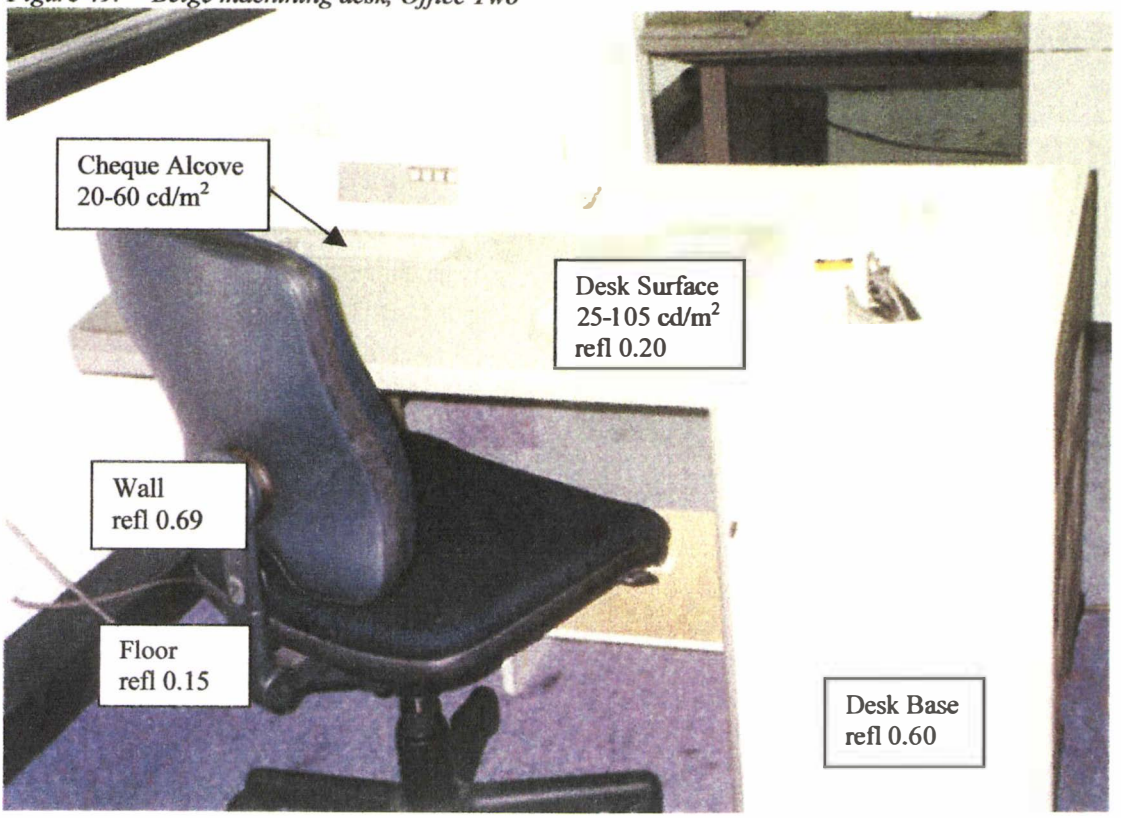


Figure 50. Dark grey machining desk, Office Three

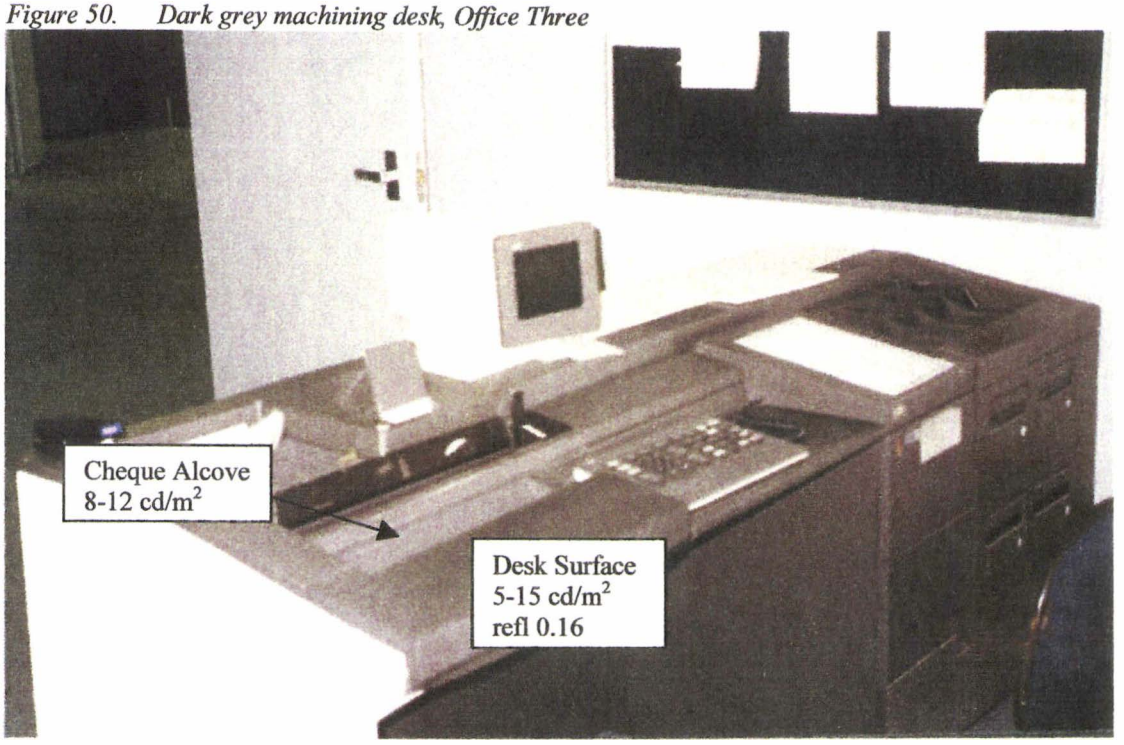


Figure 51. Operator using data entry machine

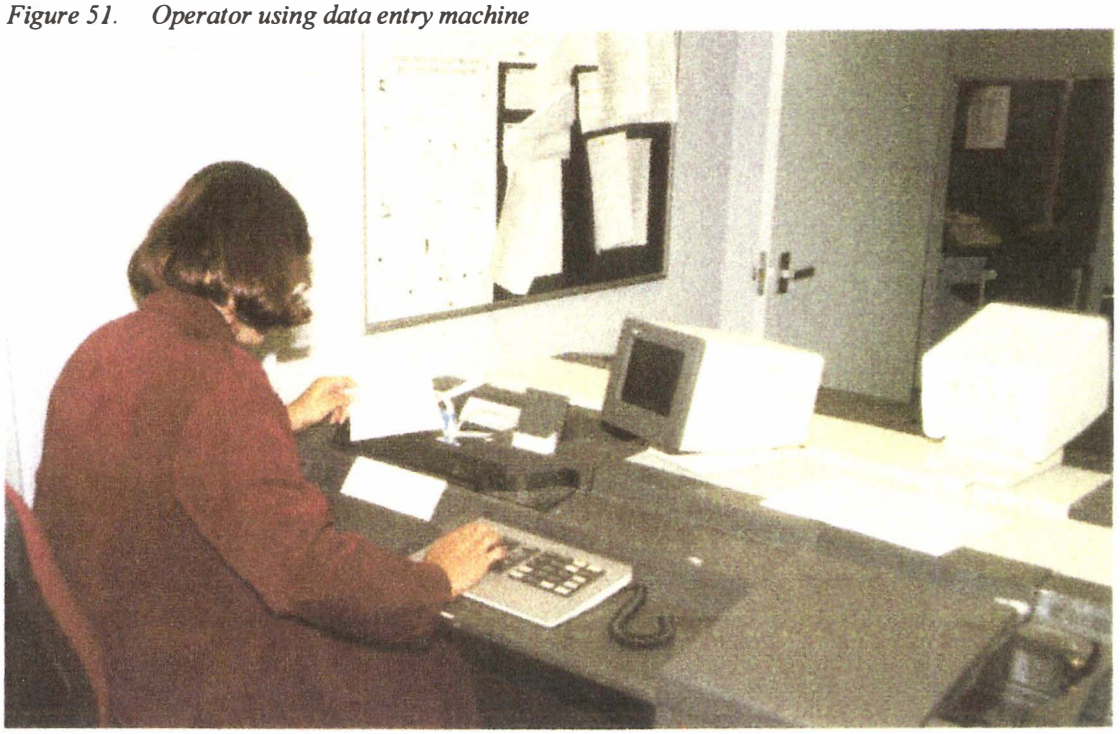
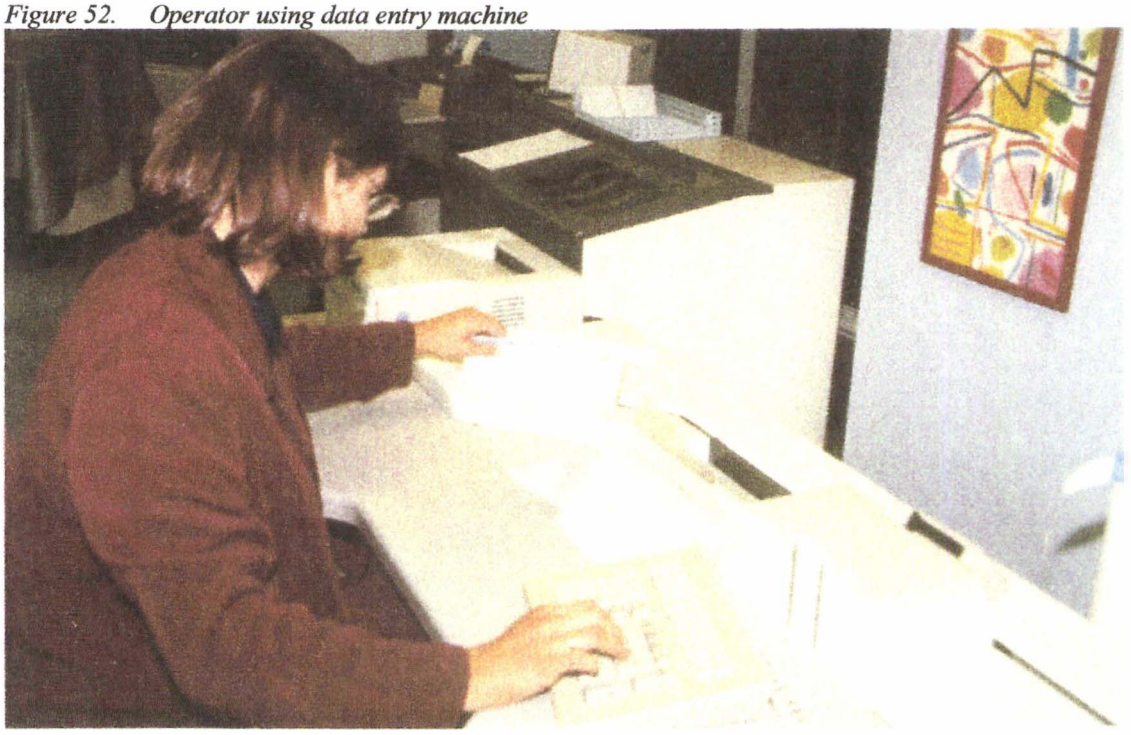


Figure 52. Operator using data entry machine



Appendix B: Lighting Layout and Office Plans

Figure 53. Lighting layout and office plan, Office One

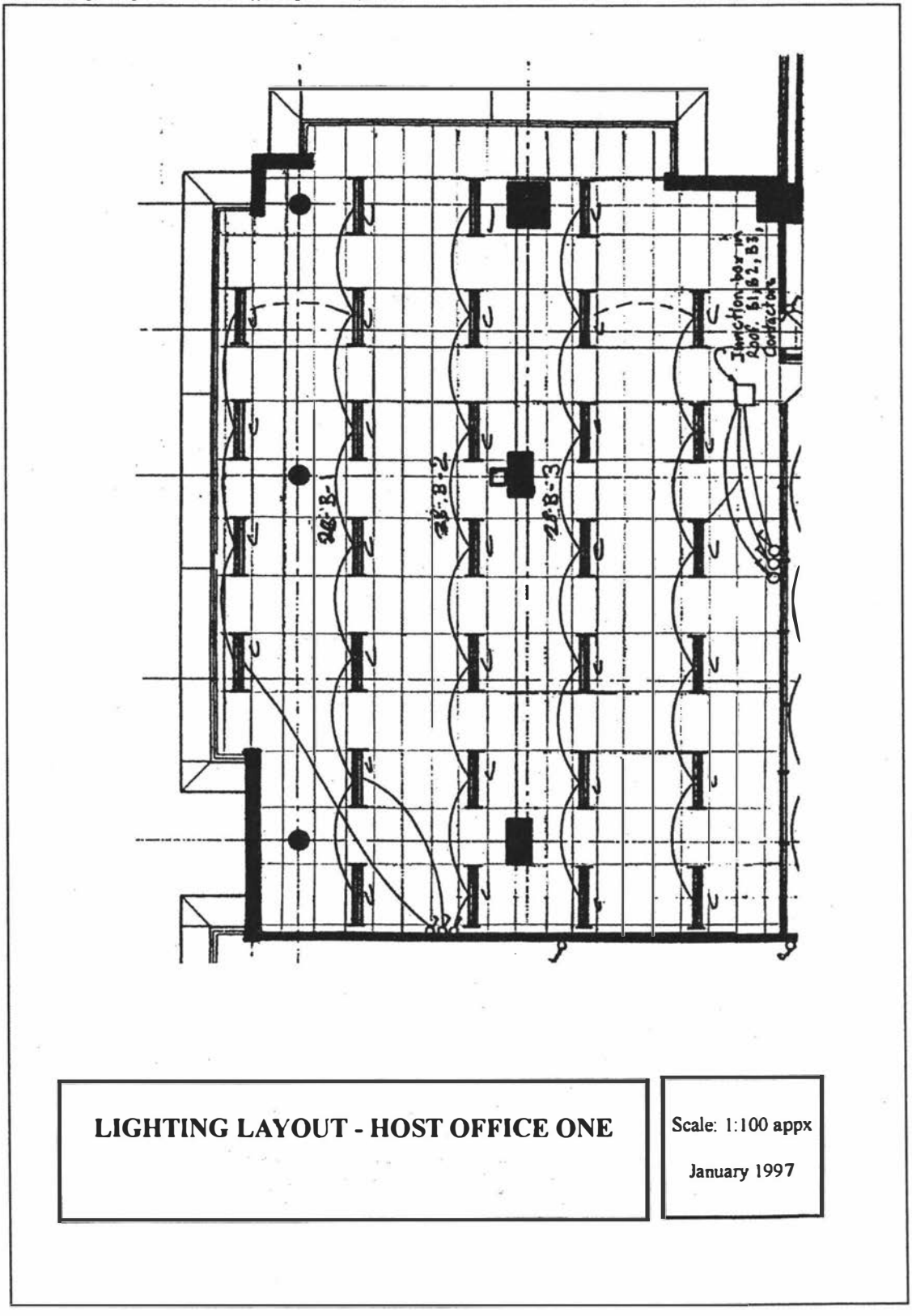


Figure 54. Lighting layout and office plan, Office Two

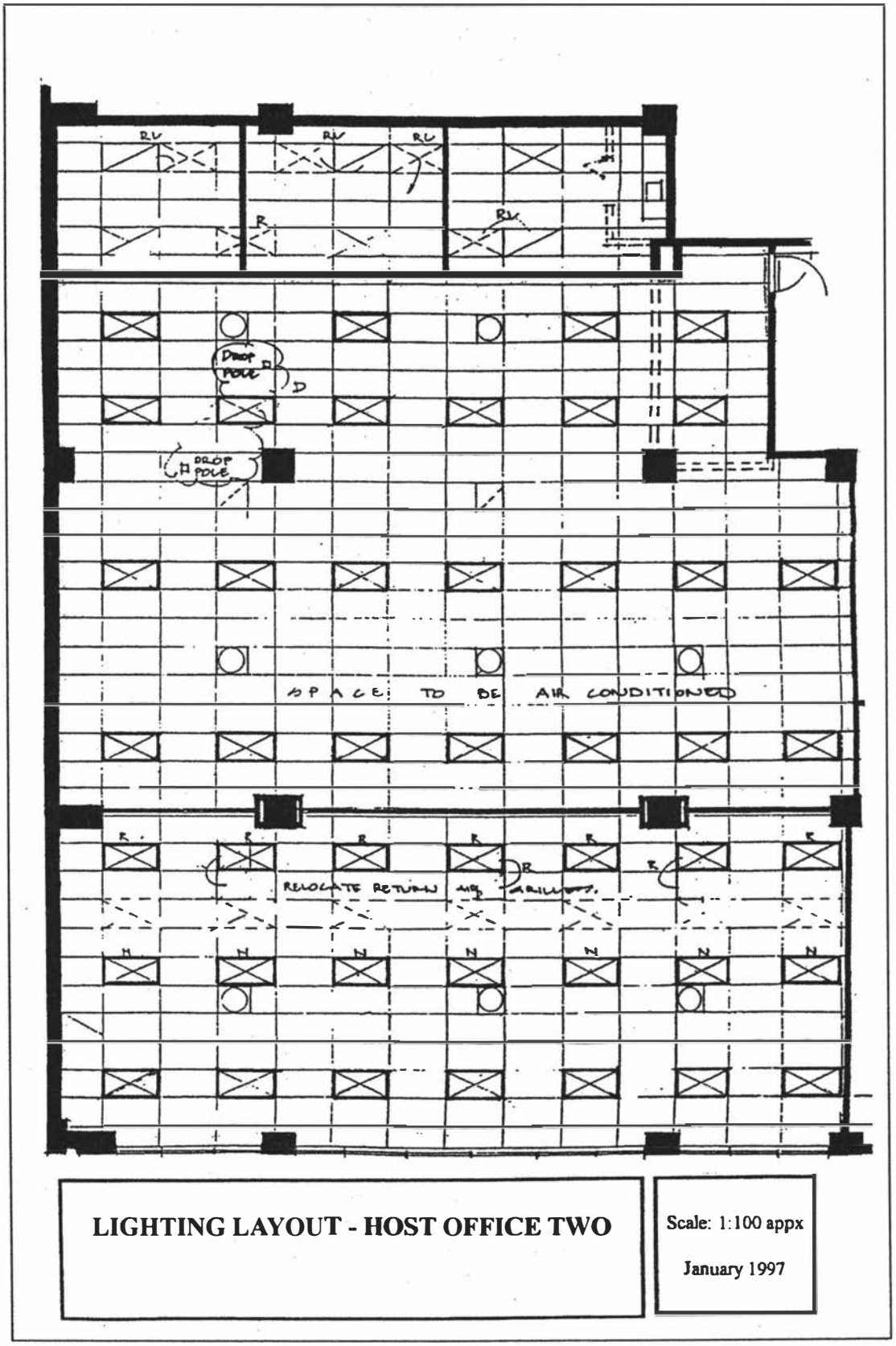
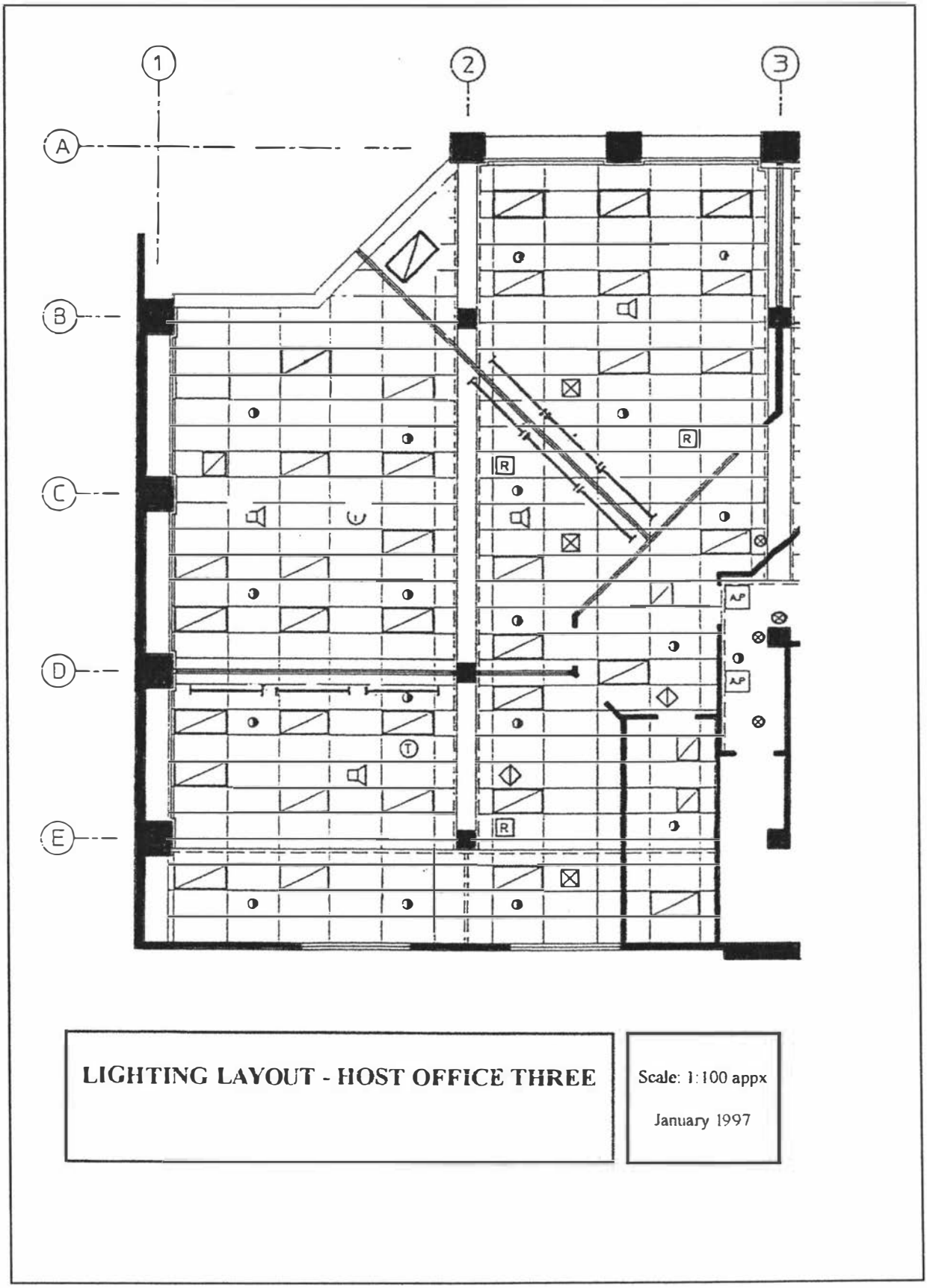


Figure 55. Lighting layout and office plan, Office Three



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Appendix C: Study Forms[88]

Pilot Study Information Sheet

MASSEY UNIVERSITY

Office Lighting Research

INFORMATION SHEET

This research study is part of a series of studies which are being used to identify aspects of fluorescent lighting which may affect the health of office workers. It is being conducted by Marie Fleming (Assistant Lecturer) as part of a Masterate thesis, and is supervised by Robyn Phipps (Lecturer) and Associate Professor Cliff Studman (Senior Lecturer). Your workplace has been selected because your work activities require a high level of visual concentration.

