The assessment of indoor environment quality in New Zealand early childhood education centres

August 2019

A thesis presented in full fulfilment of the requirements for the degree of Master of Philosophy in Science

Author: Tiffany Flood

Student Id: 16310778

At Massey University, Albany, New Zealand

To my husband,

son and mother

whose love and support

never fades

- thank you.

Abstract

The review of literature highlighted a knowledge research gap in the understanding of New Zealand early childhood education indoor environment quality, particularly in Auckland. The objective of this thesis was to, therefore, begin to fill this gap. This was achieved by predominantly monitoring the indoor environment quality in four early learning education centres for one year.

The results showed a lack of indoor environment quality standards in early childhood education. Mean carbon dioxide levels in 75% of the sleep rooms monitored exceeded ASHRAE and Ministry of Education school guidelines; the mechanical ventilation in one of the centres did not meet the New Zealand mechanical ventilation standard and the thermal comfort range was exceed 14% of the time during operating hours. The maximum relative humidity guideline set by ASHRAE and recommended in New Zealand schools, was exceeded 29% of the time during operating hours and 66% of the time outside operating hours, therefore possibly supporting mould and bacterial growth. Building audits identified poor cleaning routines in most rooms. Only 22% of the classrooms met the New Zealand building code G7 for Natural light and 55% had poor views to outside, as also required under G7. None of the classrooms achieved a daylight factor greater than 2% as set out in the Ministry of Education school guidelines and 33% of the classrooms interior lighting met New Zealand interior and workplace lighting standards. Those classrooms with mostly hard floors and ceilings have potential reverberation issues.

This study highlighted that further research is needed to investigate the ventilation requirements in sleep rooms and the natural light, views to outside and interior lighting requirements within early childhood classrooms. The Ministry of Education and Ministry of Health should provide guidance and advice before a centre is built. The inclusion of an indoor environment quality assessment should be considered as part of a centre’s Education Review Office assessment and that the importance of indoor environment quality should be part of the curriculum when training early learning teachers. This study may be applicable to the New Zealand early childhood education industry and researchers of indoor environment quality.

Keywords

Indoor environment quality, indoor air quality, sound, acoustics, noise, light, early childhood centres, daycare centres.

Contents

Acknowledgements

I would like to express my deepest gratitude and appreciation to my husband Phil Smith, my son, William, and my mother, Christine Macfarlane, who have been on this journey with me for the last twenty years. Thank you for all your encouragement, patience and guidance.

I would also like to share my deepest thanks to my supervisor Mikael Boulic, for his guidance and availability during this study and to Professor Robyn Phipps, who started me on this path. I also wish to express my sincere thanks to my co-supervisors Susan Mander and Wyatt Page, for their constructive guidance and encouragement.

A huge thank you to Mike Bedford for his support during the thick of it and Yu Wang for her training, guidance and kindness. Thank you too to Hugo Blackburn for bringing light to the dark art of statistics.

Thank you, also, to the early childhood education centre owners, managers and teachers who supported us in this study, with a special thank you to those who opened their centres for us over many weekends and who kept them open for us into the night after having already worked a full day. I would also like to thank our local primary school and Kindergarten for their support at the beginning of this journey, which has taught me so much.

Thank you to those within the building industry that support my research and provided their industry knowledge and advice. They include the wonderful teams at Autex Industries Ltd, Hometech Ltd, Resene Paints New Zealand Ltd, Winstone Wallboards Ltd and APL Window Solutions, in particular, David Waters.

I dedicate this work to the warriors by my side and to all those who believe in beautiful human spaces and that we MUST do better for our *tamariki* (children).

It is also a pleasure to acknowledge the publishers for their permissions to reproduce their copyright material. They include Clarke Roberts from Cirrus Research for Figure 2-9; Peter R. Boyce and CRC Press, for Figure 2-4; F. Alton Everest, Ken C. Pohlmann and McGraw-Hill Education, for Table 2-2; Inductiveload and NASA for Figure 2-4; Thomas Higher Education, for Figure 2-8; Creative commons, for Figure

2-19 a; Google maps, for Figure 2-19 b and Figure 5-2; Alexander Turnbull Library, for Figure 2-13; The Ministry of Education, Figure 2-15, Figure 2-17, and Figure 2-18; National Institute of Water and Atmospheric Research, for Figure 2-23; Archives NZ, for Figure 2-13 and Figure 2-14, IEEE, for Figure 2-7.

This study was carried out in accordance with Massey University Human Ethics and was approved by the Committee Massey University Human Ethics. The study was peer-reviewed and judged to be low risk.

i. List of abbreviations

AFFL	Above finished floor level
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BRANZ	Building Research Association of New Zealand
CIE	Commission Internationale de l'Eclairage
CO_2	Carbon dioxide
DQLS	Designing quality learning spaces
ECE	Early childhood education
EPA	United States Environmental Protection Agency
IAQ	Indoor air quality
IEQ	Indoor environment quality
MBIE	The New Zealand Ministry of Business Innovation and Employment
MoE	The New Zealand Ministry of Education
NIWA	National Institute of Water and Atmospheric Research
NZ	New Zealand
NZBC	New Zealand Building Code
NZS	New Zealand Standard
PM	Particulate matter
RH	Relative humidity
SNZ	Standards New Zealand
WHO	World Health Organisation

ii. List of tables

iii. List of figures

1. Introduction

The World Health Organisation (WHO) has stated that indoor environments is a health concern (World Health Organisation Regional Office for Europe, 2010). Over 90% of people's exposure to air pollutants occurs indoors (Kostinen et al., 2008). Indoor air pollutants to which people are exposed come from outdoor air pollutants entering the building, the materials from which the building is constructed, items brought into the building (e.g., furniture and clothing) and activities within the building (e.g., cooking and how it is ventilated) (J. Bennett et al., 2018; Kostinen et al., 2008; Trompetter et al., 2018).

It is estimated that, in today's society, children spend up to 85% of their time indoors (Lum, Jenkins, & Shimer, 2013). Younger children are more vulnerable than adults to the indoor environment's effects. This is due to their faster breathing rates and their larger lungs in proportion to their body sizes, as well as to their rapid growth and undeveloped bodies including their eyes and respiratory and immune systems (W. D. Bennett, Zeman, & Jarabek, 2008; Branco, Alvim-Ferraz, Martins, & Sousa, 2015; Fuentes-Leonarte, Ballester, & Tenias, 2009; Tomita, Shichida, Takeshita, & Takashima, 1989). In New Zealand (NZ) one in seven children (14%) are reported as being on asthma medication, and the third most common cause of death in NZ is respiratory disease (Telfar Barnard & Zhang, 2018).

Government regulation and guidelines set minimum standards for indoor environment quality (IEQ) factors such as indoor air quality (IAQ), lighting, and acoustic quality. For example, New Zealand Building Code (NZBC) G7 Natural Light sets a minimum performance requirement of "*an illuminance of no less than 30 lux at floor level for 75% of the standard year"(*MBIE, 2014a, p. 3*)*. Research from around the world including Holland (de Waard & Zeiler, 2014), Korea (Kabir, Kim, Sohn, Kweon, & Shin, 2012), Portugal (Branco et al., 2015; Oliveira, Slezakova, Delerue-Matos, Pereira, & Morais, 2017), Malaysia (Salleh, Salim, & Kamaruzzaman, 2016), and the United States of America (Satterlee, Molavi, & Williams, 2015) has found that when IEQ factors are measured in Early Childhood Education (ECE) centres, they are falling below the minimum regulated standards.

In 2017, there were a total of 5,527 licensed and certified ECE services across NZ, of which 2,558 were ECE centres. From 2005 to 2017, the number of ECE centres alone grew by 46% (804 ECE centres). In 2017, 66% of New Zealand children under five-years-old were enrolled in early education services, with 38% of these children living in Auckland (MoE, 2017b, 2017d). The climate in Auckland is subtropical, with warm, humid summers and mild, wet winters with a high and reasonably consistent relative humidity throughout the year (Chappell & National Institute of Water and Atmospheric Research, 2014).

Through the review of literature, a research knowledge gap was highlighted in NZ ECE IEQ, particularly in Auckland. The objective of this thesis was to, therefore, begin to fill this research knowledge gap. It does this by being the first to investigate NZ ECE IEQ, particularly in Auckland through the following three research questions:

1. What is the NZ education facilities environment, and is there an interest for IEQ research, particularly in ECE?
2. How can ECE centres be safely and sensitively monitored?
3. What is the IEQ in Auckland ECE centres and how does it compare with local regulations, standards and guidelines?

To answer these research questions the objective of:

- Research question one was to gather industry feedback regarding the local NZ education facilities environment from ECE to schools and see if there is was an interest for IEQ research, particularly in ECE.
- Research question two was to determine the scope and appropriate materials and methodology to measure the IEQ of an ECE centre safely and sensitively in NZ. The planning for the symposium began in June 2016 with the four case studies starting shortly after that.
- Research question three was to measure the IEQ within four urban ECE centres in Auckland over a year and to assess these results against current NZ building

regulations and educational guidelines. Nine classrooms and four sleep rooms were monitored in total.

The factors included were IAQ, light and sound. The factors included within IAQ were carbon dioxide (CO2) as an indication of ventilation rate, relative humidity (RH), temperature and dust.

The key limitation of this study was the sample size of four centres, nine classrooms and four sleep rooms. However, this smaller sample size enabled data to be collected over a period of a year across multiple IEQ factors by one researcher.

This study is applicable to the New Zealand early childhood education industry as it begins to fill the knowledge gap in the understanding the NZ ECE IEQ, particularly in Auckland.

2. Literature review

2.1. Introduction

This literature review begins by presenting the results of a systematic review of indoor environment quality academic journals, which concerned buildings whose occupants are considered to be more vulnerable to IEQ (World Health Organisation Geneva, 1999), i.e. ECE centres, schools or aged care. It then briefly explores three key IEQ factors: IAQ, light and sound. How these factors can be managed is then discussed and concludes with a summary of the effects of the IEQ on humans, particularly children.

Focus next turns to NZ, highlighting the health of the country's population and it's building stock. It then discusses NZ ECE services in greater detail, including the history of ECE building typology, ECE services today and the ECE regulatory framework that influences the IEQ in ECE centres. Bringing the argument to a more localised context, the section examines the population, geography and climate specific to Auckland, NZ.

2.2.A systematic review of IEQ academic journals

A systematic search and review was conducted to understand what IEQ research has been undertaken in those buildings whose occupants are more vulnerable to IEQ. Particular focus was given to what specifically they studied and how these studies were carried out.

2.2.1. Method

The methodological guideline used to complete the systematic review was based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRIMSA) (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group (2009), 2009). This approach has been used in other similar IEQ studies (Jung et al., 2017).

The approach adopted in the search and review was iterative. The online Massey University Library Information Resources: (*http://www.massey.ac.nz/massey/research/library/find-information/find-information_home.cfm)* were used to search for relevant ECE IEQ academic journals. Research databases used within this library were Discover, Web of Science, Google Scholar and Scopus.

An initial word search was run in the online library to find relevant words. An initial filter was applied during these searches only to include academic journals written in English and no restriction on the date was applied. The results of these searches returned a positive number of potential academic journals. To determine how recent the academic journals were, and if an age filter should be considered, a filter was applied using the year the academic journals were published against the word combination of 'indoor environment quality'.

The words 'indoor environment quality' were then paired with each of the relevant ECE words to identify potentially relevant academic journals. More than 50% of the journals found were IAQ based studies with only a few reviewed academic journals related to light and sound. A further academic journal search was therefore undertaken specifically using the words 'light' or 'acoustics'. This search was restricted to the Discover database due to the significant use of the phrases 'in light of' or 'light on' and it was the only database that could facilitate this kind of filter and pairing of words.

Any duplicates from across the databases were then removed. Following this, the academic journals that met the following eligibility criteria were selected for assessment if their full-text articles could subsequently be sourced:

- The study was focused on those buildings whose occupants are considered to be more vulnerable to IEQ or a component of IEQ, i.e. ECE centres, schools or aged care; and
- The study investigated children's health or wellbeing or that of the elderly and
- PDF academic journal was accessible through Massey University's search engine or Google Scholar.

A final search was undertaken of the above journals references to identify further relevant academic journals. Any relevant academic journals identified were then searched for in the online Massey University library or in Google Scholar and added to EndNote X9 if they met the above criteria. A summary of the methodology used is presented in Figure 2-1.

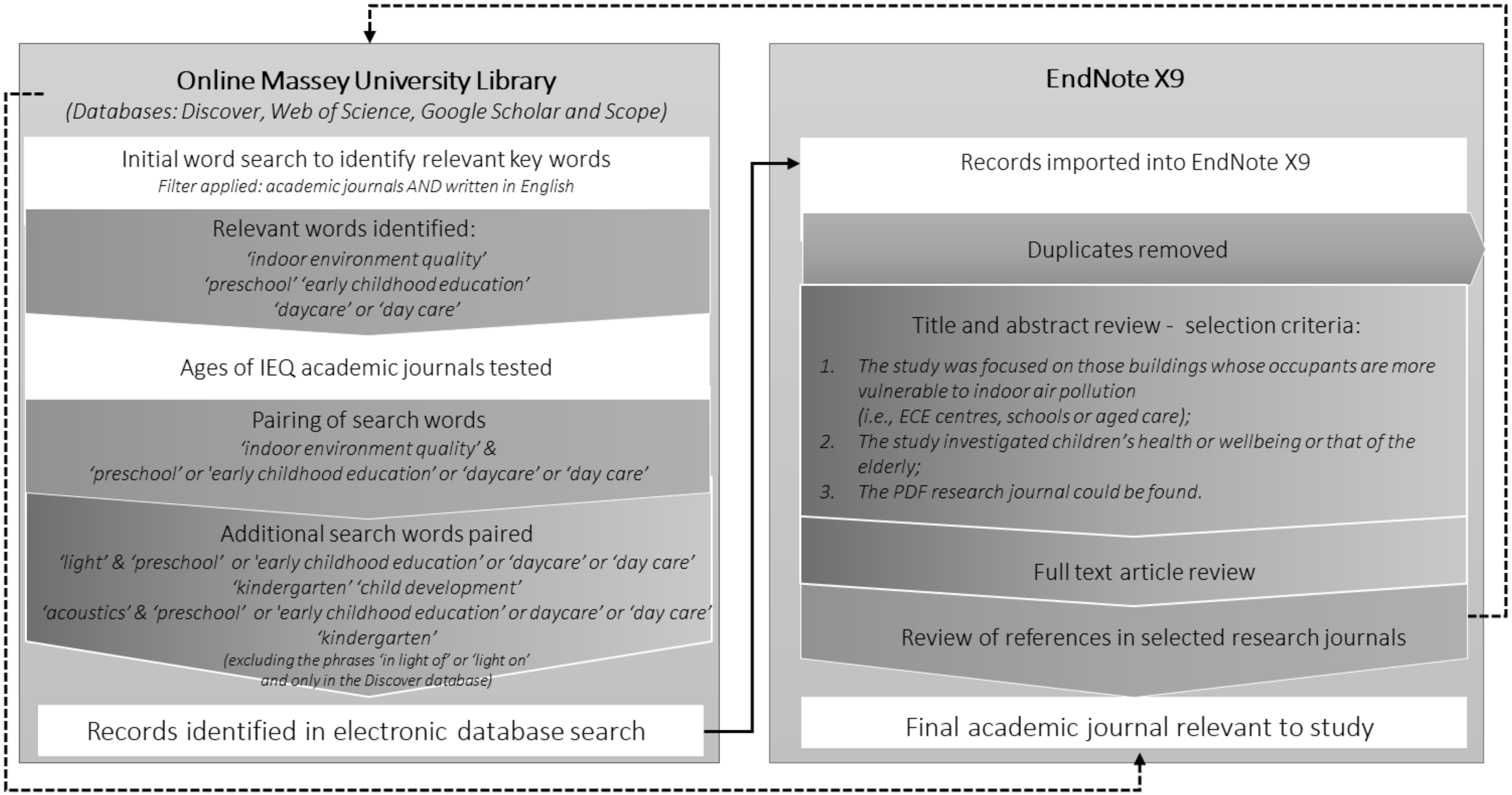


Figure 2-1 A summary of the methodology used to search for relevant IEQ academic journals in those buildings whose occupants are considered to be more vulnerable to IEQ.

2.2.1. Search results

As presented in Figure 2-2, a total of 3,363 records were identified in the electronic database search. Once transferred into EndNote X9, 209 duplicate records were removed. After an initial title review, 2,046 records were removed then 440 records more were removed after reviewing their abstracts. A further 553 were later eliminated with the full-text article either not found or was inaccessible. This resulted in 115 relevant academic journals with 134 additional relevant academic journals found through either the references of these 115 academic journals or other sources.

Of the final 249 relevant academic journals, most were IAQ related research journals. 15 (6%) were from NZ however, three of these related to the same study and only two concerned ECE. The first studied sound, and the second reported the durability of hardware and the safety of doors and windows.

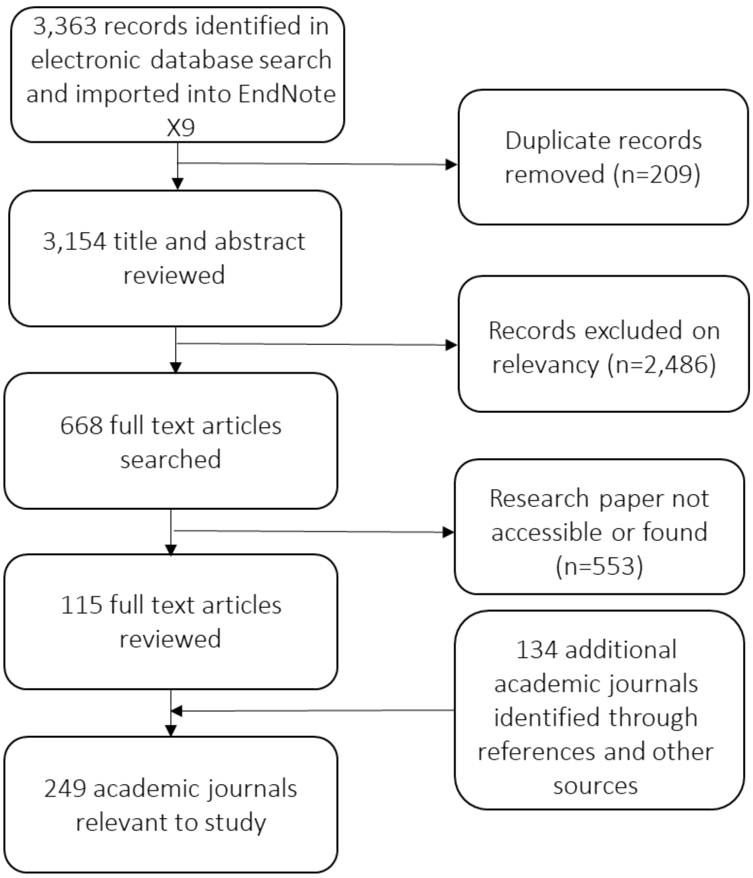


Figure 2-2 A summary of the results from the search for relevant IEQ academic journals in those buildings whose occupants are considered to be more vulnerable.

Currently, in NZ, there are only two other ECE indoor environment studies. The first study has just been completed and was undertaken in Wellington, NZ. This study investigated temperature, relative humidity and space standards against how often children and teacher get sick. The second study is a pilot study currently being undertaken in Auckland, NZ and is investigating how the wellbeing of ECE occupants could be assessed in relation to their environment.

The low number of research papers indicates that little research has been done in ECE indoor environments, in particular in NZ with only one other in Auckland.