This research contributes towards isolating and remedying factors in buildings which cause discomfort to the occupants. It is one of series of studies conducted by the Building Technology Group at Massey University to improve office environments.

The study will involve filling out a short questionnaire on a daily basis for four weeks. The questionnaire is asking how you feel the lighting affects your health and productivity. A short section at the beginning asks for background information such as age, gender, etc. At the end of each week, the questionnaire will be placed in a box at your workplace, which will be cleared by the researchers. If you give your permission, the standard productivity measurement conducted by data entry operators, will be used as part of the analysis.

The material obtained from this research will be published as part of a masterate thesis, it may also contribute to presentations, conferences and publications in international scientific journals. The sponsors of this research will also receive a summary of the results. All raw information is completely confidential to the researchers, and will not be released to any other parties. It will not be possible to identify individual respondents or the office studied in reports or other publications resulting from this research.

[88] This Appendix includes formatting which differs from the thesis template. Therefore the layout, fonts and styles may differ from the body of this document.

You have the right to:

- decline to participate in this research;
- refuse to answer any particular questions and to withdraw from the study at any time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the findings of the study when it is concluded;
- agree to participate in the study under the conditions set out in this information sheet.

Thank you for your time.

A consent form will be distributed at your next shift.

If you have any queries please contact
Marie Fleming, Ph: (06) 350 4929 or Robyn Phipps, Ph: (06) 350 5107
Building Technology Group, Massey University

Pilot Study Information Sheet

KEEP FOR REFERENCE

MASSEY UNIVERSITY

Office Lighting Research

The questionnaire has three sections.

Section One – Background Information
Please fill out the Background Information Sheet on the first day you participate in the research. This section is asking for background information such as gender, length of time as a data entry operator, age, etc. You will only have to fill in this sheet once.

The number that is placed beside the Operator Number, is a code that is used to identify your individual responses while ensuring your confidentiality. This number is only known to you and to the researchers, and will not be used for any other purposes.

Section Two – Daily Health Symptoms
Please fill out the Daily Health Symptoms section at the end of your work shift. Do not fill out the days that you do not work on. This section is in two parts.

Part One: This part asks about the eye symptoms, headaches, and lethargy (tiredness) that you experienced throughout your shift. Please include all symptoms that you experienced as follows:

Eye Symptoms – include; sore eyes, blurred vision, tired eyes, stinging or dry eyes or other eye complaints;

Headaches – include dull, intense, localised (front of head, etc.), throbbing headaches and migraines or other forms of headache;

Lethargy – include lethargy or tiredness regardless of what you feel caused it i.e. include lethargy from late nights, hot weather, air conditioning, Mondayitis.

You do not need to list the type of symptom – just how severe or mild it feels to you.

Part Two: This part asks whether your symptoms disappeared after work, i.e. did the symptoms that you experienced at work disappear either immediately or gradually after work finished, or did they continue at the same or similar intensity throughout the rest of the day or evening.

Section Three – Lighting Quality and Productivity

Please fill out the Lighting Quality and Productivity section at the end of your working week, (i.e. at the end of the last shift you work on any particular week, regardless of what day it is). This section asks how you felt about the quality of the lighting in your workspace over the last week, i.e. the lighting was too bright or too dark, makes the room and people look pleasant, etc. The second part of this section asks whether you felt that these lighting conditions affected your productivity in the last week.

Please fill out the forms carefully and accurately. If you have any comments about the questionnaire, please use the form at the back of the questionnaire to write these down, or contact one of the researchers at the phone number at the bottom of the page.

All answers are strictly confidential

If you have any queries please contact
Marie Fleming, Ph: (06) 350 4929 or Robyn Phipps, Ph: (06) 350 5107
Building Technology Group, Massey University

Pilot Study Consent Form

MASSEY UNIVERSITY

Office Lighting Research

CONSENT FORM

I have read the information sheet, and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask the researchers any questions that arise at any time.

If I agree to participate, I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to fill out the questionnaire on the understanding that my name will not be used without my permission, and that individual respondents will not be able to be identified in any material arising from this research.

I agree/do not agree to participate in this study under the conditions set out in the Information Sheet. *(Please cross out one)*

I agree/do not agree to release my productivity measurements to the researchers on the understanding that they will remain confidential to only the researchers, and will not be released to any other parties. (*Please cross out one*)

Signed: .....

Name: .....

Date: .....

Pilot Study Questionnaire

SECTION A - BACKGROUND INFORMATION
(fill in on Day One)
Please fill in this sheet at the beginning of the research. Tick in the box provided or write on the dotted line.

1. Operator No: .....

2. How long have you been working as a data entry operator?

..... years ..... months

3. What is your gender? *tick one*

Male ☐
Female ☐

4. What was your age last birthday? ..... years

5. Are you?... *tick one*

a current tobacco smoker? ☐
a former smoker? ☐
never smoked? ☐

6. How long is it since you have last had your eyes tested by an Optometrist or other eyes specialist?...

never had them tested ☐
within the last two years ☐
more than two years ago ☐

7. Are you? *(you may tick as many squares as are appropriate)*

	yes	no	don't know
short sighted	☐	☐	☐
far sighted	☐	☐	☐

8. Do you wear?... *tick one*

- glasses (include glasses for reading or driving) ☐
- contact lenses ☐
- neither ☐

9. Have you been treated or are you being treated for any of the following? *(you may tick as many squares as are appropriate)*

	been treated	being treated	taking medicatn	
eye infections	☐	☐		☐
cataract	☐	☐		☐
glaucoma	☐	☐		☐
retinal problems	☐	☐		☐
migraine	☐	☐		☐
diabetes	☐	☐		☐
thyroid problems	☐	☐		☐
high blood pressure	☐	☐		☐
depression	☐	☐		☐
other (please specify)	_____			

10. Please indicate the medications you are currently taking (excluding birth control).

_____

_____

_____

SECTION B - DAILY HEALTH SYMPTOMS
(please fill in at the end of your shift)
This section is asking you whether you experienced any eye symptoms, headaches or lethargy on each day that you worked, and how severe you considered the symptoms to be. For each of the following questions circle the number (0 = no symptoms, 9 = very severe symptoms) that best describes the symptoms that you had. Do not fill in the days that you do not work

MONDAY 12.02.96 *(please refer to instruction sheet for more information if required)*
(Do not fill in if you didn't work on Monday)

HEALTH SYMPTOMS EXPERIENCED AT WORK - MONDAY

Work shift began at .....

Work shift ended at .....

		no symptoms									*very severe symptoms*
1.	Eye symptoms	0	1	2	3	4	5	6	7	8	9
2.	Headache symptoms	0	1	2	3	4	5	6	7	8	9
3.	Lethargy or tiredness	0	1	2	3	4	5	6	7	8	9

(End of questions for Monday)

.....

TUESDAY 13.02.96 *(please refer to instruction sheet for more information if required)*
(Do not fill in if you didn't work on Tuesday)
Thinking back to the last shift that you worked, did the eyestrain, headaches, or lethargy that you experienced the last time you were at work disappear after work.

		yes	no	n/a
1.	My eye symptoms went away after work	☐	☐	☐
2.	My headache symptoms went away after work	☐	☐	☐
3.	My lethargy or tiredness went away after work	☐	☐	☐

HEALTH SYMPTOMS EXPERIENCED AT WORK - TUESDAY

Work shift began at .....

Work shift ended at .....

		no symptoms									*very severe symptoms*
1.	Eye symptoms	0	1	2	3	4	5	6	7	8	9
2.	Headache symptoms	0	1	2	3	4	5	6	7	8	9
3.	Lethargy or tiredness	0	1	2	3	4	5	6	7	8	9

(End of questions for Tuesday)

.....

WEDNESDAY 14.02.96 *(please refer to instruction sheet for more information if required)*

(Do not fill in if you didn't work on Wednesday)

Thinking back to the last shift that you worked, did the eyestrain, headaches, or lethargy that you experienced the last time you were at work disappear after work.

		yes	no	n/a
1.	My eye symptoms went away after work	☐	☐	☐
2.	My headache symptoms went away after work	☐	☐	☐
3.	My lethargy or tiredness went away after work	☐	☐	☐

HEALTH SYMPTOMS EXPERIENCED AT WORK - WEDNESDAY

Work shift began at .....

Work shift ended at .....

		no symptoms									*very severe symptoms*
1.	Eye symptoms	0	1	2	3	4	5	6	7	8	9
2.	Headache symptoms	0	1	2	3	4	5	6	7	8	9
3.	Lethargy or tiredness	0	1	2	3	4	5	6	7	8	9

(End of questions for Wednesday)

.....

THURSDAY 15.02.96 *(please refer to instruction sheet for more information if required)*

(Do not fill in if you didn't work on Thursday)

Thinking back to the last shift that you worked, did the eyestrain, headaches, or lethargy that you experienced the last time you were at work disappear after work.

		yes	no	n/a
1.	My eye symptoms went away after work	☐	☐	☐
2.	My headache symptoms went away after work	☐	☐	☐
3.	My lethargy or tiredness went away after work	☐	☐	☐

HEALTH SYMPTOMS EXPERIENCED AT WORK - THURSDAY

Work shift began at .....

Work shift ended at .....

		no symptoms									*very severe symptoms*
1.	Eye symptoms	0	1	2	3	4	5	6	7	8	9
2.	Headache symptoms	0	1	2	3	4	5	6	7	8	9
3.	Lethargy or tiredness	0	1	2	3	4	5	6	7	8	9

(End of questions for Thursday)

.....

FRIDAY 16.02.96 *(please refer to instruction sheet for more information if required)*

(Do not fill in if you didn't work on Friday)

Thinking back to the last shift that you worked, did the eyestrain, headaches, or lethargy that you experienced the last time you were at work disappear after work.

		yes	no	n/a
1.	My eye symptoms went away after work	☐	☐	☐
2.	My headache symptoms went away after work	☐	☐	☐
3.	My lethargy or tiredness went away after work	☐	☐	☐

HEALTH SYMPTOMS EXPERIENCED AT WORK - FRIDAY

Work shift began at .....

Work shift ended at .....

		no symptoms									*very severe symptoms*
1.	Eye symptoms	0	1	2	3	4	5	6	7	8	9
2.	Headache symptoms	0	1	2	3	4	5	6	7	8	9
3.	Lethargy or tiredness	0	1	2	3	4	5	6	7	8	9

(End of questions for Friday)[89]

.....

[89] The pilot study questionnaire included as part of this thesis was the first week of the pilot study. Subsequent weeks did not include Section A: Background Information, and began by asking participants to recall if symptoms experienced on Friday disappeared after the work shift had concluded, as shown above for Monday to Thursday.

SECTION C - LIGHTING QUALITY AND PRODUCTIVITY

(fill in at the end of the last shift that you work in the week)

The following questions are asking how you felt about the quality of the lighting in your workspace over the last week and whether you felt that these lighting conditions affected your work in the last week. *(please refer to instruction sheet for more information if required)*

1. Light Quality

Circle the number that describes the satisfaction that you have with the lighting in your office space. (0 = very dissatisfied, 5 = indifferent, 9 = very satisfied)

very dissatisfied				*indifferent*					*very satisfied*
0	1	2	3	4	5	6	7	8	9

What aspects of the lighting did you like or dislike in the last week?

.....

.....

.....

2. Lighting and Productivity

Circle the number that best describes the impact that you feel that lighting conditions had on your productivity in the last week. (0=very negative impact, 5=no impact, 9=very positive impact).

very negative impact				*no impact*					*very positive impact*	
0	1	2	3	4	5	6	7	8	9	don't know ☐

3. Flicker

In the last week have you seen flicker from fluorescent tubes while at your workstation? yes ☐ no ☐

4. Flicker and Productivity

Circle the number below that best describes the impact that flicker from fluorescent tubes has had on your productivity. (0 = very negative impact, 5 = no impact, 9 = very positive impact).

very negative impact				*no impact*					*very positive impact*	
0	1	2	3	4	5	6	7	8	9	don't know ☐

MASSEY UNIVERSITY

Office Lighting Research

COMMENTS SHEET

Please put any positive or negative comments that you have about the questionnaire on this sheet, i.e. it was too long, it was easy to understand and fill out, it did not ask questions that you think are important, etc. Please give as much detail as possible.

Thank you for completing this questionnaire.

Please return the completed questionnaire in the envelope provided

Main Study Information Sheet

MASSEY UNIVERSITY

Office Environment Research

INFORMATION SHEET

Who are we & why are we here?

Our proposed study is part of a series of studies on the design of commercial offices. This particular research study looks at environmental conditions which may affect office workers health. It is being conducted by Marie Fleming, as part of a Doctorate thesis, and is being supervised by Dr Cliff Studman and Robyn Phipps. Marie, Robyn, and Cliff are part of the Building Technology Research Group at Massey University, who conduct research into factors in the work environment which affect the health and well being of office personnel. This research is sponsored by the Health Research Council of New Zealand (HRC), Energy Management Limited and Massey University.

Why me?

Your workplace has been selected because your work activities require a high level of visual concentration, and therefore good environmental conditions are important for you to carry out your day to day tasks.

What do I have to do?

If you choose to participate in this study, you will be asked to fill out a very short questionnaire on the days which you work for four months. The questionnaire asks how you feel about your work environment. A short section at the beginning of the survey asks for background information such as age, gender etc. At the end of every week, the questionnaire will either be collected by us, or mailed directly to Massey University. A sample questionnaire is appended for your information.

If you give your permission, your productivity measurements will also be used as part of the analysis. This will be given to us, in confidence by your office supervisor, and will only be used for the purposes of the research. You may choose to fill out the questionnaire, but not release your productivity measurements.

What happens to the results?

The material obtained from this research will contribute to a doctorate thesis. It may also be published or presented at conferences or seminars, and publications in industry and scientific journals.

The sponsors of this research will also receive a summary of the results. All original information is confidential to the researchers, however the anonymous material may be used for related research. Confidentiality of your responses, and the office that you work in, will be maintained at all times.

What changes will be made to the workplace?

Minor changes will be made to environmental conditions in your workplace throughout the study period. You probably won't notice any changes. All of the changes will be made using standard, commercially available fixtures and fittings, which are commonly used in offices throughout New Zealand, and are at levels which meet all the occupational health and safety guidelines.

Why is this research important?

This research will contribute to improving your own workplace, and the work environment of other people throughout New Zealand. It may also be used to change the New Zealand standards for commercial offices, and to promote fixtures and fittings which have been demonstrated to improve the comfort of office workers.

This research is important to help identify what aspects of the office environment cause symptoms such as headaches, eyestrain and tiredness.

What are my rights?

You have the right to:

- Agree to participate in the study under the conditions set out in this information sheet;
- Ask questions about the study at any time during participation;
- Provide information on the understanding that your name will not be used unless you give permission to the researcher;
- Request a summary of the findings of the study when it is concluded;
- Refuse to answer any particular questions and to withdraw from the study at any time;
- Decline to participate in this research.

If you have any queries please contact
Marie Fleming Ph: (06) 350-4929, Robyn Phipps Ph: (06) 350-5107, or
Cliff Studman Ph: (06) 350-5105
Building Technology Research Group, Massey University.

Main Study Consent Form

MASSEY UNIVERSITY

Office Environment Research

CONSENT FORM

I have read the information sheet, and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask the researchers questions at any time.

I understand that any alterations to environmental conditions in this office will involve commercially available fixtures and fittings which are commonly used in offices throughout New Zealand, and are at levels which meet all the occupational health and safety guidelines.

I understand that if I agree to participate, I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to fill out the questionnaire on the understanding that my name will not be used without my permission, and that individual respondents will not be able to be identified in any material arising from this research. This information will be used only for research purposes.

I agree/do not agree to participate in this study under the conditions set out in the Information Sheet. *(please cross out one)*

I agree/do not agree to my productivity measurements being released to the researchers. *(please cross out one)*

Signed:

.....

Name:

.....

(please print)

Date:

.....

Main Study Questionnaire - Demographic Information

SECTION A - BACKGROUND INFORMATION
(fill in on Day One)
Please fill in this sheet at the beginning of the research. Tick in the box provided or write on the dotted line.

1. Name / Operator No: .....

2. How long have you been working as a data entry operator?

..... years ..... months

3. What is your gender? *tick one*

Male ☐
Female ☐

4. What was your age last birthday? ..... years

5. Are you?... *tick one*

a current tobacco smoker? ☐
a former smoker? ☐
never smoked? ☐

6. How long is it since you have last had your eyes tested by an Optometrist or other eye specialist?...

tick one

never had them tested ☐
within the last two years ☐
more than two years ago ☐

7. Do you wear?... *tick all that apply*

glasses ☐*Go to Q. 8*
(including glasses for reading or driving)
contact lenses ☐*Go to Q. 8*
neither ☐*Go to Q.9*

8. Are you?
(you may tick as many squares as are appropriate)

	yes	no	don't know
short sighted	☐	☐	☐
long sighted	☐	☐	☐

9. Have you experienced any of the following conditions in the past two years?
(you may tick as many squares as are appropriate)

	yes	no
eye infections	☐	☐
cataract	☐	☐
glaucoma	☐	☐
retinal problems	☐	☐
migraine	☐	☐
diabetes	☐	☐
thyroid problems	☐	☐
high blood pressure	☐	☐
depression	☐	☐

10. If you answered yes to any of the questions above, please indicate whether you are currently being treated and/or if you are taking medication for the condition?

	being treated	taking medication
eye infections	☐	☐
cataract	☐	☐
glaucoma	☐	☐
retinal problems	☐	☐
migraine	☐	☐
diabetes	☐	☐
thyroid problems	☐	☐
high blood pressure	☐	☐
depression	☐	☐

11. Please indicate the medications you are currently taking (excluding birth control)?

_____

_____

12. How would you rate your overall job satisfaction?

very dissatisfied			*neither satisfied or dissatisfied*			*very satisfied*
-3	-2	-1	0	1	2	3

13. How much control do you feel you have over your work routine?

very little			*some*			*a lot*
-3	-2	-1	0	1	2	3

12. How would you rate your overall satisfaction with your office environment?

very dissatisfied			*neither satisfied or dissatisfied*			*very satisfied*
-3	-2	-1	0	1	2	3

SECTION B - Complete survey only for days worked

Part 1. Fill out this section at the end of your work shift. This section is asking you whether you experienced any eye symptoms, headache or lethargy on each day that you worked, and how severe you considered the symptoms to be. For each of the following questions circle the number (1 = no symptoms, - 7 = very severe symptoms) that best described the symptoms that you experienced.