2.3. Key indoor environment quality factors

Environmental health is defined by WHO as:

"All the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments." (World Health Organisation Regional Office for South-East Asia, 2019, p. 1)

Therefore the assessment of indoor environmental factors can assist in quantifying the IEQ of an indoor environment (de Waard & Zeiler, 2014). The three indoor environmental factors considered in this thesis are IAQ, light and sound. The Building Research Association of NZ (BRANZ) includes these three factors in the environmental parameters that should be considered when designing an optimal, cost-effective learning space. (MoE, BRANZ, Acoustic Society of NZ, & Victoria University of Wellington, 2016).

2.3.1. *Indoor air quality*

IAQ is defined by the level of air pollution within a building or enclosed space. As shown in Figure 2-3 IAQ is determined by the cumulative air pollution generated from inside a building, any air pollution brought into that space from the outside, the extraction of this polluted air and its replacement by the intake of outside air. Components of IAQ include carbon dioxide, and other respiration derived pollutants, particulates, volatile organic compounds (VOCs) and other chemicals (ASHRAE, 2016; de Waard & Zeiler, 2014), such as formaldehyde, NO and NO_2 (World Health Organisation Regional Office for Europe, 2010).

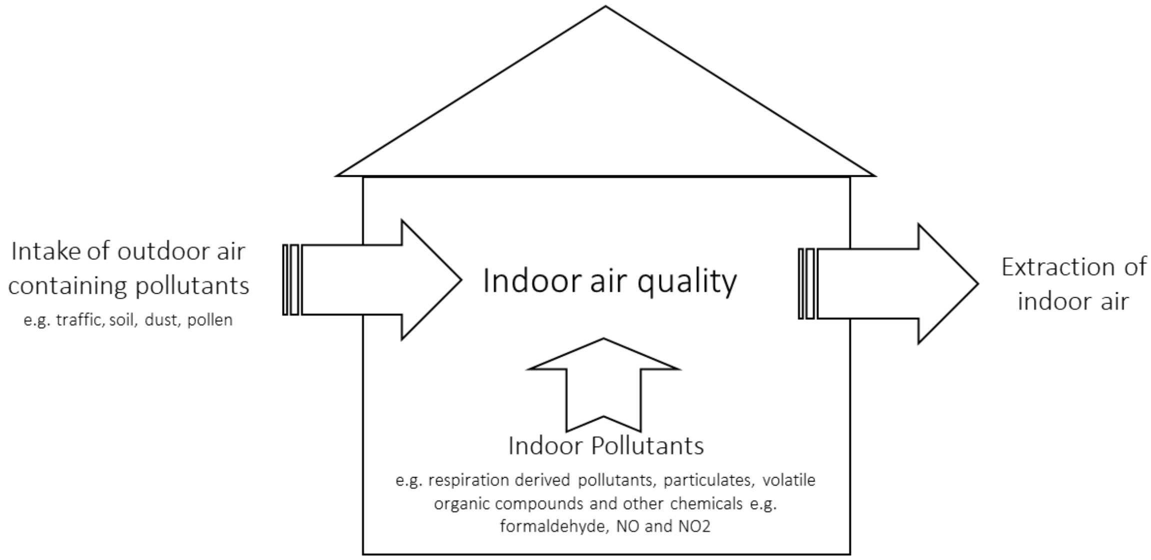


Figure 2-3 A summary of indoor air quality using the mass balance model.

The concentration of carbon dioxide (CO_2) is often used in research as a good proxy for the quality of indoor air and ventilation (J. Bennett et al., 2018; de Waard & Zeiler, 2014; Kolarik et al., 2016; Oliveira et al., 2017). The baseline comparison for indoor concentrations is the outdoor CO_2 concentration level. Outdoor concentration levels can vary, depending on location and the geographical terrain, though these levels are generally around 450 to 650 parts per million (ppm) with a global monthly mean of 410 ppm as of June 2019 (U.S. Department of Commerce, 2019). Over time, the breathing of occupants in an enclosed space increases CO_2 concentration. The relationship between indoor CO_2 concentrations and ventilation rates is therefore expressed primarily as air changes per hour (ACH) or litres per second per person (L/s/P) (ASHRAE, 2016; Standards NZ, 1990).

Particulate matter (PM) is a mixture of liquid and solid particles suspended in the air. PM may come from human or natural sources. Suspended particles of biological origin are called bioaerosols. PM is typically classified by size. PM_{10} particles includes all particles less than 10μm in diameter, and $PM_{2.5}$ particles includes those less than 2.5μm. PM_{10} particles are coarser and heavier and, therefore, can be filtered by the nose and throat, whereas $PM_{2.5}$ particles are finer and lighter and can, pass deeper into the lungs and into the bloodstream (J. Anderson, Thundiyil, & Stolbach, 2012).

Research has shown that half of the PM in schools is made up of soil tracked in from outside, organic material from a person's own body, clothing fibres, VOCs, carpeted floors, building materials and toys. The rest comes from the outdoors, including minerals from hard surfaces and road traffic. PM generation and re-suspension are caused by indoor/outdoor movement and activities. Indoor PM levels can be two to five times the outdoor levels (J. Bennett et al., 2018; Gaspar et al., 2018; Trompetter et al., 2018; Zuraimi & Tham, 2008).

VOCs and other chemicals are emitted by building materials, furnishings, appliances and resources used in a space particularly at night (Hwang et al., 2017). VOC and other chemicals become harmful to humans when they exceed relevant concentration levels (World Health Organisation Regional Office for Europe, 2010). These levels can be notably higher in new or refurbished buildings, as they tend to be higher in newer products, but the levels diminish over time (Mendell, 2007; Salleh, Salim, Kamaruzzaman, Mahyuddin, & Darus, 2016). VOCs are challenging to measure and set limits on. This is due to the broad range of compounds, the wide variety of sources and the variability in their toxicities. This also makes CO_2 concentrations an inadequate proxy for these pollutants (World Health Organisation Regional Office for Europe, 2010). Other chemicals that may be found in the indoor air include carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone, semi-volatile organic compounds and endocrine-disrupting chemicals (Mendell, 2007; MoE, 2017a; World Health Organisation Regional Office for Europe, 2010).

The human body works to maintain an internal body temperature of approximately 37°C. It accomplishes this through the exchange of heat between the environment and the body. Thermal comfort has been defined as the expression of satisfaction with the thermal environment of a space (ASHRAE, 2017). Thermal comfort directly impacts the energy consumed in a building, as the occupant's sense of discomfort leads them changing the settings of the heating or cooling system (Catalina & Lordache, 2012). Occupants of a building need to be thermally comfortable if they are to produce to their full capacity (Al horr et al., 2016).

Six factors influence thermal comfort. Four are environmental and include air temperature, mean radiant temperature, air RH and airspeed through ventilation.

The other two factors are personal: human metabolic rates and insulation provided by clothing (Katafygiotou & Serghides, 2014). Other factors influencing occupant's perceptions include gender, age and illness (Nicol & Humphreys, 2002; Smolander, 2002), along with building typology, outdoor climate and season (Frontczak & Wargocki, 2011).

Air temperature, as well as the mean radiant temperature within a building, is determined by heat transfer through conduction (when energy is transferred by direct contact), convection (when energy is transferred by the mass motion of molecules) or radiation (when energy is transferred by electromagnetic radiation). These types of heat continually flow in and out of a building in response to temperature differences between the outside and the inside. Elements that influence indoor temperature and, therefore, thermal comfort include the season, the building to orientation the sun, the external surface to internal volume ratio, the thermal conductivity and resistance of the building materials (including thermal mass and insulation), the ventilation type and the heating and cooling mechanisms.

The humidity ratio is the amount of water vapour in the air (Kg of moisture per Kg of dry air). The air can, however, hold different amounts of water vapour, depending on the temperature of that air. This relationship is measured in terms of RH.

Indoor moisture comes from both outdoor and indoor sources. Outdoor moisture can come through natural or mechanical ventilation, from a deficient building fabric or from moisture rising from subfloors or basements. Indoor sources include indoor activities e.g., cooking, bathing, non-vented fuel combustion and human, animal and plant metabolism (ASHRAE, 2009).

Psychrometric charts show the relationship between RH, temperature (wet-bulb and dry-bulb), dew point and enthalpy (heat content). As temperature decreases, RH will increase along with a constant humidity ratio. Condensation will occur along with the dew point, e.g., if there is a surface with a temperature below the dew point (RH = 100%), then condensation will occur on that surface (Plagmann, 2016). Using this chart, ASHRAE 55 (2017) defines summer and winter comfort zones.

These are acceptable ranges of operative temperature and humidity for people wearing summer and winter clothing during mostly sedentary activity (ASHRAE, 2017). This standard does not set a minimum RH level but ASHRAE Standard 62.1-2016, Ventilation for acceptable indoor air quality, does recommend an RH level at or below 65% to reduce the likelihood of environmental condition that may cause mould growth (ASHRAE, 2016). The United States Environmental Protection Agency (EPA), however, recommend an RH range of 30% to 60% (United States Environmental Protection Agency, 2017b).

2.3.2. Managing indoor air quality

There are generally two strategies used to manage IAQ and thermal comfort (Al horr et al., 2016). The first is through increasing ventilation rates (J. Bennett et al., 2018; Daisey, Angell, & Apte, 2003; Trompetter et al., 2018), and the second is by reducing sources of pollutants from within the building and tracking in from outside the buildings (Trompetter et al., 2018; Wargocki, Wyon, Baik, Clausen, & Fanger, 1999).

Increasing ventilation rates

Concentrations of indoor pollutants released by indoor sources can be reduced using ventilation (de Waard & Zeiler, 2014; Ramalho, Mandin, Riberon, & Wyart, 2013). The prediction of ventilation performance within buildings is very relevant to occupants health (Araújo-Martins et al., 2014; Mendell, 2007). Ventilation rates can be increased naturally, mechanically or through a combination of both methods (ASHRAE, 2016).

Ventilation is defined as the extraction of polluted air and the intake of fresh, clean air from outside (de Waard & Zeiler, 2014).

The occupied zone is defined as the area within 1.82m from the floor and not within 0.3m from the walls (ASHRAE, 2016). This is the area of occupancy; therefore, excessive draft velocities and temperature differences within this space are to be avoided. Factors that influence draft velocities and temperature differences, as well as pollutant removal, include:

- The effectiveness of the supply and return of the ventilation system.

- Any convection currents created through inadequately insulated exterior walls.
- The stratification of the air within the room (Khayata, 2014).

Reducing the sources of pollutants

Measures to reduce the sources of pollutants include:

- Using low VOC building materials and products (J. Bennett et al., 2018; Zuraimi & Tham, 2008).
- Maintaining a room temperature at least below 26°C and ideally below 22°C, which may reduce VOC concentrations (MoE, 2017a).
- Placing entry/exit mats at principle entries and exits to mitigate the tracking in of dust and dirt from the outside (J. Bennett et al., 2018; MoE, 2017a; Trompetter et al., 2018).
- Managing indoor bioaerosols, either through ventilation or by minimising their proliferation through moisture control. Moisture is one of the agents needed for mould growth. Therefore, indoor humidity levels and dampness should be no higher than 65% to prevent the growth of mould (ASHRAE, 2016; MoE, 2017a). A mean RH of between 40% and 60% will also potentially help reduce the survival rate of influenza (Myatt et al., 2010) and a mean RH below 50% can manage the proliferation of dust mites, which may feed on the mould (Arlian et al., 2001). On the other hand, other infection rates and viral survival rates (e.g., SARS in aerosol form) increase at lower humidity levels and lower temperatures. An RH higher than 49% and temperatures above 20°C have shown a sharp drop-off in virus survival and transmission rates (Prussin II et al., 2018).

Other indoor air quality control strategies

These include:

- Installing thermal insulation to minimise condensation and to keep buildings warm in winter and cool in summer.
- Ensuring that there are robust maintenance and cleaning schedules in place.
- Using a well-maintained HEPA vacuum cleaner (MoE, 2017a).

2.3.3. *Light*

Light more specifically, visible light is radiated energy found within a range of the electromagnetic (EM) spectrum. The EM spectrum is made up of EM radiation of varying wavelengths. Visible light is the part of the spectrum human eyes can detect, which sits between 380nm to 780nm. It is generated by the sun, an animal or plant source or an artificial human source. As seen in Figure 2-4 the frequencies of EM radiation are measured in Hertz (Hz), and its wavelengths are measured in metres (m) (Boyce, 2014).

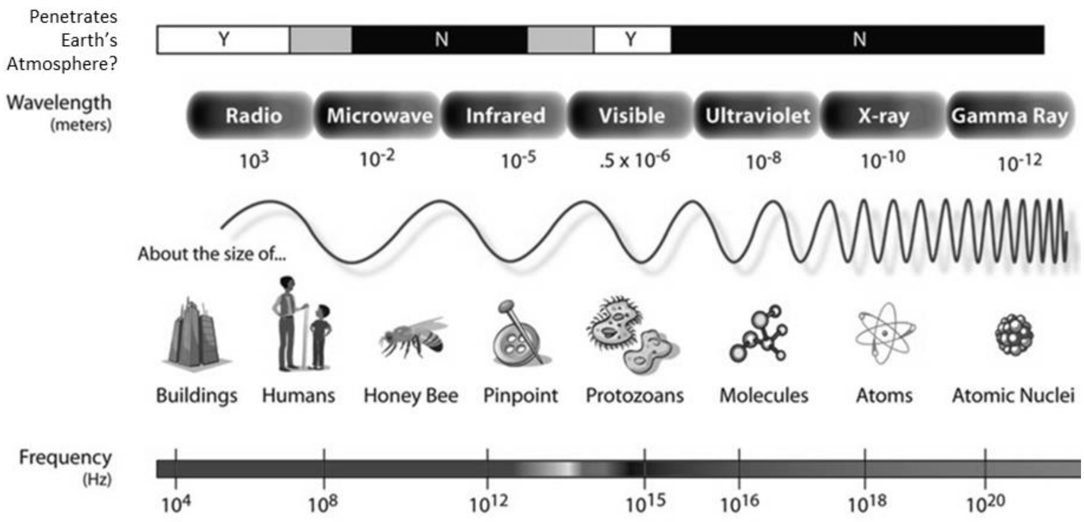


Figure 2-4 Summary of the electromagnetic spectrum properties (The National Aeronautics and Space Administration, 2007).

All visible light sources can be represented pictorially through their spectral power distributions (examples are shown in Figure 2-5). This is a representation of the radiant power emitted by a light source at each wavelength (Lighting Research Centre, 2019).

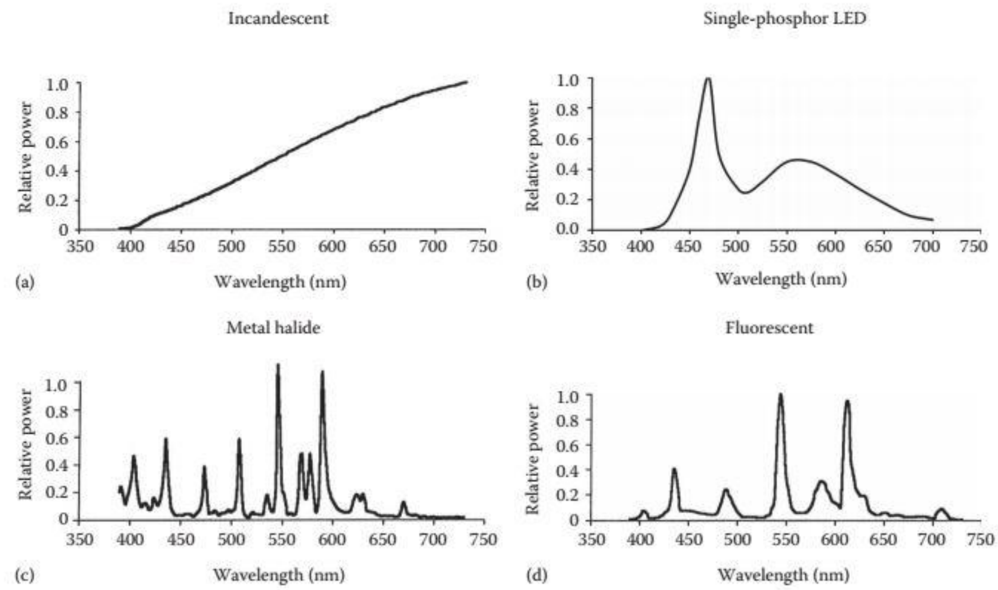
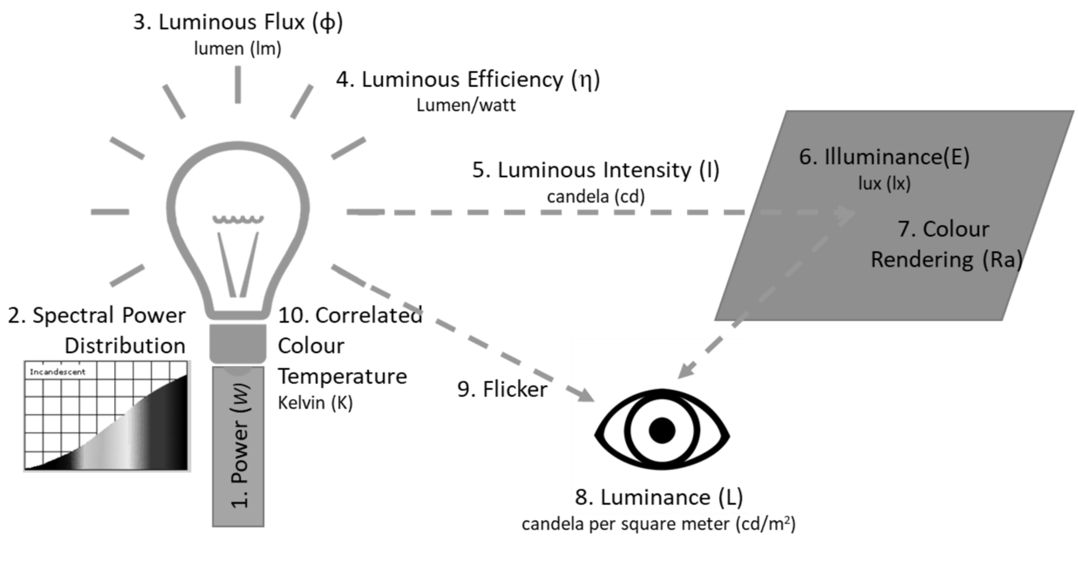


Figure 2-5 Illustrative relative spectral power distribution of four light sources. These spectral power distributions have been normalised to the unit of the wavelength with the maximum output (Boyce, 2014).

Visible light characteristics

The characteristics of visible light radiation are demonstrated in Figure 2-6 and summarised in Table 2-1 below:



Lightbulb by unknown author is licensed under CC BY-SA
http://commons.wikimedia.org/wiki/File:Simple_light_bulb_graphic.png
Eye by unknown author is licensed under Web Stock Review https://webstockreview.net/clipart-eye.html
SPD graph: https://www.lrc.rpi.edu/education/learning/terminology/spectralpowerdistribution.asp

Figure 2-6 Summary of light radiation units of measurement (Coaton & Marsden, 2011; Everest & Pohlmann, 2015).

Table 2-1 The characteristics of visible light radiation, including how it can be measured and what instruments can be used (Boyce, 2014; Coaton & Marsden, 2011).