Part 2. Fill out this section at the beginning of your next shift. This section asks you whether or not the symptoms that you experienced on the previous shift stayed the same, reduced or disappeared after you finished work for the day.

1. Operator No: .....

		PART 1 (symptoms experienced during shift)							PART 2 (symptoms continuing after shift)				
Date		no symptoms						very severe symptoms	Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Monday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
MTS ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Typing ☐ Other ☐													
Tuesday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
MTS ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Typing ☐ Other ☐													

Date		no symptoms						very severe symptoms	Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Wednesday Machining ☐ MTS ☐ Typing ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Thursday Machining ☐ MTS ☐ Typing ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Friday Machining ☐ MTS ☐ Typing ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐

SECTION C

(fill in at the end of the last shift that you work in the week)

The following questions are asking how you felt about the quality of your working environment in your workspace over the last week and whether you felt that these conditions affected your work in the last week.

1. How would you rate your overall job satisfaction this week?

very dissatisfied			*neither satisfied or dissatisfied*			*very satisfied*	
-3	-2	-1	0	1	2	3	☐ don't know

Circle the number that best describes how satisfied you have been with the following aspects of your work environment in the last week? (-3 = very dissatisfied, 0 = indifferent, 3 = very satisfied)							
	very dissatisfied			*indifferent*			*very satisfied*
Amount of fresh air and/or air circulation	-3	-2	-1	0	1	2	3
Temperature	-3	-2	-1	0	1	2	3
Lighting	-3	-2	-1	0	1	2	3
Overall work environment	-3	-2	-1	0	1	2	3

Please explain what aspects of the work environment you either liked or disliked in the last week?

.....

.....

.....

2. Circle the number that best describes the impact that you feel that the working environment had on your productivity in the last week. (-3= significantly decreased productivity, 0=no impact on productivity, 3=significantly increased productivity).

significantly decreased productivity			*no impact on productivity*			*significantly increased productivity*	
-3	-2	-1	0	1	2	3	☐ don't know

In the last week have you seen flicker from fluorescent tubes while at your workstation?

yes ☐ no ☐

Main Questionnaire - Office Two

SECTION B - Complete survey only for days worked

Part 1. Fill out this section at the end of your work shift. This section is asking you whether you experienced any eye symptoms, headache or lethargy on each day that you worked, and how severe you considered the symptoms to be. For each of the following questions circle the number (1 = no symptoms, - 7 = very severe symptoms) that best described the symptoms that you experienced.

Part 2. Fill out this section at the beginning of your next shift. This section asks you whether or not the symptoms that you experienced on the previous shift stayed the same, reduced or disappeared after you finished work for the day.

1. Operator No: .....

		PART 1 (symptoms experienced during shift)							**PART 2 (symptoms continuing after shift)**				
Date		no symptoms						very severe symptoms	Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Monday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Inside Room ☐													
Outside Room ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐ Other ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Tuesday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Inside Room ☐													
Outside Room ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐ Other ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐

		no symptoms					very severe symptoms		Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Wednesday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Inside Room ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Outside Room ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐ Other ☐													
Thursday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Inside Room ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Outside Room ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐ Other ☐													
Friday	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Inside Room ☐	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Outside Room ☐	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Machining ☐ Other ☐													

SECTION C

(fill in at the end of the last shift that you work in the week)

The following questions are asking how you felt about the quality of your working environment in your workspace over the last week and whether you felt that these conditions affected your work in the last week.

1. How would you rate your overall job satisfaction this week?

very dissatisfied			*neither satisfied or dissatisfied*			*very satisfied*	
-3	-2	-1	0	1	2	3	☐ don't know

Circle the number that best describes how satisfied you have been with the following aspects of your work environment in the last week? (-3 = very dissatisfied, 0 = indifferent, 3 = very satisfied)							
	very dissatisfied			*indifferent*			*very satisfied*
Amount of fresh air and/or air circulation	-3	-2	-1	0	1	2	3
Temperature	-3	-2	-1	0	1	2	3
Lighting	-3	-2	-1	0	1	2	3
Overall work environment	-3	-2	-1	0	1	2	3

Please explain what aspects of the work environment you either liked or disliked in the last week?

.....

.....

.....

2. Circle the number that best describes the impact that you feel that the working environment had on your productivity in the last week. (-3= significantly decreased productivity, 0=no impact on productivity, 3=significantly increased productivity).

significantly decreased productivity			*no impact on productivity*			*significantly increased productivity*	
-3	-2	-1	0	1	2	3	☐ don't know

3. In the last week have you seen flicker from fluorescent tubes while at your workstation? yes ☐ no ☐

SECTION B - Complete survey only for days worked

Part 1. Fill out this section at the end of your work shift. This section is asking you whether you experienced any eye symptoms, headache or lethargy on each day that you worked, and how severe you considered the symptoms to be. For each of the following questions circle the number (1 = no symptoms, - 7 = very severe symptoms) that best described the symptoms that you experienced.

Part 2. Fill out this section at the beginning of your next shift. This section asks you whether or not the symptoms that you experienced on the previous shift stayed the same, reduced or disappeared after you finished work for the day.

1. Operator No: .....

		PART 1 (symptoms experienced during shift)							PART 2 (symptoms continuing after shift)				
Date			no symptoms					very severe symptoms	Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Monday		1. Eye symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐
Red Room	☐												
White Room	☐	2. Headache symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐
Blue Room	☐ Other ☐												
		3. Lethargy symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐
Tuesday		1. Eye symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐
Red Room	☐												
White Room	☐	2. Headache symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐
Blue Room	☐ Other ☐												
		3. Lethargy symptoms	1	2	3	4	5	6 7	☐	☐	☐	☐	☐

		no symptoms						very severe symptoms	Symptoms Remain	symptoms reduce	symptoms disappear	took medication	can't remember
Wednesday Red Room ☐ White Room ☐ Blue Room ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Thursday Red Room ☐ White Room ☐ Blue Room ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
Friday Red Room ☐ White Room ☐ Blue Room ☐ Other ☐	1. Eye symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	2. Headache symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐
	3. Lethargy symptoms	1	2	3	4	5	6	7	☐	☐	☐	☐	☐

SECTION C

(fill in at the end of the last shift that you work in the week)

The following questions are asking how you felt about the quality of your working environment in your workspace over the last week and whether you felt that these conditions affected your work in the last week.

1. How would you rate your overall job satisfaction this week?

very dissatisfied			*neither satisfied or dissatisfied*			*very satisfied*	
-3	-2	-1	0	1	2	3	☐ don't know

Circle the number that best describes how satisfied you have been with the following aspects of your work environment in the last week? (-3 = very dissatisfied, 0 = indifferent, 3 = very satisfied)

	very dissatisfied			*indifferent*			*very satisfied*
Amount of fresh air and/or air circulation	-3	-2	-1	0	1	2	3
Temperature	-3	-2	-1	0	1	2	3
Lighting	-3	-2	-1	0	1	2	3
Overall work environment	-3	-2	-1	0	1	2	3

Please explain what aspects of the work environment you either liked or disliked in the last week?

.....

.....

.....

2. Circle the number that best describes the impact that you feel that the working environment had on your productivity in the last week. (-3= significantly decreased productivity, 0=no impact on productivity, 3=significantly increased productivity).

significantly decreased productivity			*no impact on productivity*			*significantly increased productivity*	
-3	-2	-1	0	1	2	3	☐ don't know

3. In the last week have you seen flicker from fluorescent tubes while at your workstation? yes ☐ no ☐

Work Habits Questionnaire

Office Environment Research - Questionnaire

Operator Number/Name .....

1. Please indicate which of the following best describes you. You may tick as many boxes as are appropriate.

This is my only paid employment	☐
I have another full time job	☐
I have another part time job	☐
I am a full time student	☐
I am a part time student	☐
I am a homemaker/caregiver with children	☐
I am a homemaker without children	☐
Other	

2. Please indicate how many hours you would normally work per week at the Proof Centre?

1 - 10	☐
10 - 15	☐
15 - 20	☐
20 - 25	☐
25 - 30	☐
30 - 35	☐
35 - 40	☐
More than 40	☐

3. Please indicate how many shifts a week you would usually work?

1 or 2	☐
2 or 3	☐
3 or 4	☐
4 or 5	☐

Interview Sheet – Medical Interview

Dessert & Coffee for Two
at
Strawberry Fare Dessert Restaurant

Dear .....

As you may have heard there is a Part Two to the Lighting Study, and for this one you don't have to fill out a questionnaire for 18 weeks!

Part two of the study looks at factors outside the workplace that may be contributing to symptoms such as headache and eyestrain in the workplace. For example, headaches experienced at work could may be due to back or spine misalignment.

Regardless of whether you experience headaches, eyestrain or lethargy while at work, we would welcome your participation in this study. It is independent of your workplace and anonymity and confidentiality of your responses will be maintained at all times.

The study takes less than an hour, and will be conducted on three different days (6th, 9th and 11th of December), you can choose any hour on any one of these days that suits you. The study has two parts; a short questionnaire and a medical consultation. The consultation includes a brief physical examination. This is discussed in more detail on the attached information sheet.

In compensation for your time and effort, you will receive a voucher for Dessert & Coffee for two at the Strawberry Fare Dessert Restaurant. We thought that this would be a nice way to say thank you, and it will make a lovely Christmas treat or gift.

If you decide to participate, please fill in the enclosed consent form by placing your name and contact details on the front page and the times that you are available for the interview on the second page. Post the consent form in the Freepost envelope included. **For more details, read the information sheet and consent form attached. Only ten people from your office can take part, so please return your form as soon as possible.**

Kindest regards

Marie Fleming
Building Technology Research Group

Consent Form – Medical Study

MASSEY UNIVERSITY

Office Environment Research

Part Two - Medical Interview

CONSENT FORM

I have read the information sheet, and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask the researchers questions at any time.

If I agree to participate, I have the right to withdraw from the study at any time, to decline to answer any particular questions & decline to participate in any aspect of the study.

I agree to participate in this study on the understanding that my name will not be used in any material arising from this study, and that individual respondents will not be able to be identified in any material arising from this research.

I understand that this information will be used only for research purposes, and raw data will either be destroyed or returned to me at the conclusion of the study.

I agree/do not agree *(please cross out one)* **to participate in this study under the conditions set out in the Information Sheet.**

Signed:.....

Name: .....

Date: .....

Contact Phone Number : Daytime .....
(to confirm medical interview time)
Evenings .....

Medical Interview - Interview Times

Please indicate on the sheet below the times that you are available for the interview. If you have a preference for a particular time, please indicate when this is, and we will endeavor to have your interview then. We will call you to confirm your exact interview time. The interview will take place at Dr Whiteside's medical practice at The Kelvin Chambers, 44 The Terrace, in central Wellington, and should take less than an hour.

.....

Time	**When I am available**
Saturday 6th December	
9.00	
10.00	
11.00	
12.00	
1.00	
2.00	
3.00	
4.00	
5.00	
Tuesday 9th December	
9.00	
10.00	
11.00	
12.00	
1.00	
2.00	
3.00	
4.00	
5.00	
Thursday 11th December	
9.00	
10.00	
11.00	
12.00	
1.00	
2.00	
3.00	
4.00	
5.00	

Questionnaire – Medical Interview

CONFIDENTIAL QUESTIONNAIRE

SECTION A - BACKGROUND INFORMATION

1. Name: .....

2. What is your gender? *tick one*
   - Male ☐
   - Female ☐

3. What was your age last birthday? ..... years

4. Please indicate which of the following best describes you. You may tick as many boxes as are appropriate.
   - This is my only paid employment ☐
   - I have another full time job ☐
   - I have another part time job ☐
   - I am a full time student ☐
   - I am a part time student ☐
   - I am a homemaker/caregiver with children ☐
   - I am a homemaker without children ☐

5. Are you?... *tick one*
   - a current tobacco smoker? ☐
   - a former smoker? ☐
   - never smoked? ☐

6. How long is it since you have last had your eyes tested by an Optometrist or other eye specialist?... *tick one*
   - never had them tested ☐
   - within the last two years ☐
   - more than two years ago ☐

7. Do you wear?... *tick all that apply*
   - glasses (including glasses for reading or driving) ☐ *Go to Q. 8*
   - contact lenses ☐ *Go to Q. 8*
   - neither ☐ *Go to Q.9*

8. Are you?
(you may tick as many squares as are appropriate)

	yes	no	don't know
short sighted	☐	☐	☐
long sighted	☐	☐	☐

9. Have you experienced any of the following conditions in the past two years?
(you may tick as many squares as are appropriate)

	yes	no
eye infections	☐	☐
cataract	☐	☐
glaucoma	☐	☐
retinal problems	☐	☐
migraine	☐	☐
diabetes	☐	☐
thyroid problems	☐	☐
high blood pressure	☐	☐
depression	☐	☐

9. If you answered yes to any of the questions above, please indicate whether you are currently being treated and/or if you are taking medication for the condition?

	being treated	taking medication
eye infections	☐	☐
cataract	☐	☐
glaucoma	☐	☐
retinal problems	☐	☐
migraine	☐	☐
diabetes	☐	☐
thyroid problems	☐	☐
high blood pressure	☐	☐
depression	☐	☐

10. Please indicate the medications you are currently taking (excluding birth control)?

SECTION B - SYMPTOMATIC RESPONSES

	How often have you experienced this symptom at work in the last four weeks?					How severe would you consider this symptom to be? (if the symptom varies in severity, circle the number that describes the level of severity that most commonly occurs).								Does this symptom usually reduce, disappear or remain after your work shift?			
		never	1-3 month	1-3 week	almost always	No symptoms						very severe symptoms	not applicable		symptom reduces or disappears	symptom remains	not applicable
Tired or strained eyes	1	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	1	☐	☐	☐
Focusing difficulties	2	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	2	☐	☐	☐
Dry or irritated eyes	3	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	3	☐	☐	☐
Watering eyes	4	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	4	☐	☐	☐
Smarting or burning eyes	5	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	5	☐	☐	☐
dull headache	6	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	6	☐	☐	☐
throbbing headache	7	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	7	☐	☐	☐
migraine headache	8	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	8	☐	☐	☐
Tiredness	9	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	9	☐	☐	☐
Drowsiness	10	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	10	☐	☐	☐
Lethargy	11	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	11	☐	☐	☐

	How often have you experienced this symptom in the last month?					How severe would you consider this symptom to be? (if the symptom varies in severity, circle the number that describes the level of severity that most commonly occurs).								Does this symptom usually reduce, disappear or remain after your work shift?			
		never month	1-3 week	1-3 always	almost	no symptoms						very severe symptoms	not applicable		symptom reduces or disappears	symptom remains	not applicable
poor concentration	12	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	12	☐	☐	☐
poor memory	13	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	13	☐	☐	☐
irritability	14	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	14	☐	☐	☐
scratchy throat	18	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	15	☐	☐	☐
flu like symptoms	19	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	16	☐	☐	☐
chest tightness or wheezing	20	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	17	☐	☐	☐
Other																	
.....	21	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	18	☐	☐	☐
.....	22	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	19	☐	☐	☐
.....	23	☐	☐	☐	☐	1	2	3	4	5	6	7	☐	20	☐	☐	☐

SECTION C

1. Do you consider any of the health symptoms that you described in Section B to be related to the office environment or use of office equipment?

Yes ☐ No ☐

Specify:

Physician Questionnaire – Medical Study

Health of Office Personnel

Medical Interview Form

1. Past medical history

(a) Head or neck injury

(b) Musculoskeletal pain or disability

(c) Anaemia

(d) Chronic infection

(e) Persistent sleep disturbance/depression

(f) Allergies or chemical sensitivity

Medical Evaluation

1. Visual acuity

   (a) Near vision

   (b) Far vision

   (c) Stereopsis

2. Neck and head movement and upper spine evaluation

3. (a) Ear, nose and throat examination

   (b) Lower respiratory system evaluation

4. Evaluation for anaemia, arthritis, blood pressure, height/weight ratio and mental health.

Appendix D: Pilot Study

Introduction

A pilot study was completed in a comparable data entry office. The primary objective of the study was to evaluate the validity of the questionnaire, determine participation and attrition rates, and to complete a power analysis to determine sample sizes for the main study. The lighting was not modified during the pilot study period. Aspects of the methodology which were comparable to the main study are summarised in this section and discussed in detail in Chapter Two (Experimental Methodology).

Objectives

- Determine sample sizes required for main study;
- Assess questionnaire validity;
- Assess the impact of environmental factors on symptom severity.

Methodology

A field study was conducted in a data entry office (n=19) for a one month period. The study collected information on the symptom severity, satisfaction with lighting, perceived productivity and actual productivity of the participants for a four week period (Appendix C). Environmental parameters including desktop illuminance, temperature, humidity and carbon dioxide levels were monitored throughout the study period.

The office personnel's primary task was cheque date entry; transferring the written amount on a cheque into computer legible text at a rate of between 500 and 1200 cheques per hour. The operators worked between one and five evening shifts per week of approximately two and a half to four hours dependent upon workload, with the workload peaking at four weekly intervals.

The building in which the study was conducted was a two storey commercial building in Palmerston North. The building featured openable windows and the air was heated by a wall mounted radiator at one end of the space. The office was lit by a regular configuration of twin lamp full spectrum fluorescent lamps in battens without diffusers.

Questionnaire

The questionnaire (Appendix C) was distributed on a weekly basis and included;

- An initial (once only) section for bibliographic details such as age, gender, eyeglass and smoking history;
- A daily symptoms diary for symptom occurrence and severity of headache, eyestrain and lethargy symptoms;
- A weekly section on assessment of lighting quality (perception of flicker, aspects of lighting liked or disliked, and perceived effects of lighting on productivity).

Non work related symptoms from other malaise's (influenza, allergy, etc.) were identified by filter questions, and were excluded from the analysis. A ten point interval scale was used for the majority of the questionnaire measures. A nominal scale was used for health and demographic questionnaire items such as smoker/non-smoker, female/male.

The number of entries into the data entry machines was logged continuously, however the speed of data entry was only assessed over a one hour interval by the management when elected by the operator. The frequency of productivity measures was thus determined by the individual and occurred at irregular intervals (between 0 and 12 times per month).

Results and Discussion

Eighteen of the nineteen office occupants elected to participate in the study with two participants subsequently withdrawing. The data was entered into a spreadsheet with

output as an ASCII file. SPSS was used for the analysis. The analysis revealed that symptoms were experienced in 50% of all work shifts with an average perceived severity of 3.3 on a scale of 0-9 (0 = no symptoms 9=very severe symptoms).

Fifty percent of eyestrain and sixty five percent of headache and lethargy symptoms reduced or disappeared at the conclusion of the work shift, suggesting that they could be attributed to the work environment. The age, glasses and smoking history of the participants did not influence their symptom reporting or productivity.

Humidity and temperature met international recommended standards, however illuminance on the work plane was below the New Zealand recommended standards (NZS6703: 1984) at many of the work stations in the evenings when there was no daylight contribution (Table 62). The fresh air circulation[111] was also inadequate during the evening shifts, particularly when the office was fully occupied.

Table 62. Illumination, Temperature and Humidity: Office Measurements

	Measured levels
Illlumination levels	240 – 700 lux
CO_2	400 – 1800 ppm
Temperature	19 – 24 °C
Humidity	40 – 60 RH

The pilot study demonstrated that participants were experiencing symptoms in the workplace that could be attributed to environmental conditions. These included inadequate lighting conditions and poor air circulation. In addition, participation and attrition rates, symptom incidence and symptom severity were assessed for a group of office personnel who were comparable to the main study population. This information enabled a power analysis to be conducted as outlined in Appendices E & F. Finally, minor changes were made to the questionnaire used in the main study to reflect changes recommended by the study participants or more accurately capture participant responses.