Figure 2-6 reference number	Measurement name	What is measured	Unit of measure
1.	Power	The unit of power is the rate of energy used by an appliance, e.g. a bulb.	watt (W)
2.	Spectral power distribution (SPD)	The electromagnetic composition of a light source.	Usually normalised radiated power (mW/lumen) per wavelength (nm)
3.	Luminous flux (ϕ)	The quantity of light energy emitted per second in all directions by a light source	lumen (lm)
4.	Luminous efficacy (η)	Lumen output per electrical input (Lumen/watt)	lumens/watt (lm/W)
5.	Luminous intensity (I)	The luminous flux that is emitted in a particular direction per unit solid angle by a light source (Lumen/unit solid angle)	candela (cd)
6.	Illuminance (E)	How much light arrives at a surface per m^2 (Incident lumen/m^2)	lux (lx)
7.	Colour rendering (Ra)	How realistically light can reproduce the colour of an object	
8.	Luminance (L)	The intensity of light emitted from a surface per unit area in a given direction, i.e. how bright something appears to the observer (Candela/m^2)	Candela per square meter (cd/m^2)

9.	Temporal light modulation (also known as flicker)	The changes in light brightness over time	
10.	Correlated colour temperature (CCT)	The colour appearance of the light being emitted	Kelvin (K)

Light sensitivity of the eye

Through the night and day, eye sensitivity changes from scotopic to photopic. This shift in sensitivities means that at night, the eye adapts to the dark, perceiving fewer colours but being more sensitive to various blues, rather than greens and yellows.

The eye's maximum sensitivities to broad daylight and night light are 555nm and 507nm respectively, and the eye can take up to 30 minutes to make this shift (Coaton & Marsden, 2011).

In the early 2000s, the photopigment melanopsin, a light-sensitive retinal protein, was discovered in a sub-class of the eye's retinal ganglion cells. Over the last two decades, understanding of the melanopsin-expressing, intrinsically photosensitive retinal ganglion cells (ipRGCs) has substantially increased. It is now known that the eyes have a third retinal photoreceptor along with the cones and rods. ipRGCs appear to be photosensitive to luminance and colour temperature changes, e.g., as daytime moves into night time (Palumaa et al., 2018).

Melanopic lux is a recently developed metric (Lucas et al., 2014) that aims to predict the nonvisual effects of electrical light sources aligned to the Melanopic curve, a series of wavelengths that support wake/sleep states (Nowozin et al., 2017). The WELL building standard, the first human health standard, codified a daily minimum threshold in learning areas of at least 125 equivalent melanopic lux at 75% or more for at least four hours per day throughout the year, on the vertical plane facing forward at 1.2m from the finished floor level (International WELL Building

Institute, 2019a). To ensure compliance, post-occupancy checks are made with a spectrometer from any location at an unknown time of the year, with melanopic ratios calculated using the Melanopic illuminance Excel-based toolbox (Faculty of Life Sciences The University of Manchester, 2019).

Temporal light modulation

Alternating current (AC) voltage power is supplied at a low-frequency voltage of 50Hz or 60Hz, depending on the country. This means that the current is supplied in 50 to 60 cycles per second. Between each of these cycles, the voltage drops to zero, which is called the zero-point or the off-cycle. As more traditional lamps have a slower response to these cycles, the light they emit is less affected. Gas-discharge or incandescent lamps generally do not exhibit a zero-light output during an off-cycle, with the respective phosphor and filament in these lamps continuing to glow as the AC supply voltage passes the zero-point (Boyce, 2014). However, with the fast response found in ageing fluorescent and LED lights, temporal light modulation may result (Vogels, Sekulovski, & Perz, 2011), as seen in Figure 2-7 below. This temporal light modulation, also called flicker, can be both in colour (chromatic flicker) and brightness (luminance flicker). It can also be visible, frequencies within 3 to 70 Hz, or non-visible, frequencies below 165 Hz (Wilkins & Lehman, 2010).

When a particular frequency is achieved, there will be no more visible flicker. This point is called the critical fusion frequency (CFF). It differs between observers, but, generally, it is around 100 Hz (Boyce, 2014).

Flicker can also cause a stroboscopic effect. This occurs when flicker is at first invisible to a static observer in a static environment, though, as soon as there is a moving object, the object will appear to move discretely rather than continuously (Vogels et al., 2011).

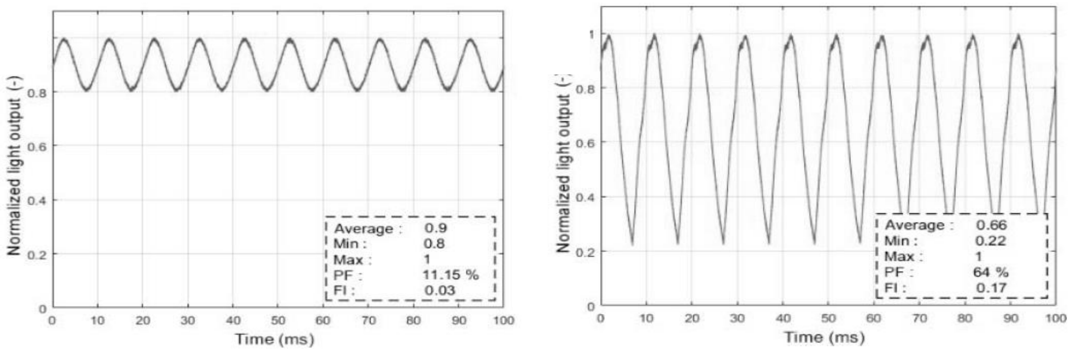


Figure 2-7 Examples of luminous flux measurements. (Left) An incandescent lamp with a strong 100 Hz component and a low luminous flux oscillation, therefore, the visibility of flicker is less likely. (Right) An LED with a high luminous flux oscillation; therefore, the stroboscopic effect is more likely (Kobav & Colarič, 2018).

Interior lighting principles

When designing the lighting of an interior space, several factors must be considered, and some factors must be regulated. Principles to be considered include (Standards NZ, 2006, 2008a):

- Visual comfort, including reflection, contrast, glare and gloom.
- Reflectance.
- Uniformity.
- Maintenance.
- Field of view in relation to walls and ceilings.
- Easy to access switching.

Daylight factor

Outside, natural light levels vary greatly, and human eyes are remarkably well adapted to these changing light levels. For this reason, contrasts between indoor and outdoor light levels are perceptible. Therefore, indoor natural light can be measured as a percentage of the outdoor light level.

The amount of natural light available for use in a room is expressed as a percentage between the room and the illuminance that is simultaneously present outside, called the daylight factor. As natural light is often unevenly distributed in a room, the minimum daylight factor should be accounted for at the worst lit working plane. The daylight factor is used to indicate how far natural light penetrates a room. Depending on the illumination level of the sky, a room with an average daylight factor of 4% to 5% would be considered well lit (300 lux). An average daylight factor below 2% would look subdued and therefore most occupants would feel like additional light was needed and turn on the lights (Coaton & Marsden, 2011; MoE & BRANZ, 2007; Standards NZ, 1984).

2.3.4. *Sound*

Sounds are vibrations that travel through a medium, typically air. Some of these vibrations can be perceived by a receptor, such as the human ear. They travel in the form of a wave and are constantly being generated everywhere by anything that mechanically vibrates. The vibrations humans can hear are generally classified as ‘sounds’ or noise, while those with low frequencies (below 200 Hz) are often classified as ‘vibrations’. However, under the 1991 NZ Resource Management Act, there is no distinction between noise (sound) and vibration (Ministry for the Environment, 1991b).

The human ear can generally hear between 20 Hz and 20 kHz. Ultrasound has a frequency above 20 kHz, and infrasound has a frequency below 20 Hz (Everest & Pohlmann, 2015). When these vibrations are within an acceptable level, based on human perception, they generally go unnoticed. If, however, they have an adverse effect on an individual (McLaren, 2008; Tahara Kemp, Delecrode, Guida, Ribeiro, & Vieira Cardoso, 2013), they become acoustic noise (Sheposh, 2018).

Dr Robert Thorne defines noise as: ‘*a sound that is audible to an individual and has definable characteristics that modify the individual’s emotional and informational responses to that sound from pleasurable or neutral to adverse*’ (Thorne, 2007, p. 213). The EPA defines noise as an unwanted sound that ‘interferes with normal activities such as sleeping, conversation, or disrupts or diminishes one’s quality of life’ (United States Environmental Protection Agency, 2017a).

In NZ, Environmental Health seeks to protect local communities and their people. Determinants of health include the physical environment, social and economic environments and a person’s individual characteristics and behaviours. Environmental determinants are the physical, chemical, biological and psychosocial factors in the surrounding environment, including water, air, noise and vibration (Ministry of Health, 1956).

In education, there is evidence that early childhood and new entrant classrooms generally have the greatest noise levels (Tahara Kemp et al., 2013).

The health effects of noise depend on the characteristics of the sound, as well as a person's health status and informational and emotional response to the noise. Key characteristics of sound that reveal its health effects include:

- The sound pressure level.
- The frequencies present in sound.
- How long a person is exposed to the sound.

Loudness is the subjective perception of sound pressure level, typically ordered on a scale extending from quiet to loud. The greater the pressure, the greater the amplitude of the sound wave; therefore, the louder the sound. This, however, is not an absolute relationship as the same sound at the same pressure level can be perceived very differently by the same people, depending on the time of day, their health status and their informational and emotional responses. Sound pressure levels are measured in decibels (dB). A decibel is 1/10 of a Bel (Everest & Pohlmann, 2015).

When reading decibels on a sound level meter (SLM), they are proportional to the logarithm (base 10) of sound pressure squared (Pa^2) relative to 20 uPa. As the scale is logarithmic, two-decibel readings cannot be directly added together. An increase of 3 dB anywhere on this scale corresponds to a doubling of the sound power (pressure-squared). A 1 dB change is almost undetectable (except to a trained ear); a 3 dB change is noticeable; a 5 dB change is obvious; and a +10 dB change is perceived to be twice as loud for simple sounds (Everest & Pohlmann, 2015). Relative amplitudes and dB for environmental sounds are summarised in Table 2-2 below.

Table 2-2 Relative amplitudes and dB of environmental sounds, courtesy of Thomson Higher Education 2007 (Thomson Higher Education, 2019).

Sound	Relative amplitude	Decibels (dB)
Barely audible (threshold)	1	0
Leaves rustling	10	20
Quiet residential community	100	40
Average speaking voice	1,000	60
Live band (amplified music)	100,000	100
Propeller plane taking off	1,000,000	120
Jet engine taking off (pain threshold)	10,000,000	140
Spacecraft launching at close range	100,000,000	160

The frequency of the sound wave determines the pitch a person perceives. The higher the frequency, the higher the pitch. Doubling the frequency of a wave increases the pitch by an octave (Everest & Pohlmann, 2015).

Auditory response area

When plotting sound pressure and frequency on a graph, the auditory response area of human beings can be seen. This is the area below the threshold of feeling and above the threshold of hearing. The threshold of hearing, also called the audibility curve, shows that humans are most sensitive to 2,000Hz to 4,000Hz, and this is the range in which speech sits, particularly the consonants (Everest & Pohlmann, 2015).

The ear responds differently, depending on the frequencies and the sound pressure level (SPL) in decibels. Each point along a curve is perceived as the same loudness. These curves are known as equal-loudness curves. For instance, at 80dB a person would hear almost equal loudness across the frequencies in Figure 2-8 below, however, at 40dB the high and low frequencies would sound softer than the rest of the frequencies in that range (Everest & Pohlmann, 2015).

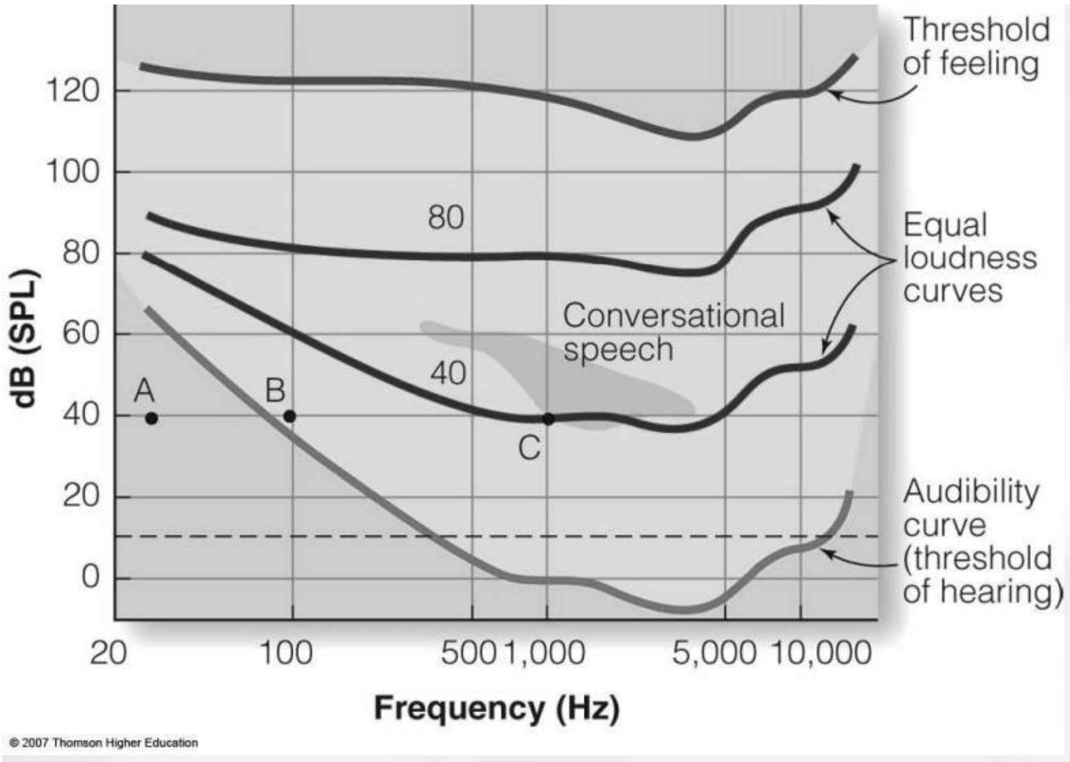


Figure 2-8 The range of human hearing, with human beings most sensitive to 2,000Hz to 4,000Hz. That is 40dB at point A would not be heard, at point B would be barely heard C would be heard (Thomson Higher Education, 2019).

Frequency weighting

Frequency weighting was originally developed to account for the perceptions of pure tone loudness and can be seen in Figure 2-9 below. The A-weighting is the standard weighting of audible frequencies, which reflects the perceived loudness with frequency. It covers the range from 20Hz to 20kHz. The C-weighting is the standard weighting used to measure the Peak Sound Pressure. The Z-weighting is a flat frequency response between 10Hz and 20kHz ±1.5dB, excluding the microphone response. When measuring sound, it is important that the correct frequency weighting is used. Therefore, most instruments will record at all three weightings to remove the possibility of measuring incorrectly (Roberts, Tingay, & Cirrus Research, 2011).

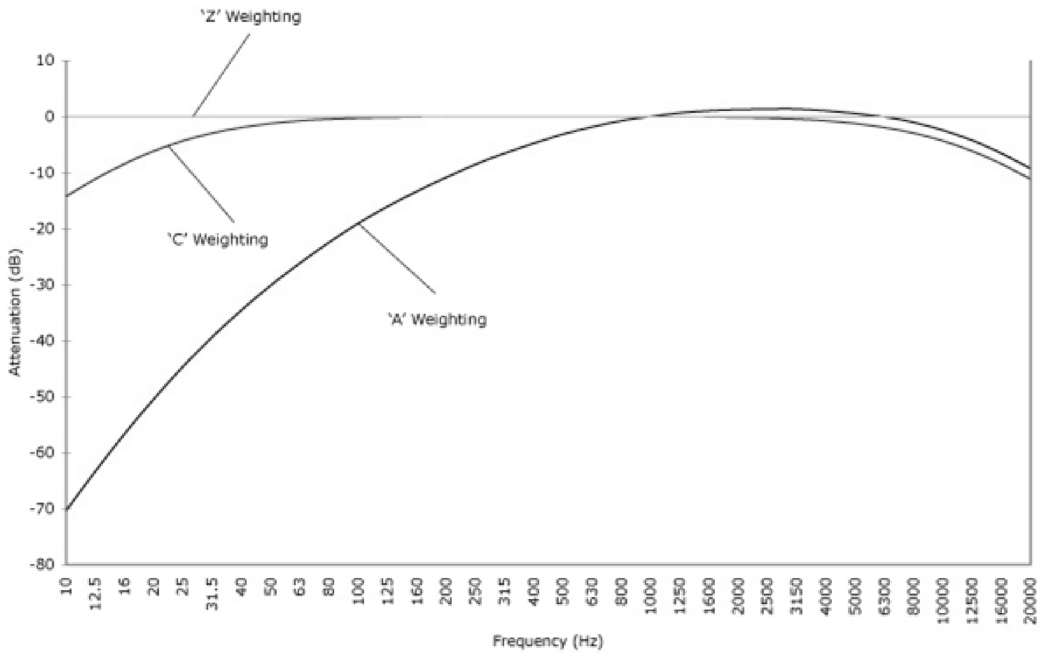


Figure 2-9 'A', 'C' and 'Z' frequency weighting curves (Roberts et al., 2011).

Noise descriptors

Noise is a complex phenomenon with many different single-number measurement quantities or 'noise descriptors' having been developed. Broadly speaking noise descriptors are used either to quantify the 'continuous' part of exposure or 'transitory' (impulsive) part of the exposure. Examples of noise descriptors that quantify the 'continuous' part of exposure include Time-average level: $L_{Aeq,T}$ (dB); Sound Exposure: E_A (Pa^2s or Pa^2h) and Sound Exposure Level $L_{AE\ (dB)}$; Centile levels: background sound level: $L_{A90,t}$ (dB). Examples that quantify the transitory (impulsive) part of exposure include Maximum level: $L_{AFmax,T}$ (dB) and Peak Level: $L_{Cpeak,T}$ (dB) (Everest & Pohlmann, 2015; Pierce, 2019).

Sound propagation

Sound levels drop the further away a person is from the source. This phenomenon is called sound propagation. Assuming sound propagation is equal in all directions (spherical), if the distance is doubled, the sound pressure levels will drop by 6 dB. However, this is only possible in large, open, outdoor spaces (Pierce, 2019).

Sound indoors

A sound field is produced when sound is generated in a closed room and the direct and reflected waves accumulate. As demonstrated in Figure 2-10, direct waves originate from the source and travel directly to the listener. Reflected waves are produced from all the reflections of the sound on the surfaces of the room. The amount of energy reflected by a particular surface is dependent on its acoustic behaviour. A surface's acoustic behaviour is defined by its coefficients of absorption, reflection and transmission. As a result of reflected sound, the levels do not drop off very quickly over distance. Often, outdoor sounds can appear louder indoors than outdoors due to the room resonance and the sound energy not being able to easily escape (Pierce, 2019).

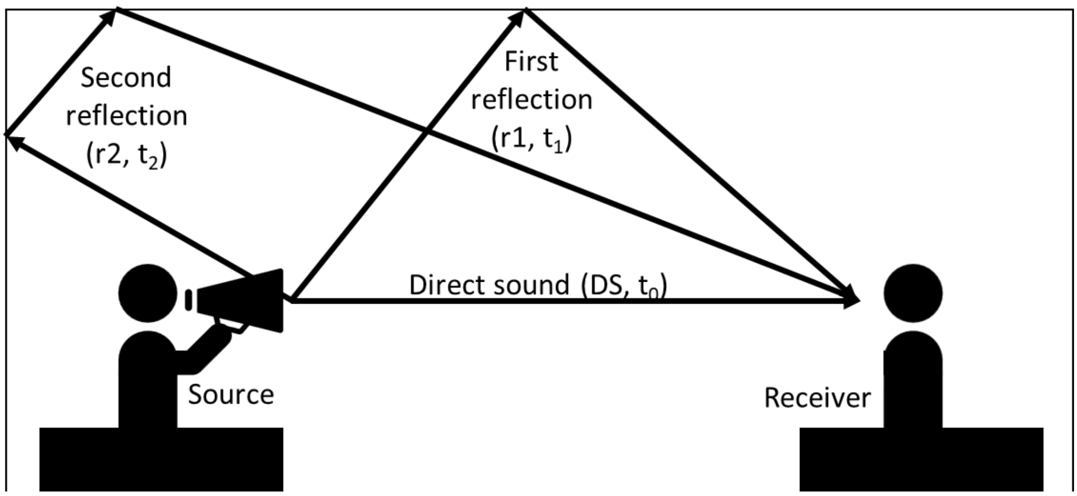


Figure 2-10 The reflective nature of sound waves indoors (*Page, 2019*).