[111] Measured by carbon dioxide levels in the space

The changes made to the main study questionnaire included:

- The ten point Likert scale was changed to a seven point scale;
- The questionnaire layout was changed to make it shorter and easier to complete;
- More information was included on how to complete the questionnaire;
- Questions were changed to reflect differences between the offices studied;
- Questions were included on other aspects of the work environment.

Further analysis was not conducted on the pilot study, as the primary objectives had been fulfilled.

Appendix E: Power Analysis

Introduction

A power analysis was undertaken by Dr Siva Ganesh[112] (Appendix F) to determine if the number of personnel available to participate in the proposed main study would be sufficient to detect a difference in mean eye symptoms between any two lighting treatments of 1 (on an 9 point Likert scale). The power analysis utilised the results from the pilot study and a comparable study completed by Wilkins et al. (1989).

Methodology

A four week pilot study was undertaken in a comparable office environment. In this study, eighteen of the nineteen personnel participated in the study with an attrition of two people.

The numbers of people employed by each of the proposed host offices was 51, 45 and 32 respectively. All three offices were assumed to have equivalent attrition rates of approximately one person per month[113], equating to five people per office throughout the course of the study.

The power analysis was based on the pilot study and Wilkins et al. (1989) and was used to provide an estimate of the 'sampling variation' under similar conditions. The pilot study consisted of data from 16 participants who were subjected to controlled lighting conditions (Appendix D). The research paper by Wilkins et al. (1989) described the average (weekly) incidence of eyestrain and headache experienced by forty two participants before and after the changeover in lighting conditions. As the current study concentrates on the severity of symptoms, rather than the incidence rate, this research paper was of limited use in determining the sample size required for the proposed experiment.

---

[112] Senior Lecturer, Institute of Information Sciences, Massey University, New Zealand.

[113] Assumption based on discussions with office management and attrition from the pilot study.

The statistical design of the proposed (main) study provided information such as the degrees of freedom associated with the anticipated tests, and was used in power computations.

The analysis assumed that the main aim of the study was to compare the effects of the lighting treatments on human participants with respect to severity of eye, headache and lethargy symptoms. This severity is measured on a 0 - 9 scale (no symptoms - very severe symptoms). The intention was to use either the monthly or the weekly average symptoms for assessing the effects of lighting treatments. It was assumed that an equal number of participants would be available in each office, and that they would complete all three trials.

If the monthly average symptoms data was utilised it was concluded that about twenty participants per office were required to provide a beta risk of 0.09 or power of at least 0.90, if the difference in mean eye symptoms of any two lighting treatments was as large as 1. If the difference is set at 0.5 then 80 participants are required, or at 2 then only 6. In the case of the weekly average symptoms data, the corresponding number of participants was doubled, i.e. 40 participants for a difference of one mean eye symptom.

The report concluded that the uniqueness of this study may limit the accuracy of the estimates of standard deviations, and would provide more precise estimates that could be utilised in future research projects.

Conclusion

The power analysis indicated that the number of personnel in the three offices should be sufficient assuming comparable participation and attrition rates. It is expected that the attrition rate will be somewhat higher than in the pilot study, leaving a small but acceptable margin.

Appendix F: Power Analysis Report

Report by Dr Siva Ganesh, Institute of Information Sciences, Massey University, New Zealand.

In any experimental design problem, a critical decision is the choice of sample size, that is, determining the number of replicates to use. Generally, if the experimenter is interested in detecting small effects, more replicates are required than if the experimenter is interested in large effects.

Computation of the number of replicates required depends on,

- An estimate of σ^2 – the 'sampling variation'
- The size of the difference to be detected (in Hypothesis tests or Confidence intervals)
- The assurance under which it is desired to detect the difference (i.e. Power of the test, usually denoted by $1 - \beta$; β is also known as the probability of type II error)
- The level of significance to be used in the actual experiment (i.e. probability of a type I error, usually denoted by α)

Several approaches are available for determining the sample size required. The choice depends on the type of test or experiments carried out and the parameters of interest.

Basic assumptions

The main aim of the proposed study is to compare the effects of 'lighting' treatments on human subjects with respect to *severity* of eye, headache and lethargy symptoms. This severity is measured on a 0 - 9 scale (*no symptoms* $\Rightarrow$ *very severe symptoms*). The intention is to use either the monthly or the weekly average symptoms for assessing the effects of 'lighting' treatments. If the subjects perceived that their symptoms did not reduce or disappear after their work shift (i.e. were not work related), the corresponding information will be ignored from the analysis.

It s also assumed that 'equal' no. of subjects are available for the study in each 'office environment' and they would complete all three trials.

Information available

Literature

Only one significant research paper (Wilkins et al., 1989) was found which relates to the recent study. However, this paper considers the average (weekly) incidence of headache, etc. before and after the changeover in lighting conditions. As the current study concentrates on the 'severity' of headache, etc. rather than the 'incidence rate', this research paper is of limited use in determining the sample size required for the proposed experiment.

Pilot Study

Although the pilot study was not planned in line with the proposed experiment, it provides an estimate of the 'sampling variation' under similar conditions. This study consisted of useable information from 16 subjects who were subjected to a controlled 'lighting' environment.

Design of proposed experiment

The 'statistical' design of the proposed experiment is known (see details of project proposal). This provides useful information such as the 'degrees of freedom' associated with the anticipated tests, which will be used in the 'power computations'.

Methodology used

For the current situation, we may adapt a procedure suggested by Montgomery et al., (1984). This provides the sample size necessary to reject the null hypothesis if the difference between any two treatment means exceeds a specific value.

This approach utilises the concept of 'operating characteristic curves', also known as the "OC-Curves". An OC curve is a plot of the 'type II error' probability of a statistical test for a particular sample size versus a parameter that reflects the extent to which the null hypothesis is false. These curves can be used in selecting the number of replicates so that the design will be sensitive to important potential differences in the treatments.

In a typical ANOVA, the test statistic, say, $F_0 = MS_{treatments} / MS_{error}$ is distributed as a noncentral F distribution with f_1 and f_2 degrees of freedom if the null hypothesis (that there are no differences among the treatments) is false. The types of OC curves that are of interest here are the plots of the probability of type II error against a parameter Φ which is related to the noncentrality parameter of the above F distribution. Such curves are available for $\alpha = 0.05$ and $\alpha = 0.01$ and a range of degrees of freedom for numerator (treatments) and denominator (error).

The essence of the approach is that a sample size is selected so that, if the difference between any two treatment means exceeds a specified value, the null hypothesis is rejected. If the difference between any two treatment means is as large as D, then the minimum value of Φ^2 is

$$\Phi^2 = \frac{ND^2}{2a\sigma^2}$$

where $a = f_1 + 1$, and N is the no. of replicates used for computing treatment means.

Determination of sample size(s) required

Monthly average symptoms data

The sources of variation (of interest) and their degrees of freedom associated with the analysis of the proposed experiment are shown over.

Source of variation	d.f.	
Subjects	3n-1	(assuming n subjects available in each office)
Office	2	3 offices …
Error1	3n-3	'error' for testing 'office' differences
Trials	2	3 trials
Subjects*Trials		
Lighting	2	3 lighting treatments
Lighting*Office	4	interaction …
Error2	6n-8	'error' for 'lighting', 'trials' & interaction effects
Total	9n-1	

Only information from 'eye' symptoms from the pilot study were used. The pilot study gave a mean eye symptom of 2.297 per subject with a standard deviation of 1.4799.

Consider the case of testing the main effects of 'lighting' treatments. Suppose we decide that the null hypothesis should be rejected with a high probability if the difference in mean eye symptoms between any two lighting treatments is as great as D. Assuming that n subjects are used in each of the three offices, we have:

$$\Phi^2 = \frac{3nD^2}{6\sigma^2}$$

as the minimum value of Φ^2 with $f_1 = 2$ and $f_2 = 6n\text{-}8$ degrees of freedom. Assuming that $\alpha = 0.05$ and $\sigma = 1.4799$, we can use the OC curve shown in Figure 57 to construct the following table for $D = 0.5$, 1 and 2.

D	n	Φ^2	Φ	f_1	f_2	β
0.5	20	1.1415	1.07	2	112	≈0.70
	40	2.2830	1.51	2	232	≈0.35
	80	4.5660	2.14	2	472	≈0.08
1	20	4.5660	2.14	2	112	≈0.09
2	6	5.4792	2.34	2	28	≈0.08

We may conclude that about 20 subjects per office are required to provide a β risk of about 0.09, if the difference in mean eye symptoms of any two lighting treatments is as large as 1. Thus, 20 replicates are required to provide the desired sensitivity (or power of at least 0.90) so long as our estimate of the standard deviation of eye symptoms is not seriously in error. Note that, if the desired difference is set at 0.5, then about 80 subjects per office are required for the study! On the other hand, only about 6 subjects are required per office if a larger difference (of 2) is to be allowed.

Weekly average symptoms data

The ANOVA associated with this case resembles a 'repeated measures' situation. In addition to the monthly average symptoms ANOVA table (where sums of squares, etc. are now computed using the 'weekly' totals), we have a 'repeated measures' portion as follows: (Again, only 'eye symptoms' from the pilot study are used, which gave a weekly mean eye symptom of 2.198 per subject with a standard deviation of 1.8393).

Source of variation	d.f.	
Weeks	3	4 weeks
Weeks*Office	6	interaction effects …
Weeks*Lighting	6	interaction effects …
Error3	27n-15	'error' for testing 'weeks' & 'interaction' effects
Total	36n-1	

We may consider the case of testing the 'week' main effect and its interaction with 'lighting', etc. Suppose we decide that the null hypothesis should be rejected with a high probability if the difference in mean eye symptoms between any two 'week*lighting' treatments is as great as D. Assuming that n subjects are used in each of the three offices, we have:

$$\Phi^2 = \frac{3nD^2}{14\sigma^2}$$

as the minimum value of Φ^2 with $f_1 = 6$ and $f_2 = 27n\text{-}15$ degrees of freedom. Assuming that $\alpha = 0.05$ and $\sigma = 1.8393$, we can use the OC curve shown in Figure 58 to construct the following table for $D = 0.5$, 1 and 2:

D	n	Φ^2	Φ	f_1	f_2	β
0.5	150	2.3753	1.54	6	$\approx \infty$	$\approx$0.10
1	40	2.5337	1.59	6	1065	$\approx$0.09
2	10	2.5337	1.59	6	255	$\approx$0.09

Thus, for example, 40 subjects are required to provide the desired sensitivity (or power of at least 0.90) for detecting a difference of 1 mean eye symptoms between any two week*lighting interaction effects.

An Important Remark

It should be noted that there was virtually no previous literature available related to the planned study, and the pilot study was also fairly inadequate! Thus the estimates of the standard deviations may be inferior.

However, since the planned study is based on a sound experimental design, it could be expected to provide more precise estimates than that of the pilot study. In fact, the planned study may even be regarded as a 'large scale pilot study' which in turn would form a solid base for further research projects in this area.

Figure 56. Operating characteristic curve for monthly average symptoms data.

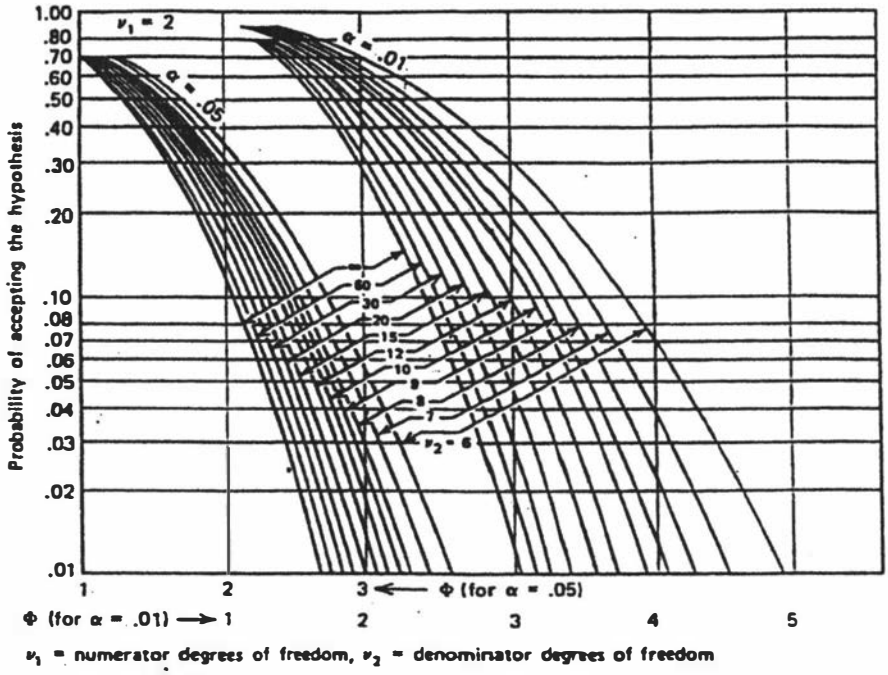
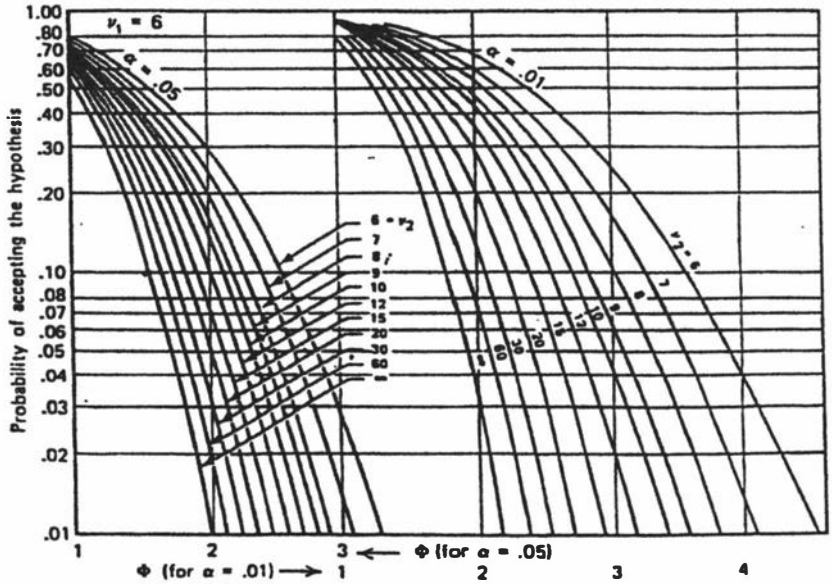


Figure 57. Operating characteristic curve for weekly average symptoms data.



Appendix G: Environmental Monitoring Data and International Standards

Recommended Illuminance and Luminance: Standards

Table 63. Recommended standard service illuminances (NZS6703: 1984)

Area	**Position of measurement**	**Illuminance (lx)**
General offices with mainly clerical tasks and occasional typing	Desk	500
Visual display units	Keyboard Hard copy	200 500

Table 64. Recommended maintenance illuminance levels[114] for visual work (AS1680:1990).

Task	**Contrast**	**Illuminance (lx)**
Simple	High	160
Ordinary or moderately easy	High	240
Moderately difficult	Low	400
Difficult/small size	Low	600
Very Difficult	Low	800

Table 65. Recommended illuminance levels for visual work (IESNA: 2000).

Task	**Contrast**	**Work tasks**	**Illum. (lx)**
Large size	High	Handwritten ballpoint pen	300
	Low	Open plan office – intermittent VDU use	500
Small size	High	Open plan office – int. VDU use	500
	Low	Handwritten #4 pencil and harder leads	1000
Near visual threshold	-	Fine bench or machine work Inspection – exacting	1000 – 10 000

[114] Illuminance at which maintenance is required.

Table 66. Recommended brightness (luminance) ratios for indoor lighting.

Work Area	**Luminance ratio (CIBSE: 1984)**	**Luminance Ratio (IESNA: 2000)**
Task and immediate surroundings	1:3	1:3
Task and general surroundings	1:10	-
Task and remote surroundings	1:10	1:10
Light sources and to large adjacent area	1:10	-

Luminance: Office Measurements[115]

Table 67. Luminance Measurements Office Two

Surface	**Specific location**	**Range of readings (cd/m^2)**
Work task	Placed in cheque alcove	70-160
Task surrounds	Cheque alcove	20-60
	Surrounds of task (beige desk)	25-105
	Surrounds of task (grey desk)	11-50
	Keypad	50-80
VDU	Screen	15
Floor		15-40
Wall	Eye level: columns	90-130
	walls	70-130
	End wall	30-50
	Upper wall between luminaires	40-70
	Upper wall adjacent to luminaires	70-90
	Glazed partition	30-80
	View to exterior (from interior)	8-40
Ceiling	Between luminaires	30-70
	Adjacent to luminaires	30-70

[115] See Environmental Monitoring for details of illuminance measurements.

Table 68. *Luminance Measurements Office Three*

Surface	Specific location	Range of readings (cd/m^2)
Work task	Placed in cheque alcove	38-90
Task surrounds	Cheque alcove	4-12
	Surrounds of task (beige desk)	7-40
	Desk base (white)	170
	Surrounds of task (grey desk)	5-15
	Keypad	6-40
	Blue flat desk (horizontal)	50-90
	(vertical)	30-50
VDU	Screen	3-13
Floor		25-40
Wall	Eye level	16-70
	Upper wall between luminaires	30-50
	Upper wall adjacent to luminaires	8-20
	Glazed partition	8-40
	Reflection in glazed partition	60-140
Ceiling	Between luminaires	20-40
	Adjacent to luminaires	20-40
Windows	dark	3-5
	luminaire reflected in window	15-25

Recommended Reflectance Standards

Table 69. *Recommended reflectance for indoor work environments.*

Surface	Reflectance (IESNA: 2000)	Reflectance (NZS6703: 1984)
Floor	0.2-0.4	0.2 – 0.3
Walls	0.5-0.7	0.5 – 0.8
Ceiling	0.8+	0.6+
Partitions	0.4-0.7	-
Furniture	0.25-0.45	-

Reflectance and Yxy Tristimulus colour co-ordinates: Office Measurements

Table 70. Measured Reflectance and Yxy tristimulus colour co-ordinates for cheques used in the study.

Work Task	Reflectance[116] (Y)	x	y
Bank A white payment slip	0.80	0.31	0.32
Bank A Grey cheque	0.72	0.31	0.31
Bank B Green cheque	0.61	0.31	0.32
Bank C grey cheque	0.72	0.32	0.32
Proforma white (dot matrix printer)	0.75	0.31	0.31
Bank C blue cheque (white number)	0.65	0.30	0.31
Bank D blue cheque (white number)	0.64	0.30	0.31
Bank D white cheque with blue/redlines	0.70	0.31	0.32
Bank E Grey cheque	0.68	0.32	0.33

Table 71. Measured Reflectance and Yxy tristimulus colour co-ordinates for Office Two

Surface	Reflectance(Y)	x	y
Machining desk, immediate surrounds of task – dark beige	0.20	0.33	0.34
Machining desk, background colour – light beige	0.46	0.33	0.34
Machining desk 2, immediate surrounds of task – medium grey	0.16	0.32	0.32
Machining desk 2, background colour – light grey	0.33	0.31	0.32
Flat desk, interior office, light grey	0.36	0.31	0.32
Floor	0.15	0.30	0.30
White wall	0.69	0.31	0.32
White textured wall	0.66	0.31	0.32
Ceiling	0.81	0.31	0.32
Blue sorting desk	0.30	0.26	0.28
Customwood pigeon holes	0.36	0.40	0.38

[116] Compared to an ideal relecting diffuser with a reflectance of 100%.