The human ear uses a combination of direct sound and early reflections to localise a sound's source and improve speech intelligibility (Everest & Pohlmann, 2015).

If the time delay of a reflection is longer than approximately one-tenth of a second (100 milliseconds, about 33 m path length difference) relative to the direct wave, the reflection may be perceived as an echo. Strong, late reflections significantly reduce speech intelligibility. The time it takes for a loud sound to fade away to the point of being inaudible can be measured and is called the reverberation time (RT60 or T_{60}). The reverberation time is one of the key parameters of acoustic design.

A special sound is generated to measure the reverberation time of a room, and the time it takes for that sound to decay by 60 dB (by one millionth) across the audible frequencies is measured. Typically, the time taken for a sound to drop by 30 dB (T_{30}) is measured and this result is doubled to calculate T_{60}, as seen in Figure 2-11 below. The special sound, between 90 dB and 110 dB, can be for example an impulse generated from a start pistol, a balloon pop or a wide-range omni-directional speaker (Jambrosic, Horvat, & Domitrovic, 2008).

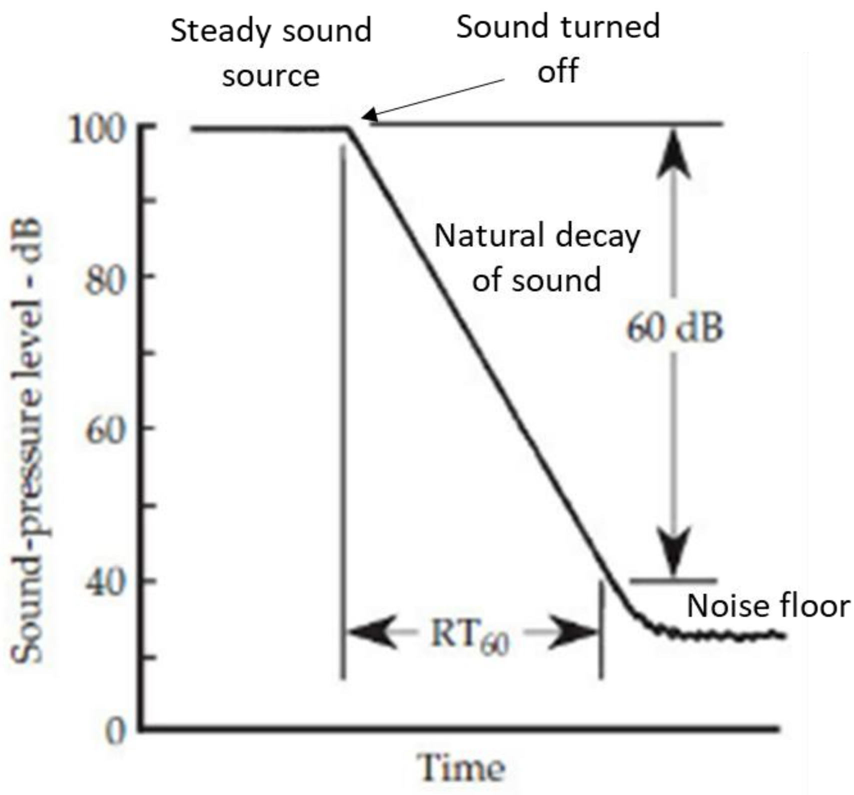


Figure 2-11 The measurement of reverberation time. An example of full 60-dB decay adapted from (Everest & Pohlmann, 2015) though, in reality, this rarely occurs. The source strength and noise level determine the length of the decay trace.

AS/NZ 2107:2016 Acoustics recommends design sound levels and reverberation times for building interiors and provides measurements for compliance assessments (Standards NZ, 2016). Reverberation time measuring methods are defined in AS/NZ 2460:2002 Acoustics Measurement of the Reverberation Times in Rooms (Standards NZ, 2002) and in AS/NZS 1269.1:2005 Occupational noise management Part 1: presenting the measurement and assessment of noise immission and exposure (Standards NZ, 2005). While these documents extensively cover educational spaces, they do not specifically include ECE centres. The closest description would be that of a single, open-plan, classroom with teaching spaces or a nursery set at a design level range of 35 $L_{Aeq,t}$ to 45$L_{Aeq,t}$ and a design reverberation time (*T*) range, *s*, on Curve 3, where reverberation time should be minimised for noise control, according to AS/NZ 2107:2016 (Standards NZ, 2016). The WHO Guidelines define values for community noise, including indoor pre-schools, as 35 dB L_{Aeq} and a reverberation times as 0.6s (World Health Organisation Geneva, 1999). Massey University recommends a reverberation time for standard rooms within ECE of less or equal to 0.4 s and for large rooms less or equal to 0.6 s and a speech transmission index of greater than 0.6 (Page, 2019). The speech transmission index is a method used to estimate speech intelligibility. It is an indexed scale between 0 and 1, where 0 = bad, 0.6 = good and 1 = excellent (Everest & Pohlmann, 2015).

A reverberation time calculator, such as Sabine's formula, can give an approximate reverberation time for a simple box room at different frequencies (CSG Network, 2019). This can be done by making a few assumptions and by knowing the room dimensions, as well as the sound absorption properties and areas of all room surfaces.

Communication in noise

Two physiological phenomena that particularly affect communication indoors are the 'Integration Time of Speech' and the Lombard Effect (J. Whitlock & Dodd, 2008).

The Integration Time of Speech is the point in time after the reflections of a speech signal no longer fully add their energy to that of the direct signal. The effect is that reflections after this point interfere with speech perception, as they overlap with speech phonemes and, therefore, reduce intelligibility. For adults, the Integration Time of Speech is generally accepted to be 50ms (Haas, 1972; Henry, 1851; Miller, 1948; J. Whitlock, 2001). Whitlock and Dobb demonstrated that, for children, the time might be shorter, at approximately 70% of the adult value. This would suggest that classrooms should be designed to ensure reflections reach a child within 35ms (with a path difference of about 11m) (J. Whitlock & Dodd, 2008). The cyclical relationship between reverberance, general noise and speech intelligibility often experienced in cafés is referred to as the Café Effect depicted in Figure 2-12 (MacLean, 1959).

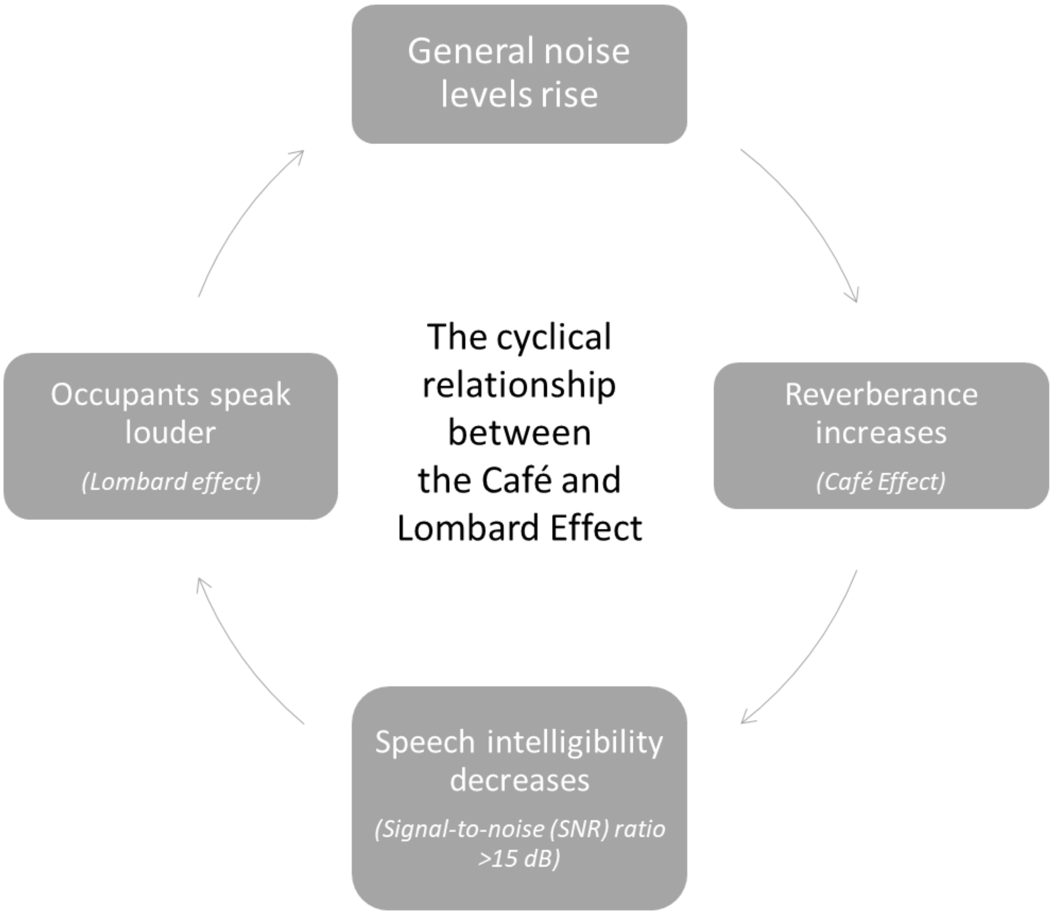


Figure 2-12 The cyclical relationship between the Café and Lombard effects (Page, 2019)

However, as Cherry described, often the occupant in a busy room can 'tune in' to a particular conversation over the dominant background noise. This is referred to as the Cocktail Party Effect (Cherry, 1953). Etienne Lombard first identified the tendency for speakers to raise their voices when there is an impediment of the acoustic path from their mouths to their ears. This impediment may be either physiological (e.g., a hearing impairment) or environmental. (e.g., background noise). Lombard concluded that this occurs, not only so that speakers can hear themselves, but because they feel that raising their voices will allow them to be heard by the listener; while some people can, to a degree, overcome this urge to speak more loudly, most cannot (Lombard, 2003).