Table 72. Measured Reflectance and Yxy tristimulus colour co-ordinates for Office Three

Surface	Reflectance (Y)	x	y
Machining desk, immediate surrounds of task – med grey	0.16	0.3	0.31
Machining desk, background colour – light beige	0.60	0.33	0.34
Machining desk, dark grey	0.10	0.32	0.32
Machining desk, light beige immediate surrounds of task	0.20	0.33	0.34
Online desk, warm beige immediate surrounds of task	0.30	0.33	0.33
Online desk, grey background	0.49	0.32	0.33
Blue Encoding/Sorting desk	0.35	0.29	0.31
Blue pigeon holes	0.36	0.29	0.29
Encoding/sorting machine	0.50	0.33	0.34
Encoding/sorting machine (keyboard background)	0.38	0.35	0.35
Grey floor	0.13	0.29	0.29
Light blue columns with textured paint finish	0.46	0.29	0.29
Light grey textured wall paper	0.56	0.31	0.31
White wall (room two)	0.71	0.31	0.33
Textured light grey partition (room three)	0.28	0.31	0.31
Ceiling	0.86	0.31	0.32
Red chairs	0.09	0.53	0.31
Grey door	0.47	.30	0.31

Recommended Thermal Comfort Standards

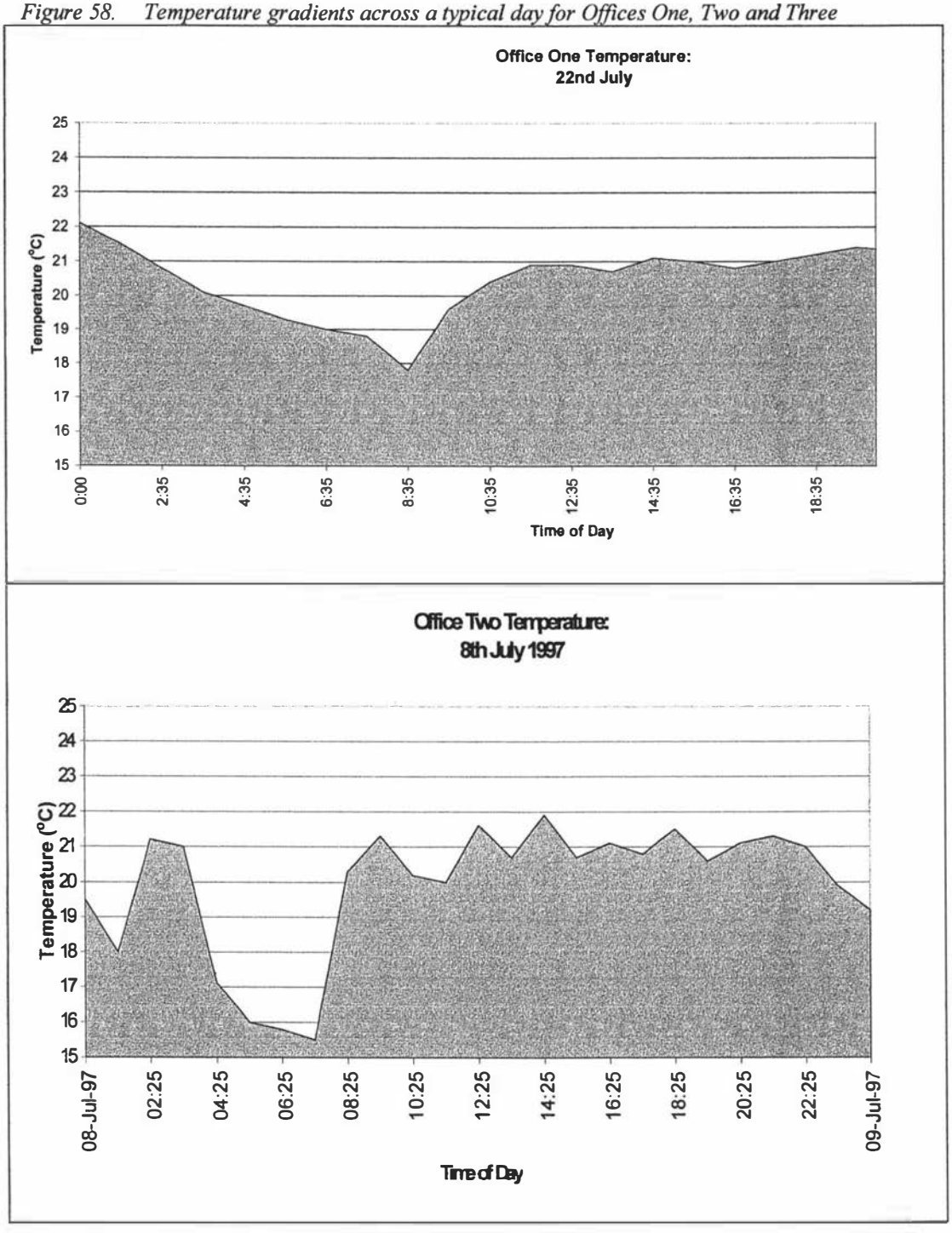
Table 73. Recommended thermal comfort standards for office environments (ASHRAE: 1992)

Season	Optimum Temperature[117]	Operative Temperature	Relative Humidity
Winter	21.7°C	20.0 - 23.6°C	25 - 60%
Summer	24.4°C	22.8 - 26.1°C	25 - 60%

[117] At 50% Humidity

Thermal Comfort: Office Measurements

Figure 58. Temperature gradients across a typical day for Offices One, Two and Three



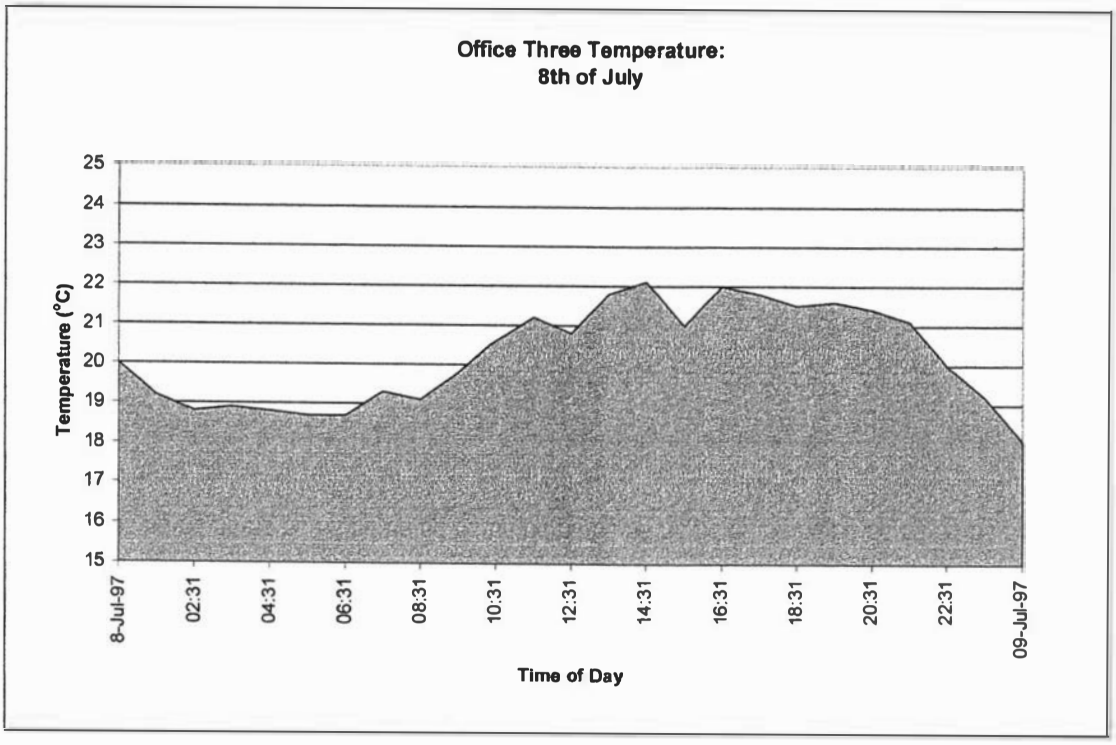
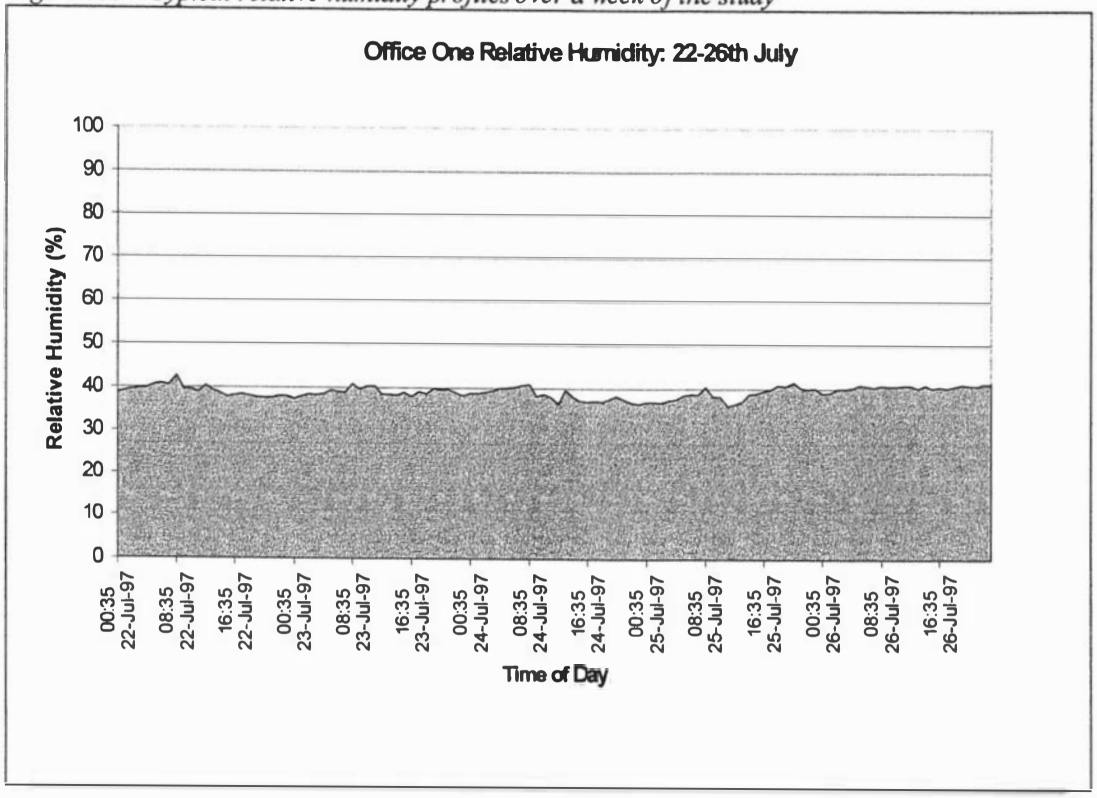
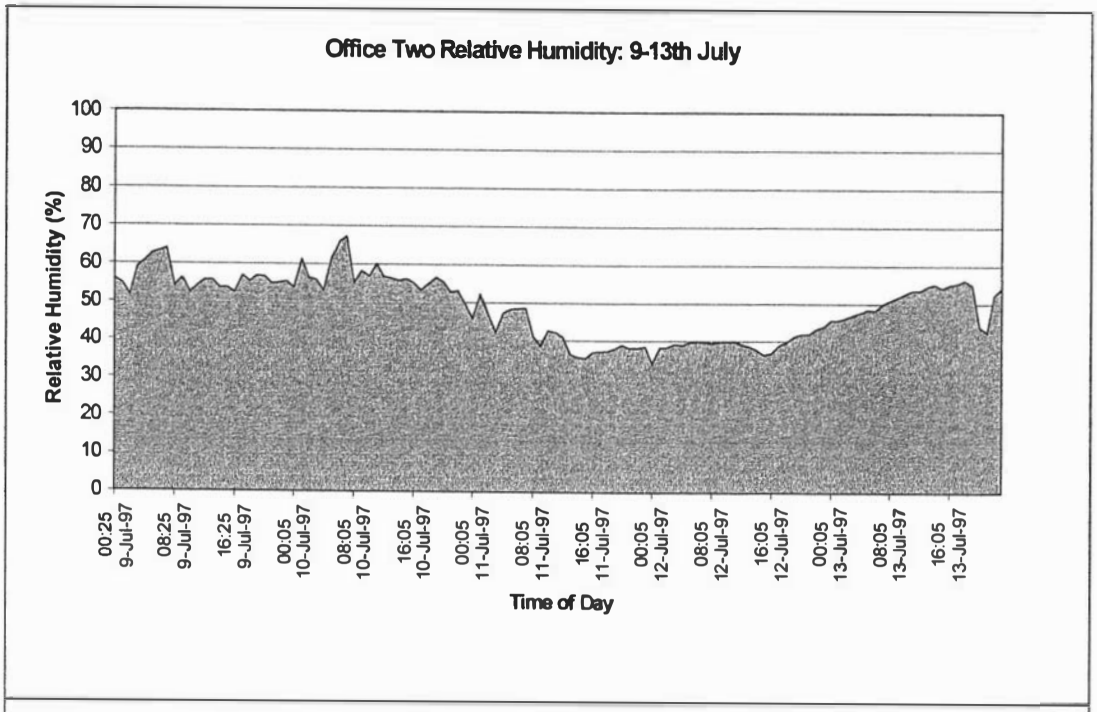
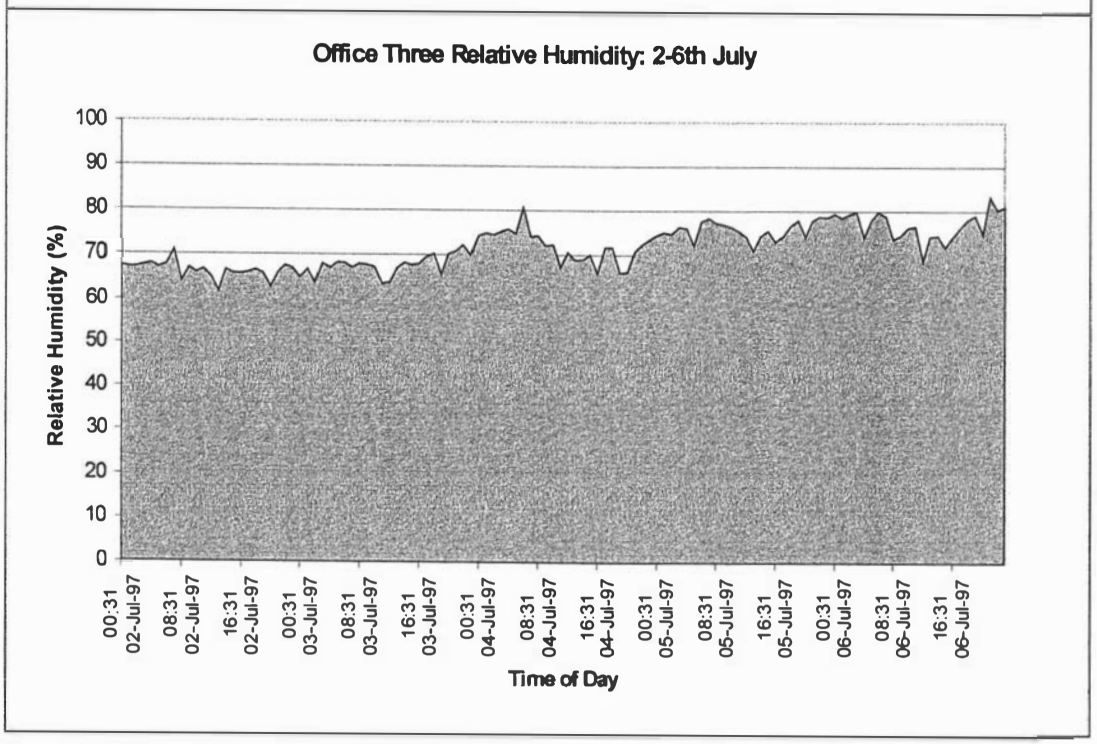


Figure 59. Typical relative humidity profiles over a week of the study

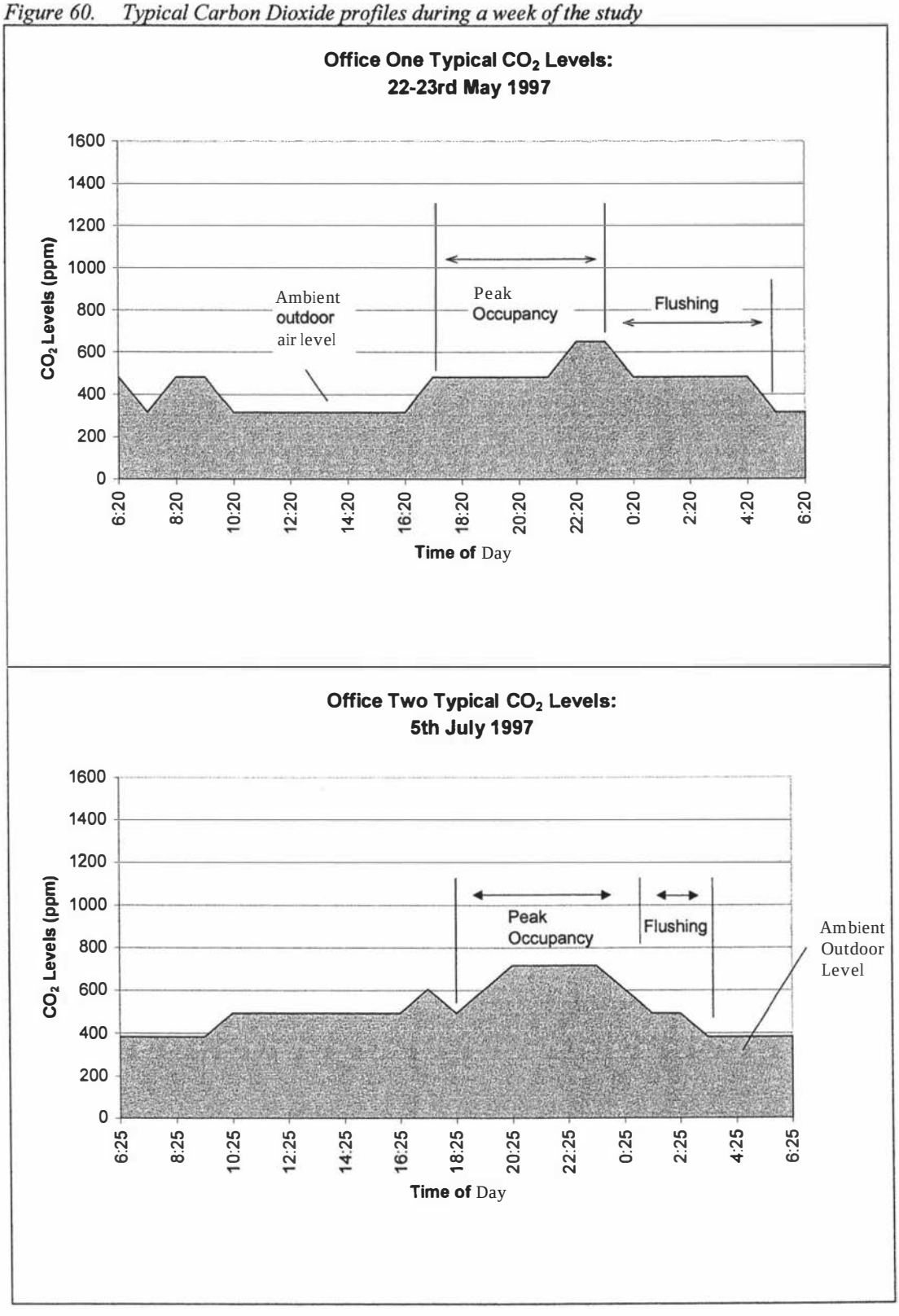


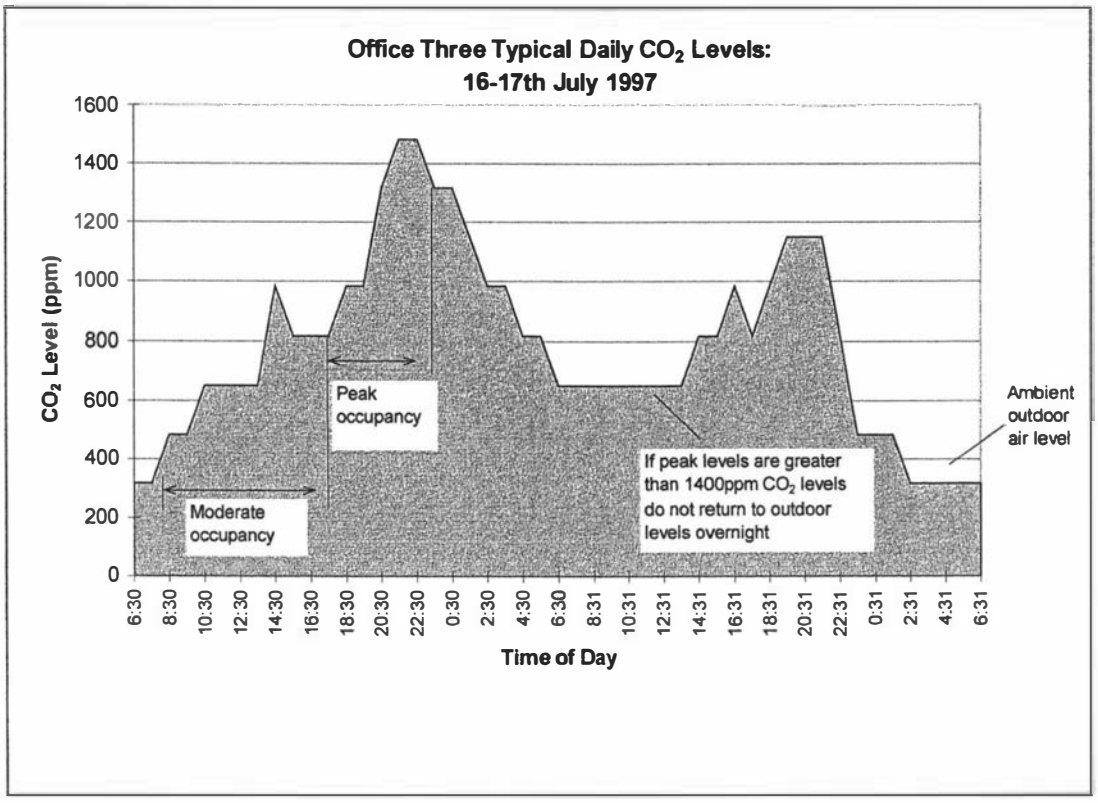

Office Two Relative Humidity: 9-13th July
Relative Humidity (%)
100
90
80
70
60
50
40
30
20
10
0
00:25 9-Jul-97
08:25 9-Jul-97
16:25 9-Jul-97
00:05 10-Jul-97
08:05 10-Jul-97
16:05 10-Jul-97
00:05 11-Jul-97
08:05 11-Jul-97
16:05 11-Jul-97
00:05 12-Jul-97
08:05 12-Jul-97
16:05 12-Jul-97
00:05 13-Jul-97
08:05 13-Jul-97
16:05 13-Jul-97
Time of Day


Office Three Relative Humidity: 2-6th July
Relative Humidity (%)
100
90
80
70
60
50
40
30
20
10
0
00:31 02-Jul-97
08:31 02-Jul-97
16:31 02-Jul-97
00:31 03-Jul-97
08:31 03-Jul-97
16:31 03-Jul-97
00:31 04-Jul-97
08:31 04-Jul-97
16:31 04-Jul-97
00:31 05-Jul-97
08:31 05-Jul-97
16:31 05-Jul-97
00:31 06-Jul-97
08:31 06-Jul-97
16:31 06-Jul-97
Time of Day

Ventilation Effectiveness: Office Measurements

Figure 60. Typical Carbon Dioxide profiles during a week of the study





Particulate Concentrations: Office Measurements

Table 74. *Office Two and Three Particulate Measurements*

Location	**Office Two ($\mu g/m^3$)**	**Office Three ($\mu g/m^3$)**
Exterior (before)	18	22
interior office/ ambient room 1	11	12
exterior office/ ambient room 2	9	14
ambient room 3	-	14
Machine One	8	13
Machine Two	8	13
Exterior (after)	14	16

Table 75. *Number of particles counted at each size increment: Office Two*

Location	0.3μm	0.5μm	1.0μm	3.0μm	5.0μm	10.0μm	Total
Exterior 9:20pm light traffic	352763	93981	85620	4171	1098	0	537633
ambient int. off.	211538	70523	51313	3581	1058	0	337725
ambient ext. off	205879	62485	39460	2628	820	0	311272
local mach.	191600	59771	37650	2657	852	0	292530
local mach	186533	59649	36122	2067	610	0	284981
cubby holes	197971	65366	38203	2095	789	0	304424
exterior 10:40 light traffic	315254	83111	79752	3776	884	0	482777

Table 76. *Number of particles counted at each size increment: Office Three*

Location	0.3μ	0.5μ	1.0μ	3.0μ	5.0μ	10.0μ	Total
Exterior 1st floor carpark 7:35pm	476939	147176	104560	4362	909	0	733946
ambient rm 1	161745	102376	132666	10235	2075	0	409097
mach. 21	162945	111624	154174	13030	2532	0	444305
ambient rm2	159172	115300	167761	14313	2937	0	459483
ambient rm3	188696	111809	136726	10359	2308	0	449898
mach 36	186338	110192	132460	9994	2171	0	441155
Exterior 9:44pm	365492	83194	80033	3115	772	0	532606

Recommended Noise Measurement Standards

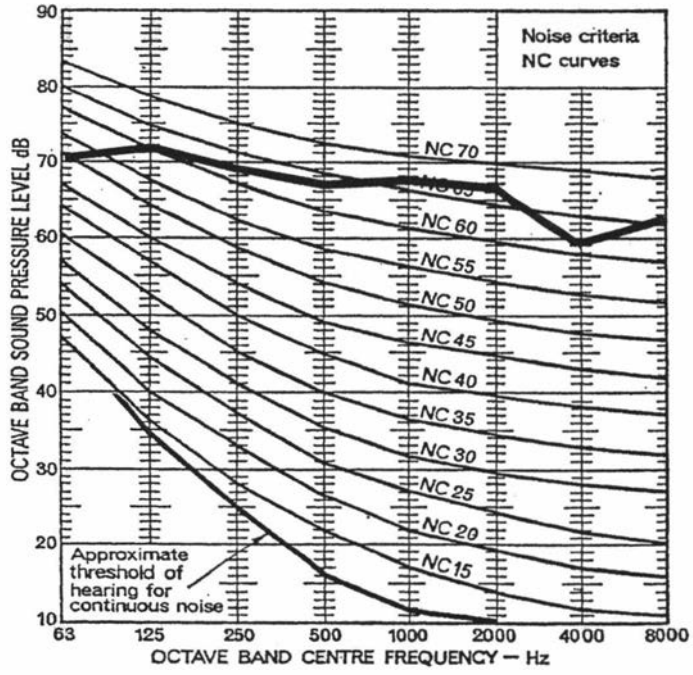
Table 77. Typical decibel readings

Decibels (dB)	Typical Example
140	Threshold of pain
120	Threshold of discomfort
100	Pneumatic breaker
80	Busy traffic
60	Conversation
40	Living room
20	Quiet countryside
0	Threshold of hearing

Table 78. Recommended range of noise criteria (NC) levels (Sharland, 1972).

Environment	Range of NC levels likely to be acceptable
Factories (heavy engineering)	55-75
Mechanised office	40-50
General offices	35-45
Private offices, libraries, courtrooms, and school rooms	30-35
Homes, bedrooms	25-35

Figure 61. Noise Criteria Curves (dB value shown as solid line)



Noise Levels: Office Measurements

Table 79. *Noise measurements in Offices Two and Three*

Location	**Office Two (dB)**	**Office Three (dB)**	**Peak Values (dB)**
interior office/ ambient room 1	70	65	94
exterior office/ ambient room 2	76	69	94
ambient room 3	-	63	94
Machine One	-	78	95
Machine Two	-	74	95

Appendix H: Environmental Monitoring Equipment

	Meter	Model	Accuracy	Comments
Illuminance	Hagner Universal Photometer	S3	+/- 3%	Two silicon diodes filtered to CIE photopic standard Observer Curves. Cosine corrected. Calibration date 1997
	Light Adapter: Extech Instruments	-	+/- 5% +/- 0.1mV	Selenium photodiode, filtered to CIE photopic standard Observer Curves. Calibration date 1996
Luminance	Hagner Universal Photometer	S3	+/- 3%	Two silicon diodes filtered to CIE photopic standard Observer Curves. Cosine corrected. Calibration date 1997
Reflectance	Minolta Chroma Meter	CR-200	+/-0.0002 colour difference	Reflected light colorimeter, 6 silicon photocells filtered to detect primary stimulus values for red, green and blue light. Filtered to CIE photopic standard Observer Curves. Self calibrated with test plate.
Colour Co-ordinates	Minolta Chroma Meter	CR-200	+/-0.0002 colour difference	Reflected light colorimeter, 6 silicon photocells filtered to detect primary stimulus values for red, green and blue light. Filtered to CIE photopic standard Observer Curves. Self calibrated with test plate.

Temperature	Semiconductor temperature transducer	AD590JN	+/- 0.2 °C	Supply Voltage: +4 to +30V Operating Temperature: -55 to 15-°C Two wire current output temperature transducer. Analog device Calibrated for field research.
	Q-Trak IAQ Monitor TSI Incorporated	8550/8551	+/-0.6°C	Thermistor Calibration date 1997.
Humidity	Semiconductor temperature transducer	AD590JN	+/- 0.2 °C temperature	Analog device. Calibrated for field research.
	Q-Trak IAQ Monitor TSI Incorporated	8550/8551	+/- 3% Relative Humidity	Thin film capacitive. Calibration date 1997.
Carbon Dioxide	Guardian II	-	+/- 2% of scale	Infrared CO_2 monitor with dual wavelength infra-red sensor. Output 4-20mA linear analogue output, voltage linear output. Calibration date 1996.
	Fuji Electric	ZPF8	+/-100 ppm	Infra-red sensor (NDIR single beam method). Calibration date 1996.

Carbon Dioxide	Q-Trak IAQ Monitor TSI Incorporated	8550/8551	+/-3% of reading +/- 50ppm at 25oC	Non-dispersive Infrared (NDIR). Calibration date August 1997.
Carbon Monoxide	Q-Trak IAQ Monitor TSI Incorporated	8550/8551	+/-3% or +/- 3ppm (whichever is greater)	Electrochemical. Calibration date 1997.
Particles	Met One	3100	Coincidence loss: <5% at 400 000 particles/ cu.ft.	Laser particle counter. Calibration date 1999.
Noise	Rion	NL18	+/- 1 decibel	Integrating sound level meter. Calibrated 2000.
Data logger	Pico Technology Ltd	ACD 16	N/A	16 bit data logging softwear with analog output.

Appendix I: Illuminance Field Measurements

An experiment was initially undertaken to balance the luminance between lighting treatments as discussed in Chapter Two (Experimental Methodology). However subsequent measurements taken in the offices found that there were small differences in illuminance between lighting treatments (Chapter Four: Environmental Monitoring). The low frequency triphosphor lighting treatment had the highest desktop illuminance levels, followed by the high frequency triphosphor lighting treatment and the low frequency halophosphate lighting treatment. The factors that may have influenced these measurements are discussed below, and recommendations for future research are proposed.

- In the experiment, the method of measuring luminance was relatively imprecise, and may not have adequately considered the distribution of light from the luminaire. More precise measurement would have been obtained by measuring the lighting treatment luminance in a room that was representative of the host offices with a comparable room geometry, surface reflectance's and lighting configuration.

- In the experiment, the light output from the two lamp types (triphosphor and halophosphate) was measured using lamps controlled by low loss ballasts. However in the high frequency triphosphor lighting treatment, the lamps were controlled with electronic ballasts. These ballasts reduce the lumen output of the lamps by approximately 5%. In the experiment, the lamps should have been controlled using ballasts with the same specification as for the actual study;

- The differences in operating temperature between the lamps may have been influential, as the tape backing on the triphosphor fluorescent lamps in the low frequency and high frequency triphosphor lighting treatments may have increased the internal temperature within the lamp, resulting in differences in the emission from the lamp and/or reduced luminous flux;

- Halophosphate fluorescent lamps depreciate at a faster rate than triphosphor fluorescent lamps. This possibly may have resulted in a measurable drop in illuminance in the low frequency halophosphate lighting treatment as the study progressed.

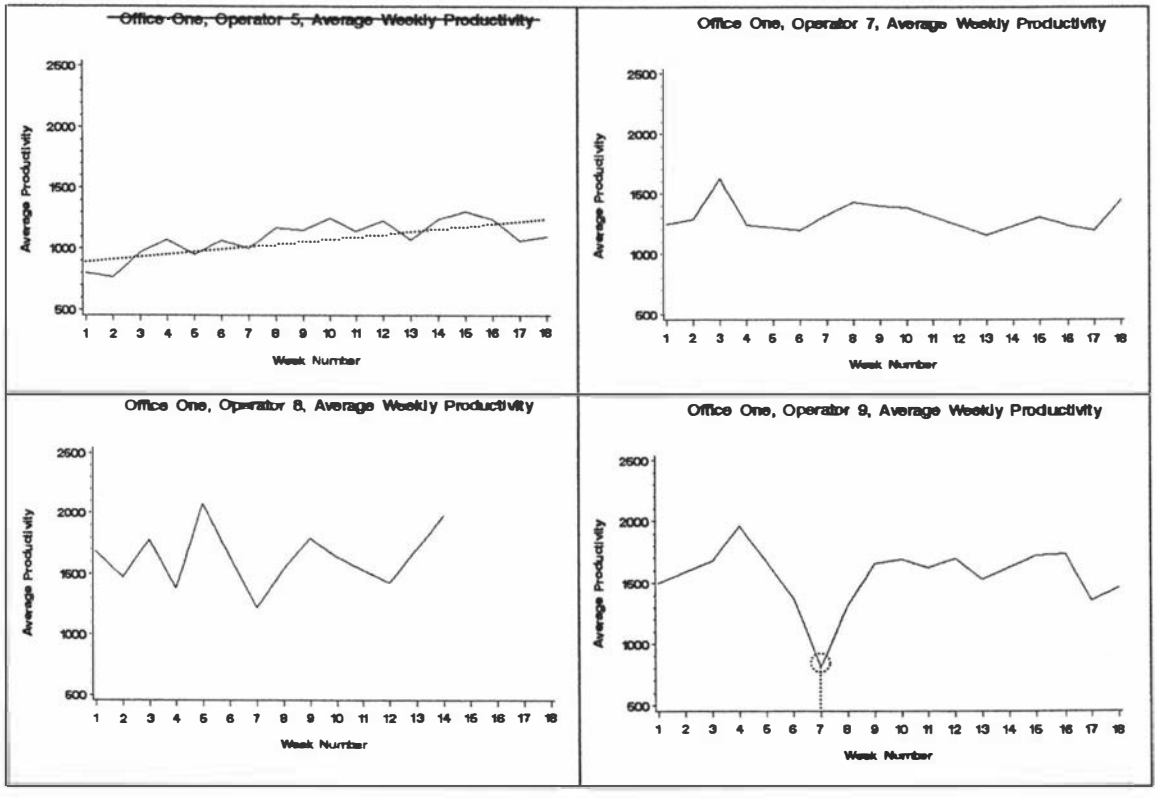
- When the illuminance was measured at each work station, the photocell was placed into the depression in the desk, either on top of existing work to be entered, or if the desk was not being used it was placed into the depression where the work tasks would be placed. It was not possible to move the cheques to provide more equivalent measuring conditions due to the nature of the work task. Differences in the reflectance of the top cheque placed in the desk and the total number of cheques present would have influenced the illuminance measured. The illuminance on this surface and the horizontal desk surface was also influenced by the size and position of the person seated at the desk, the colour of the clothing they wore and the position of the luminaires above the workstation. This method of measuring illuminance was appropriate for a field study where it was important to accurately ascertain the level of illuminance on the work plane. However, these measurements should have been combined with standardised measurements. It is recommended that future studies of this type measure illuminance using a fixed grid with the light meter at a uniform height as well as desktop measurements.

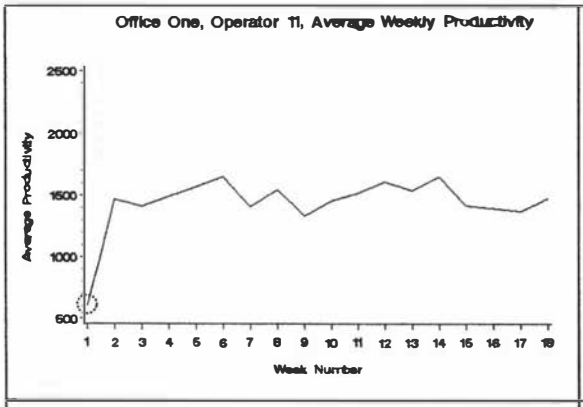
Overall, the study would have benefited from more accurate methods of calculating and measuring the light from the luminaires as discussed above. However, at the time at which the methodology was developed, a difference in lighting treatments of 15% was considered acceptable. Subsequently when the baseline lighting was installed, balancing the perceived brightness of the lamps was the primary goal; therefore the methodology adopted seemed appropriate. The findings in this study now suggest that more precision may have been prudent and taken steps to ensure that this information was collected.

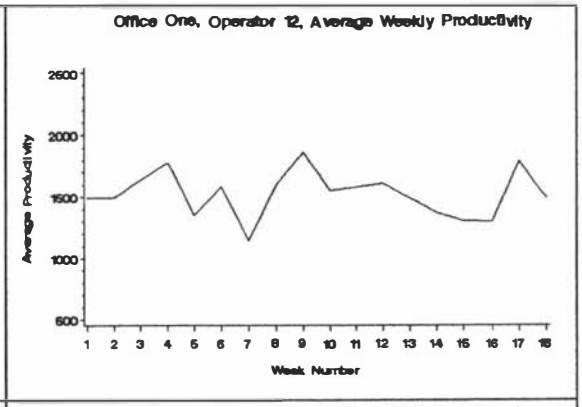
Appendix J: The Actual Productivity of Individuals from Office One and Office Two

Office One

The graphs below show the average weekly productivity of each individual for whom actual productivity data was available, and who also gave their permission for their productivity results to be available for the research study. Those graphs with an overlaid dotted line show increases in actual productivity during the study period. This data has been deleted from the analyses as discussed in the Results section and this is signified by a line through the graph title. Similarly, where a single point on the graph (showing the average actual productivity over a one week period during the study) differed from the general trend shown in the graph, this single data point was excluded from the analysis.




Office One, Operator 11, Average Weekly Productivity
Average Productivity
Week Number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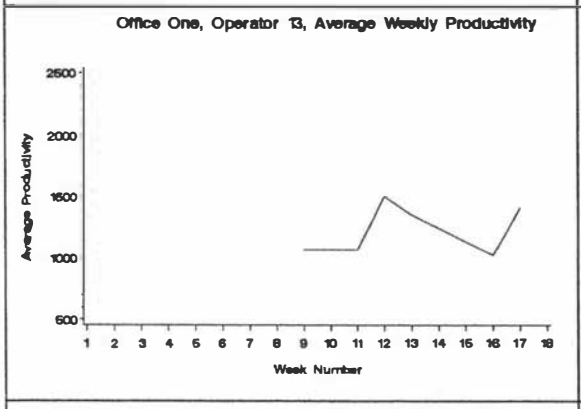
Average Productivity
Week Number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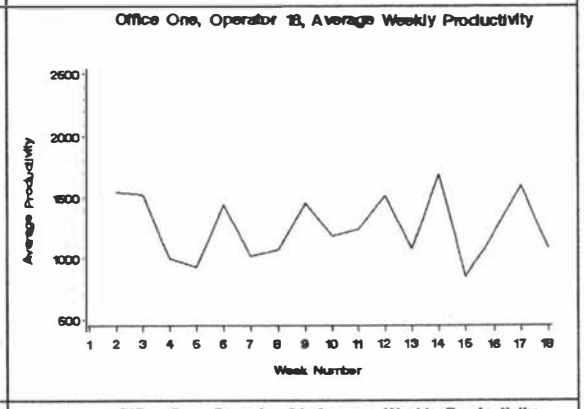
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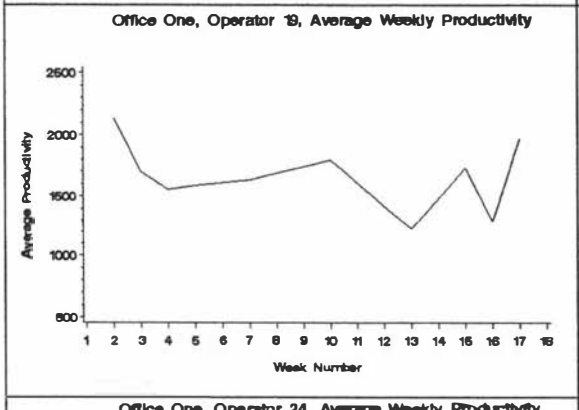
Average Productivity
Week Number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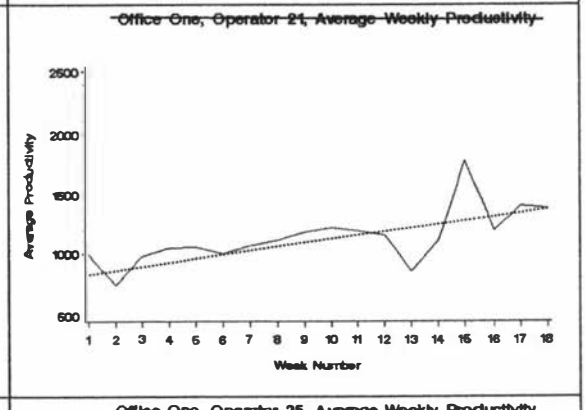
Average Productivity
Week Number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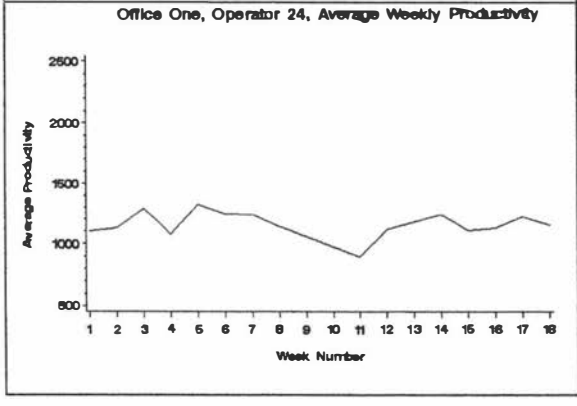
Week Number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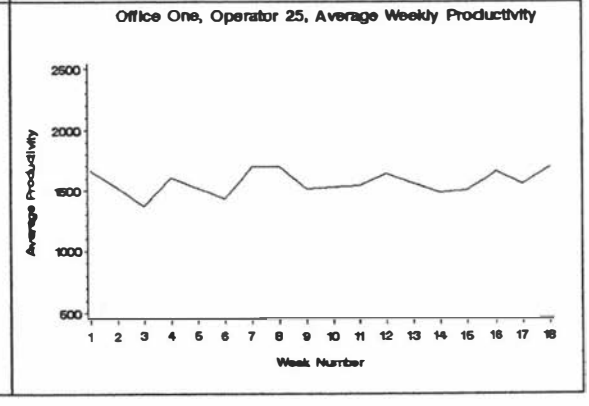
Week Number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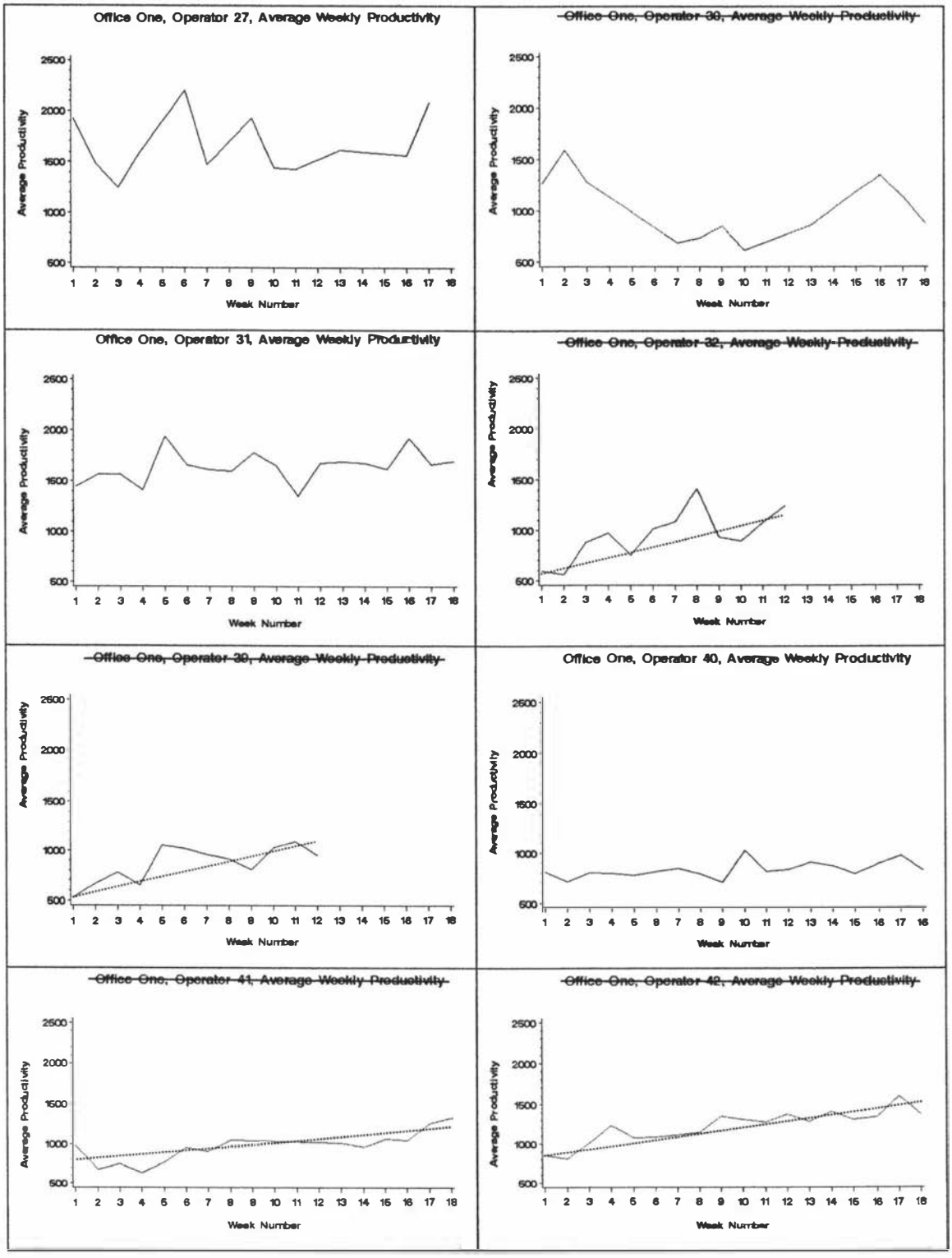
Average Productivity
Week Number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Office One, Operator 30, Average Weekly Productivity
Office One, Operator 31, Average Weekly Productivity
Office One, Operator 32, Average Weekly Productivity
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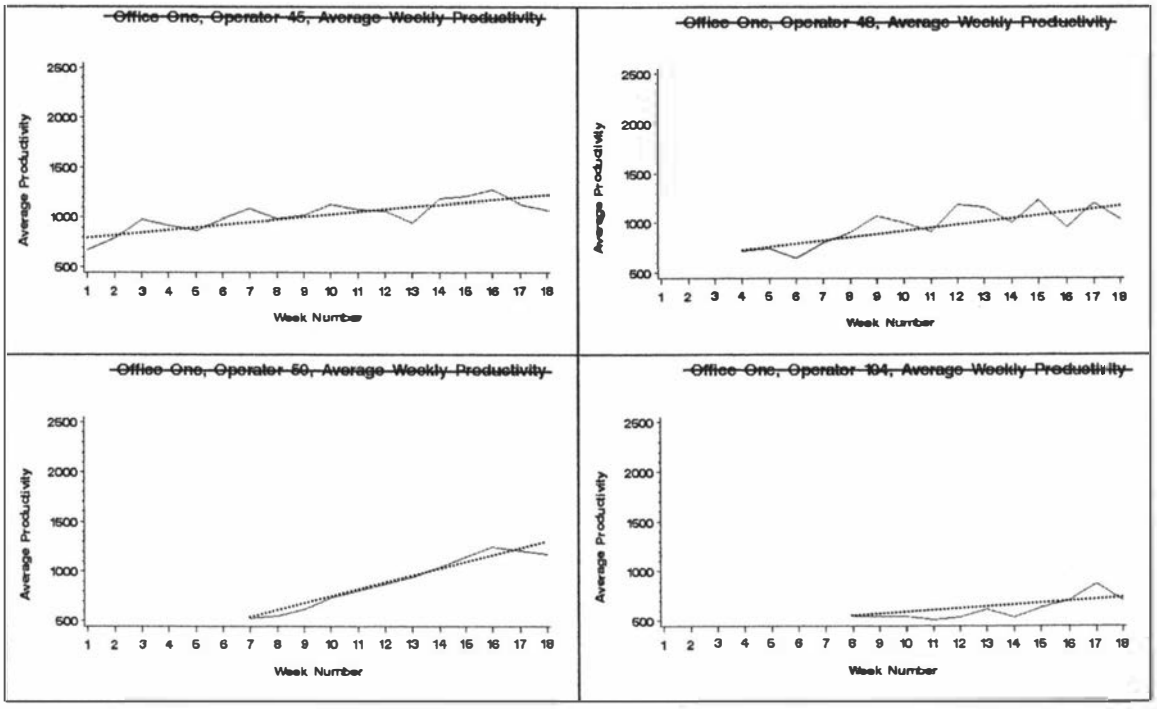
Office One, Operator 41, Average Weekly Productivity
Office One, Operator 42, Average Weekly Productivity
Average Productivity
Week Number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Office One, Operator 50, Average Weekly Productivity
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Average Productivity
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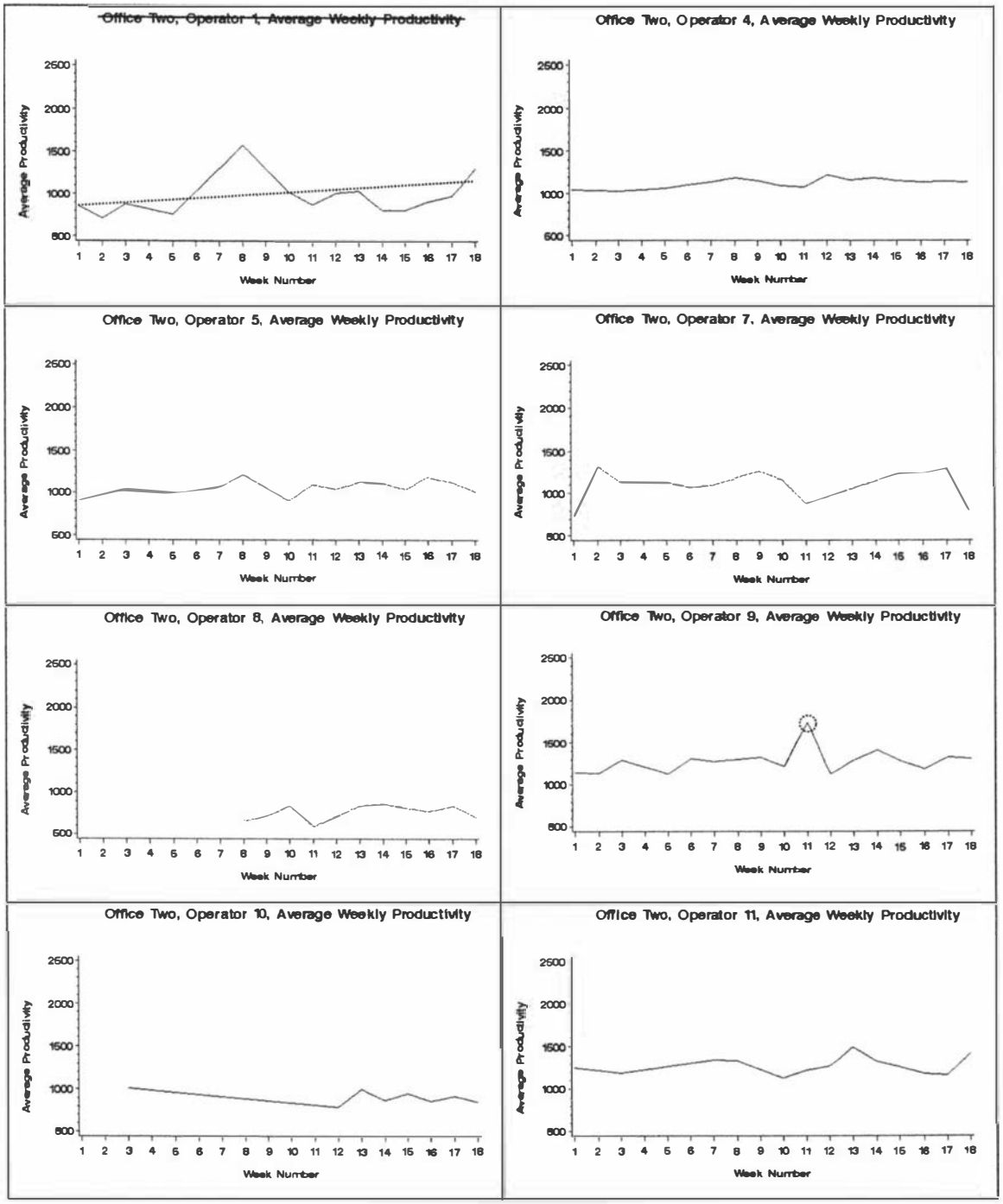
Office Two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Office Two, Operator 4, Average Weekly Productivity
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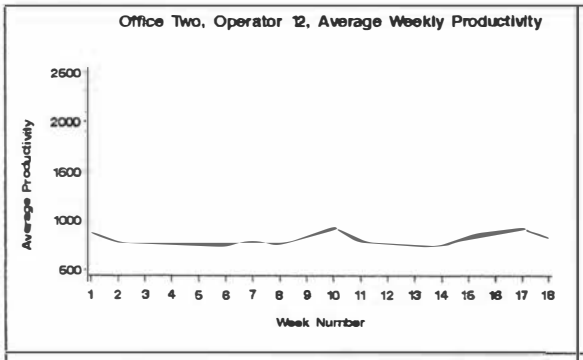
Office Two, Operator 11, Average Weekly Productivity
Average Productivity
Week Number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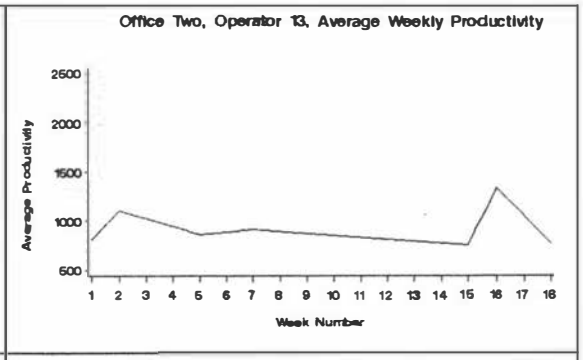
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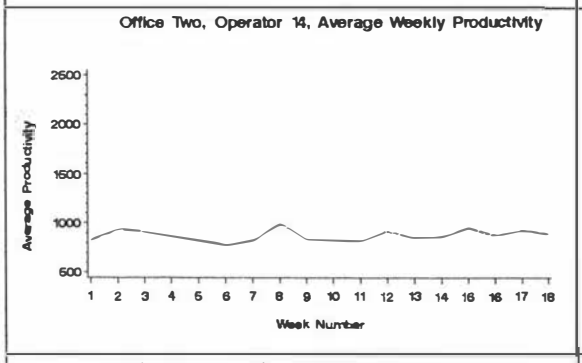
Week Number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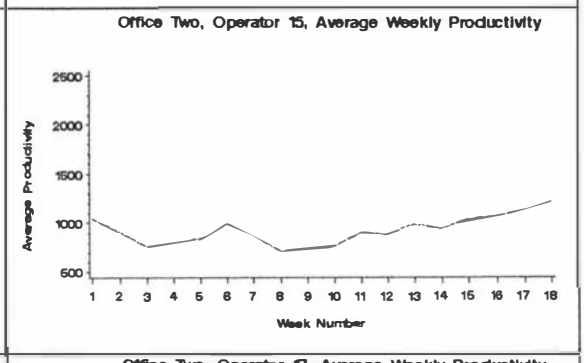
Week Number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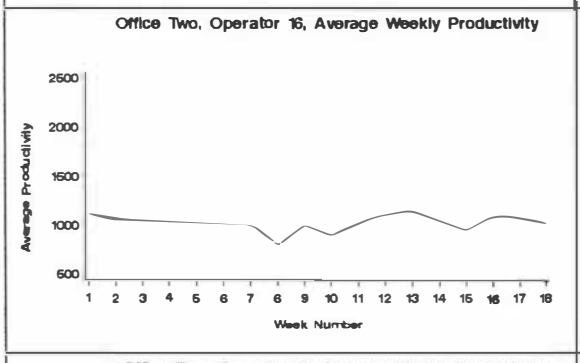
Week Number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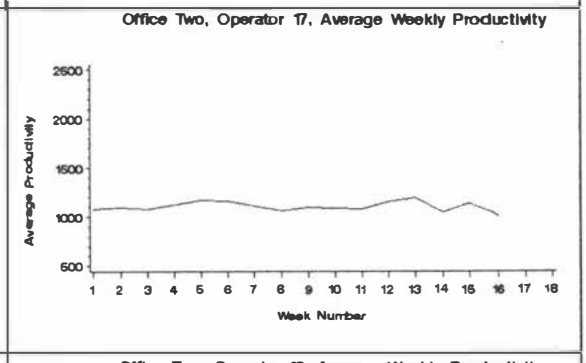
Week Number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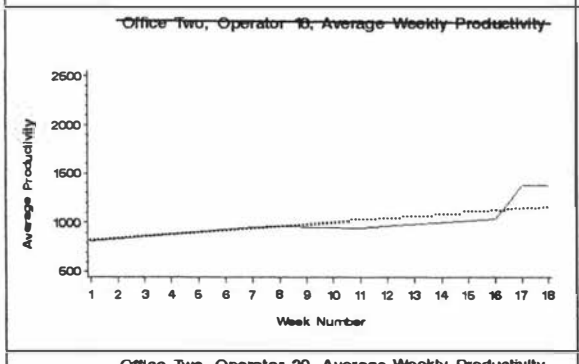
Week Number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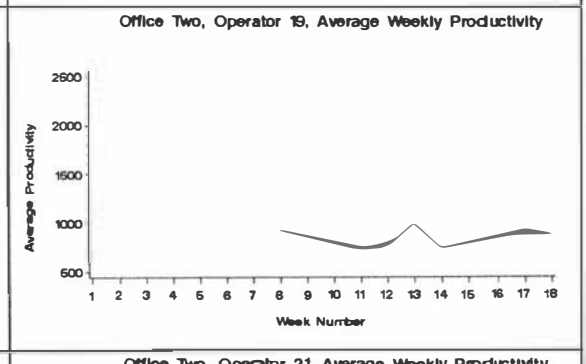
Week Number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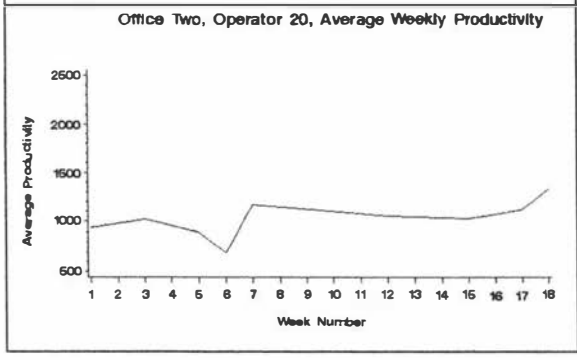
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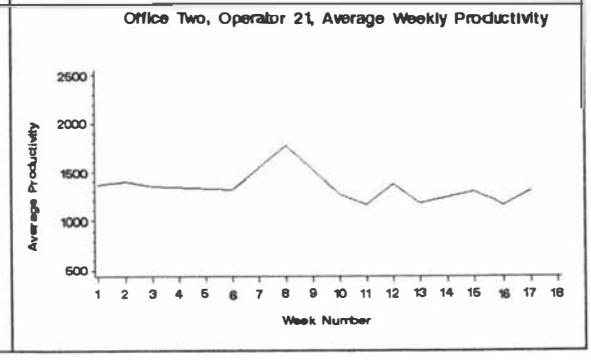
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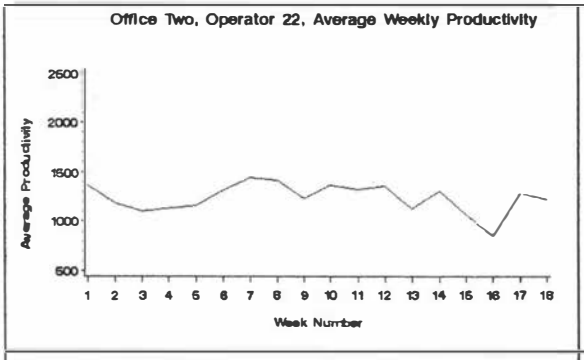
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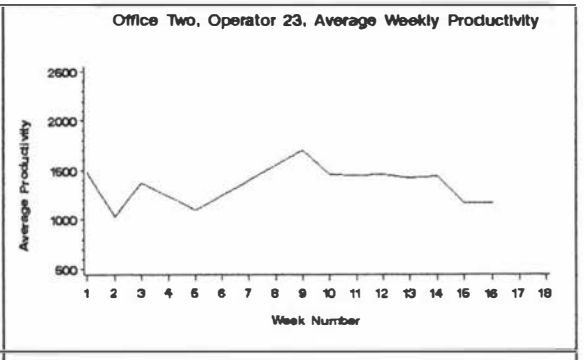
Week Number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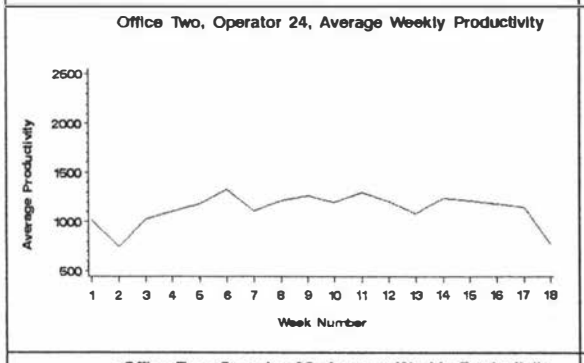
Week Number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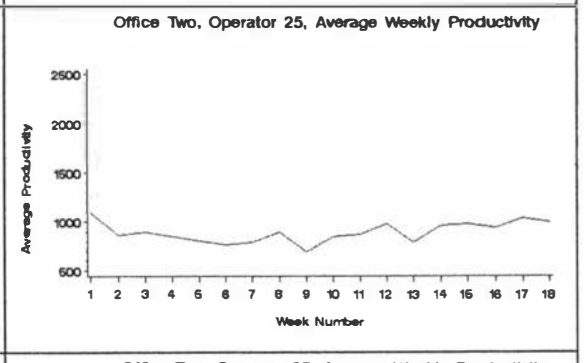
Week Number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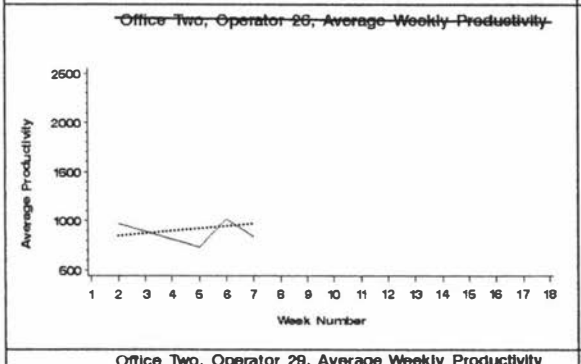
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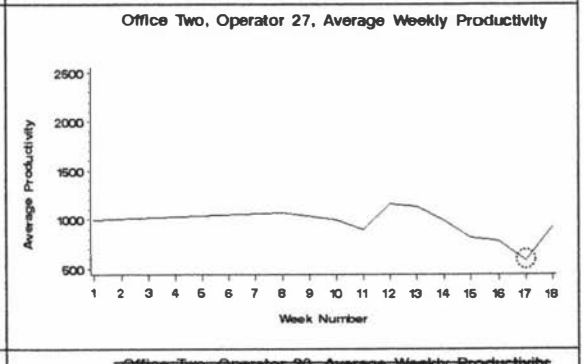
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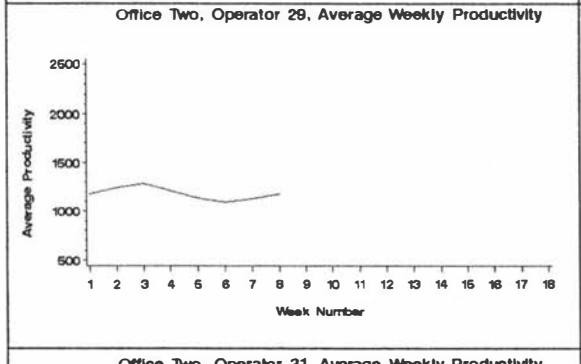
Week Number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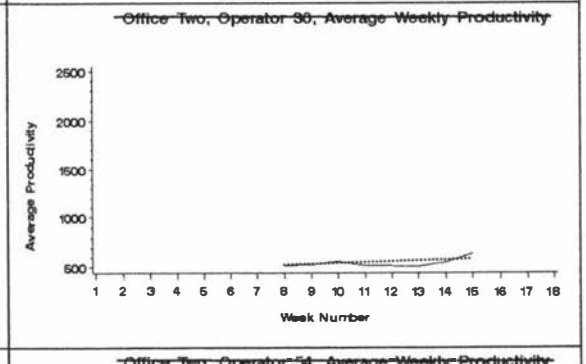
Week Number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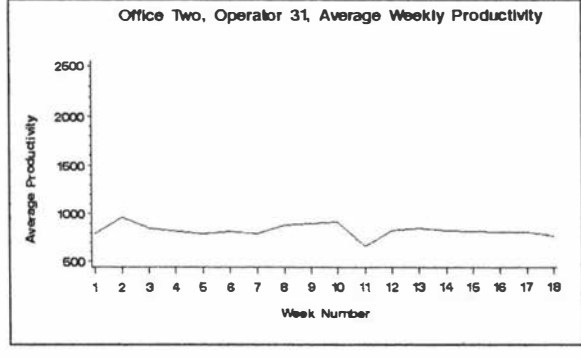
Week Number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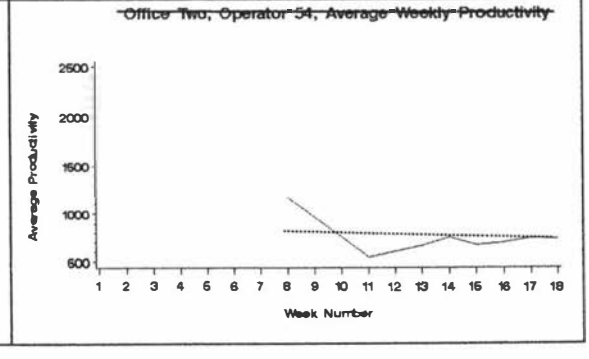
Week Number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Average Productivity
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Week Number

Appendix K: Quantitative and Qualitative aspects of Lighting: Effects on Health, Satisfaction and Productivity

Illuminance, Luminance, Luminance Contrast and Glare

There is a significant body of research that examines the effect of illuminance and luminance on the performance, satisfaction and health of research participants. The relationship between illuminance and luminance levels in relation to performance is well understood within the laboratory context and this research underpins the illuminance levels required in the workplace.

Luminance can be related to the brightness of a surface by:

$$B = a \times L^{0.33}$$

Where: B = brightness
a = constant
L = luminance in cd/m^2

The visibility of a target is dependent upon the contrast in luminance between the target and its background. The following equation is commonly used to determine the luminance contrast for visibility of tasks (such as printed text).

$$C = \left| \frac{(L_t - L_b)}{L_b} \right|$$

Where: C = luminance contrast
L_t = luminance of the target
L_b = luminance of the background

Luminance contrast can also be calculated from the light reflected from target and surround surfaces (reflectance), provided the surfaces are diffuse reflectors.

The luminance emitted from a surface is the product of the amount of light that is incident upon a surface (illuminance) and the reflectance of a surface. Illuminance describes the luminous flux density (amount of light energy) received on a surface, and is measured in lumen per meter^2 or lux. The relationship between illuminance, task contrast and size is well understood. Increases in illuminance have been shown to improve visual performance, and can partially compensate for small size and low contrast (Rea, 2000). Higher illuminance is required as task complexity or difficulty is increased.

Illuminance and luminance have been shown to have a significant effect on the perception of spaces. Research participants consistently prefer higher illuminance or luminance levels within the range of acceptable lighting for office spaces (up to approximately 1500 lux or 120 cd/m^2). Higher luminous intensity is judged as more comfortable, clearer, brighter, more colourful and more pleasant (Boyce, 1977; Boyce & Rea, 1994; Boyce & Cuttle, 1990). As task difficulty increases, increased luminous intensity is preferred, with older participants preferring higher illuminance levels (Boyce, 1973; Rea, 2000;). However, high luminous intensities can result in excessive contrast between the light source, the work task and surrounding surfaces. This can cause glare, particularly if there is excessive contrast between the work task and the immediate surrounds.

The light distribution within spaces also plays an important role in our perception of interior spaces. The pattern of light on surfaces in the field of view affects the perception of the space and comfort as well as task visibility. Too large a difference in luminance contrast can lead to excessive contrast, leading to eye fatigue and glare. Too little a difference and the work task is not sufficiently highlighted from the background, and the space lacks visual interest (Boyce, 1981; Loe et al., 1994).

Luminous intensity can be used to manipulate the mood and feelings of research participants when used in combination with the colour temperature of the lighting.

Baron et al. (1992) overall found greater positive affect under low illuminance levels (150 lux) than high illuminance levels (1500 lux). In contrast, Knez (1995) found that while the combination of luminous intensity and colour temperature that was most preferred resulted in the largest positive effect, that this varied across gender and a consistent pattern of effects was not found. The application for this research in relation to office tasks undertaken over a long time period is unclear.

CRI, CCT,Scotopic/photopic ratios, Full Spectrum Lighting

Electric lighting is designed to emulate sunlight, and it is assumed that lighting will be preferred, produce better working conditions and induce less discomfort if the colour properties of the lamp are close to that of daylight (Wilkins, 1993). However, despite extensive research, opinions remain divided on the effect of qualitative aspects of lighting on preference, health and performance.

This section discusses qualitative aspects of lighting that may effect the perception, health and performance of office personnel including lamp colour rendering, colour temperature (CCT), the balance between scotopic and photopic components of the lamp and full spectrum lighting.

Colour Rendering

The colour rendering of lamps has been shown to be important in terms of the perception of colour scenes. A body of research has demonstrated that research participants prefer coloured settings and scenes viewed under lamps with high colour rendering indices (CRI) rating the settings as brighter and more colourful than when viewed under lamps with lower colour rendering indices (Aston & Bellchambers, 1969; Worthey, 1985; Vrabel et al., 1995; McNelis et al., 1985). In addition, research participants have identified high colour rendering lamps as having increased visual clarity. This term describes a combination of perceived colour, colour rendering, contrast, colour discrimination, colour preference and border sharpness (Rea, 2000; Vrabel et al., 1995). There is some evidence to suggest that lamps with higher colour rendering indices may require less illuminance to achieve equivalent visual clarity in

comparison to low colour rendering lamps (Aston & Bellchambers, 1969; Bellchambers & Godby, 1972). When participants were asked to match the illuminance between the settings viewed under the two different lamps, the settings lit with the low CRI lamps required more illuminance to achieve an equivalent visual clarity. Worthey (1985) also found that less illuminance was required by high colour rendering lamps to achieve equivalent border contrasts, however Vrabel et al. (1995) did not find this to be the case in a similar study, although the visual clarity effect was replicated. Boyce & Rea (1994) also found that when a full spectrum polarised lamp (CRI=91) was compared to a lamp with a CRI of 73 the lamps were not rated as significantly different with respect to visual clarity[118] for matched illuminance. When the high CRI lamp had a lower illuminance (160 lx vs 470 lx) visual clarity was rated as significantly lower.

A limited number of studies have examined visual performance and these have shown that for tasks involving colour discrimination, such as colour matching, lamps with high colour rendering indices are significantly better, however for monochromatic tasks the performance has not been shown to differ (Boyce & Rea, 1994; Vrabel et al., 1998).

Other measures of lamp colour discrimination may provide equivalent benefits. The Colour Discrimination Index (CDI), which is based upon the Gamut area enclosed by the eight test colours, has been shown to be well correlated with the colour rendering index for coloured surfaces (Boyce & Simons, 1977; Thornton, 1998). However some lamps with high CDI's do not have acceptable colour appearances (Boyce, 1977).

The collection of studies that have specifically examined colour rendering have primarily examined scenes or pictures, not physical spaces. Limited studies have been conducted using performance tasks, both coloured and achromatic. Visual comfort has received minimal research attention. Overall the research to date suggests that when scenes are compared directly that lamps with higher colour

[118] Questionnaire items: clear and sharp, colour appear natural, like the colour of the light, like the lighting, comfortable seeing.

rendering indices are preferred and that these lamps give better performance for tasks in which colour discrimination is important. However limited research has considered long term studies in work spaces, despite anecdotal evidence that occupant of spaces prefer high colour rendering sources. Effects on health (eyestrain, headache, lethargy) have not been explored. However given the eyes ability to adapt to a wide range of visual conditions, any effects that may be present can be assumed to be small.

Correlated Colour Temperature (CCT)

Research examining the effect of correlated colour temperature (CCT) has primarily revolved around the effect of CCT on mood with varying illuminance. Kruithof (Davis & Ginther, 1990) first proposed that warm colour temperatures were preferred at low illuminances and cool colour temperatures were preferred at high illuminances. This theory was based on the colours of nature. Dim morning and warm colour temperatures accompany evening light, while high light levels at noon correspond to cool colour temperatures. However neither or Davis & Ginther (1990) were able to confirm this trend, with both studies finding significant differences with illuminance. Boyce & Cuttle (1990) found that 15 subjects perceived a grey coloured room more favourably when illuminance was increased or coloured elements (fruit, flowers) were added. However, the colour temperature of the space did not effect the perception of the space or colour discrimination.

Baron et al. (1992) evaluated the effects of colour temperature on tasks that did not involve visual processing including staff appraisals, interpersonal conflict and a coding task. Participants exposed to warm white light reported stronger preferences for resolving conflict through collaboration and were prepared to contribute more time as unpaid volunteers in comparison to lamps with cooler colour temperatures. In this treatment, participants rated the room as more pleasant and less glaring, with the cool white treatment rated as less pleasant. Knez (1995) examined the performance, mood and room evaluation of 95 subjects under warm white and cool white lamps at illuminances of 300 and 1500 lux. Knez (1995) found that mood and performance varied with gender. If the room was positively perceived to a greater extent under one lamp, then the mood and performance was increased. If negatively perceived then the mood and performance decreased. Boray et al. (1989) and Veitch et al. (1991) found

no differences in cognitive performance, mood and ratings of others when comparing cool colour temperature full spectrum lamps (CCT 5000 K) to other lamps with lower colour temperatures.

The mixed results from this work does not give a clear pattern of conclusions. The research has primarily examined the perception that participants have in spaces illuminated by lamps of differing colour temperatures and attempted to measure effects due to arousal or affect. Cultural differences and familiarity with lighting conditions will significantly affect this research. Anecdotal evidence suggests that climatic or geographical differences may also be influential, and this is supported by a study which found that lighting experts from around the world rated 'good quality lighting' differently (Veitch & Newsham, 1996). Overall, research suggests that any effects due to colour temperature are likely to be due to arousal or affect, and there is no evidence to suggest effects on health and performance.

Scotopic Components of Lamps

The basis for photometry at luminance levels typically found in the work environment (>10cd/m^2) is based upon the response of the cone receptors in the retina (photopic spectral luminous efficiency). Recent research has found that the rod receptors contribute to visual responses at these higher levels (Berman et al., 1994) with the pupillary response determined by the scotopic components of lamps (Berman, 1995). The scotopic contribution of the luminous output of the lamp can be calculated from the spectral distribution of the lamp and is usually expressed in terms of the ratio of the scotopic visual response over the photopic visual response.

Berman et al. (1995) found that pupillary response is determined by the scotopic components of lamps at these levels. A series of studies were conducted that showed that the visual discrimination of subjects was increased under a scotopically rich lamp (scotopic/photopic ratio: 4.3) when compared to a scotopically poor lamp (s/c ratio: 0.85). The visual performance of the subjects was not measured directly, rather, the threshold contrast was determined and increases in visual performance were construed from the lower threshold contrasts achieved. The lamps were matched for photopic luminance. A separate study found that the reduction in pupil size was lower for older

subjects (61-66 years), and there was a corresponding reduction in change in threshold contrast (Berman et al., 1994). Further research (Berman, et al., 1996) showed that scotopically deficient lamps evoked larger pupillary glare responses.

This research has some extremely interesting implications, however further work is necessary to determine the implications in relation to lamps that are more typically used in commercial lighting installations and using tasks that more closely resemble those undertaken by office personnel. In the studies cited, the visual task was at threshold levels, and was very difficult, utilising a small target, low contrasts and brief exposure times. The scotopically rich lamp was not typical of those used in office buildings.

There have however, been several other studies that have examined commercially available lamps with differing scotopic/photopic ratios (Veitch & McColl, 1995; Vrabel et al., 1995). In these studies, other aspects of spectral distribution were the primary focus, making it difficult to separate effects due to the scotopic component of the lamps. However, the results at this stage do not show a consistent pattern that can be explained by differences in the scotopic component of the lamps used in these studies.

Full Spectrum Lighting

Many studies have been undertaken to determine the effect of full spectrum lighting on health, performance and satisfaction. Unfortunately, much of the earlier research in this field had significant methodological drawbacks. More recent research (Boray et al. 1989; Veitch et al., 1991; Boyce & Rea, 1994) compared full spectrum lighting to other lamp types in repeatable and rigorous laboratory research. Boyce and Rea. (1994) compared visual acuity, colour matching, reaction time, cognition, affect and user assessment of 28 participants who participated in a repeated measures study of three lighting settings. Two rooms were lit by full spectrum polarised lighting (470 lux and 160 lux), triphosphor fluorescent lamps in a recessed luminaire with low brightness specular reflectors lit the third room (470 lux). The reduced illuminance in one of the full spectrum lighting settings was consistent with the advocacy that full

spectrum polarised lighting required less illuminance. The results showed that illuminance level and polarisation (for low contrast stimuli) significantly affected visual acuity. Both full spectrum polarised lighting treatments significantly improved performance in a colour matching task. The low illuminance full spectrum polarised lighting treatment was assessed as less clear, natural, pleasant, comfortable and acceptable than the higher illuminance conditions. There were no significant differences for reaction time or cognitive performance. Comparable results have been reported by other researchers with the overall conclusions as follows (Boyce et al., 1992; Veitch, 1994):

- The effect of full spectrum polarised light is consistent with the current international understanding of the effects of high colour rendering, polarised lighting;
- There is no evidence of a marked decrease in illuminance for this lighting without detriment to visual performance or impression;
- There is a slight improvement in task visibility when veiling reactions occur for low contrast stimulus. This effect is due to the polarisation of the diffuser;
- There is an improvement in the accuracy of colour sorting or other tasks that are reliant on colour discrimination due to the high colour rendering of the lamp.

Claims that full spectrum polarised lighting markedly improves health, performance and user perception are not supported by the laboratory research that has been conducted. For specific work tasks involving low contrasts with veiling reflections or colour matching, full spectrum polarised lighting is superior to conventional lighting. Other lamps are also able to provide these benefits for such specialised tasks. However, the range of laboratory research conducted does not examine the long term effects of the lighting on health, performance and user perception in the work environment. Health effects in particular are not captured well by laboratory research. Despite this, the body of research available suggests that any effects are likely to be small, and other lamps may be able to provide equivalent results with higher efficacies and lower capital costs.

Overall Conclusions

The research in this field suggests that luminous intensities that optimise task performance are perceived more positively by research participants. There is, however, considerable variation in this optimum level, dependent upon the age of the participant and the nature of the work task being completed. Further research is required to understand more fully the importance of light distribution in the satisfaction of office personnel. However, unless poor light distribution results in visual discomfort, most effects are likely to be due to arousal or positive affect.

Overall the literature on qualitative aspects of lighting reveals equivocal results that are capable of a wide range of interpretation. In many of these studies the research methodology is not sufficiently outlined. Many older studies, particularly those evaluating full spectrum lamps suffer from methodological flaws, which limit their inference.

One significant limitation in many of the studies reviewed is that the majority of lamps have not been matched on aspects of spectral distribution including: colour rendering indices, colour temperature and scotopic/photopic ratio. This is extremely difficult to achieve as the phosphors selected predetermine the lamp characteristics on these measures. In addition, the laboratory research that has been conducted is limited in its ability to identify long term effects that may be due to spectral distribution. In particular, short-term studies cannot easily measure visual fatigue, visual comfort or other health or comfort aspects.

Overall, the research suggests that spectral differences may influence perception, positive affect and arousal, although the pattern of affect is not clearly understood. Further research is required to further elucidate the role that both quantitative and qualitative aspects of lighting play in the health, satisfaction and productivity of office personnel, however any effect that exists is likely to be small.

Appendix L: Typical ANOVA Table

Complete data set (C)

Monthly Average Headache Symptoms Data

Source	DF	SS	MS	F Value	Pr > F
Between Subjects:					
BANK	2	0.03855409	0.01927704	0.02	0.9810
OPERATOR(BANK)	68	68.23103270	1.00339754	(Error)	
Within Subjects:					
TRIAL	2	0.50339490	0.25169745	0.85	0.4290
TREAT	2	0.96482950	0.48241475	1.64	0.2003
TRIAL*TREAT	2	1.06534149	0.53267074	1.81	0.1699
Error	89	26.22084280	0.29461621		
Total	165	97.02399547			

R-Square = 0.729749

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