Whitlock and Dobb demonstrated that the Lombard Reflex to the Lombard Effect is stronger in children than in adults, with possible Lombard Coefficients (i.e., increase in voice level per decibel of background noise level) of 0.19 dB/dB in children compared to 0.13 dB/dB in adults (J. Whitlock & Dodd, 2008). Other similar studies have shown that children's Lombard Coefficients could, in fact, be even higher (Sutherland, Lubman, & Pearsons, 2005).

Sound modelling

When sound transmission is modelled, different noise types with different spectrums are used, including:

- White noise: a constant energy per bandwidth.
- Pink noise: $1/f$ noise, constant energy per octave, decreased at 3 dB per octave; used to model general noise.
- Red or Brown noise: $1/f^2$ noise, energy falling off at 6 dB per octave; used to model road traffic noise (Barnes & Allan, 1966).

A spectrogram is used to visually represent and interpret the spectrum of frequencies of a signal over time. Spectrograms are usually depicted as heat maps and, when plotted in 3D, are called waterfalls (Page, 2019).

Indoor noise control

Noise control is typically achieved through a combination of absorbing sound energy and controlling the transmission of sound energy through a variety of airborne (sound) and structure-borne (vibration) paths. This is accomplished by treating the internal acoustics of a room and/or the transmission of noise into or from adjacent spaces or from the outdoors. It is also worth noting that higher frequencies are easier to attenuate then lower frequencies. Noise control materials typically will either absorb sound energy (i.e., not reflect it) or block it (i.e., reflect it). Those materials that absorb sound energy are generally light and porous, while those that block sound energy are higher in mass and non-porous (Everest & Pohlmann, 2015).

The characteristics of noise control materials include how well they absorb sound energy, how well sound energy can be heard through them and how easily an impact is transmitted through them (Everest & Pohlmann, 2015). These characteristics are measured by:

- The Noise Reduction Coefficient (NRC). This is a single number index determined in a laboratory, which rates materials in terms of how absorptive they are. It ranges from zero, where the material would be perfectly reflective, to one, where the material would be perfectly absorptive.
- The Sound Transmission Class (STC). This is measured for floors, walls and ceilings and is used to determine the hearing quality through a wall.
- The Impact Insulation Class (IIC). This determines how well any impacts on a surface can be heard through that surface, between 125 Hz and 4,000 Hz.

Under G6 Airborne and impact sound, the STC and IIC between occupancies should be no less than 55 (Department of Building and Housing, 2006).

The ceiling should be treated first, then the floors, then the walls to reduce the reverberation within a room. Ceilings can be treated with acoustic panelling or by installing perforated ceiling plasterboard with acoustic insulation laid within the ceiling void or a suspended ceiling with acoustic tiles. To address the floors, improve the underlay or the acoustic rating of the floor covering, the walls can be covered with acoustic panelling. A material that has a significant impact on sound insulation for outside noise is glazing (Everest & Pohlmann, 2015; Page, 2019). Examples of sound reduction methods that can make a significant improvement are:

- Increased glazing thickness due to increased mass, particularly for lower frequencies.
- Laminated glass is used due to the dampening effect of its plastic interlayer.
- Double glazing used with an air space greater than 100 mm.
- A combination of the above.

2.3.5. The effects of the indoor environment quality on human health

Over the last 20 years, research studies have repeatedly demonstrated that IEQ impacts occupants' health, well-being and comfort (Al horr et al., 2016). In today's society, children spend up to 85% of their time indoors (Lum et al., 2013) with young children being more vulnerable than adults to the effects of indoor environments (W. D. Bennett et al., 2008; Fuentes-Leonarte et al., 2009; Tomita et al., 1989). The effects of IEQ, including IAQ, thermal comfort, light and sound on human health, particularly in children, are summarised below.

The effects of indoor air quality on human health

IAQ is an important issue that affects the short-term and long-term health of occupants (Wargocki et al., 2002). WHO estimates that poor IAQ contributes 2.7% to the burden of disease (World Health Organisation Regional Office for Europe, 2010).

Research has indicated that IAQ plays a significant role in productivity and learning (Al Horr et al., 2017) and that indoor environmental factors in ECE centres correlate with educational achievement (Satterlee et al., 2015). Inadequate IAQ increases the airborne transmission and survival rates of respiratory and gastric bacteria and viruses. It also can increase the growth of mould (Coates, Davis, & Andersen, 2019; Prussin II et al., 2018). This may be exacerbated in the bathroom as a result of toilet flushing and vomiting, which can aerosolise viral contamination (Taptiklis, Phipps, & Plagmann, 2017).

Research into poor IAQ has shown that long-term exposure relates to the increase in chronic and acute respiratory diseases, gastric bacteria transmission and infection (J. Anderson et al., 2012; Carreiro-Martins et al., 2014; Lin et al., 2016; Phipatanakul et al., 2017), atopic dermatitis, chronic inflammatory skin disease (Ahn, 2014) and childhood brain tumours (von Ehrenstein et al., 2016). Studies around the world have analysed building-related illness and sick building syndrome, where the occupant's exposure to an IAQ caused a variety of non-specific neurological and respiratory symptoms (Howden-Chapman et al., 2008; Salleh, Salim, Kamaruzzaman, et al., 2016).

Historically the most common indoor air pollutant relating to cancer and the primary cause of chronic obstructive pulmonary disease was cigarette smoke, though other causes of cancer and chronic obstructive pulmonary disease are also being increasingly researched, such as environmental factors including, exposure to low temperatures and particulate matter. More recent research has also seen a link between indoor air pollutants and non-respiratory cancers, particularly in children (Abramson, Koplin, Hoy, & Dharmage, 2015; J. Anderson et al., 2012; World Health Organisation Regional Office for Europe, 2010). In NZ, a 2012 study that found a 6% increase of mortality from cardiovascular diseases per 10 µg/m^3 in PM_{10} (Hales, Blakely, & Woodward, 2012). Huang et al. observed a link between increased rates of childhood leukaemia and formaldehyde exposure (Huang, Mo, Sundell, Fan, & Zhang, 2013).

Exposure to mould, particulates and dampness is associated with airway inflammation, nasal congestion, coughing, wheezing, throat irritation, hay fever and eczema (Ahn, 2014; Lin et al., 2016). It is also likely that increased exposure to dust heightens susceptibility to developing allergies and asthma panorama (Alvarez-Chavez et al., 2016). The correlation is strong between allergic sensitisation and allergen exposure, particularly in school children and children under five years old (J. Anderson et al., 2012; Mendell, 2007; Phipatanakul et al., 2017).

Research indicates that children are more sensitive to higher temperatures than adults and that they are better suited to temperatures a few degrees cooler (Edwards et al., 2015). This is due to their higher metabolic rates and overall level of activity (MoE, 2017a).

The MoE's Designing quality learning spaces: Indoor air quality and thermal comfort design guidelines indicate that normalised student performance drops from 110% at a CO_2 level of 800ppm to 100% at CO_2 level of 1,000ppm then falling to 95% at a CO_2 level of 2,500ppm and that total school absence increases from 5% at a CO_2 level of 1,000ppm to 15% at a CO_2 level of 2,900ppm (MoE, 2017a). In 2019, a literature review of ten recent studies concluded there is substantial evidence that the performance in decision-making challenges worsens by CO_2 concentration levels as low as 1,000ppm (Fisk, Wargocki, & Zhang, 2019).

The effects of light on human health

Research has shown the critical role that light plays in regulating numerous physiological and behavioural patterns and systems including circadian rhythms, sleep regulation, hormone levels (Goz et al., 2008; Guler et al., 2008; Hatori et al., 2008; Milner & Do, 2017; Pilorz et al., 2016) and mood (Boyce & Barriball, 2010).

A recent study has also indicated that bright light may enhance attention, cognitive performance and mood (Milosavljevic, Cehajic-Kapetanovic, Procyk, & Lucas, 2016), and, while limiting blue light at night may help mitigate its negative impact on the circadian system, the issue is more complicated as the extrinsic input of rods and cones to the melanopsin system has been ignored. (Hughes, Watson, Foster, Peirson, & Hankins, 2013; Lucas et al., 2014; Spitschan, Jain, Brainard, & Aguirre, 2014; Woeldersa et al., 2018).

Currently, while glare is not believed to have significant health effects, it i can substantially affect vision and cause fatigue and discomfort. This is especially relevant in light with a relatively high content of blue light, as blue light is liable to generate glare during the day and at night (International WELL Building Institute, 2019b, 2019c, 2019d) . There is also evidence that blue light could be a hazard to humans, which, based on animal experiments, could result in permanent retinal damage (Ham, Mueller, & Sliney, 1976).

Low levels of UV radiation can be emitted from certain lamps, including compact fluorescent, unfiltered halogen and incandescent light sources. Within the European Union, the highest measure of UV emissions from lamps has been found in offices and schools, which could be adding to the number of squamous cell carcinomas reported (World Health Organisation International Agency for Research on Cancer, 2006).

The growing phenomenon of temporal light modulation, or flicker, can cause issues for those with light sensitivities. Visible flicker, frequencies within 3 to 70 Hz, are often associated with risks of seizures. Non-visible frequencies below 165 Hz are often associated with but not limited to headaches, impaired vision and eyestrain. It may also be problematic for people with vertigo, lupus and epilepsy, (Wilkins &

Lehman, 2010) though more research is needed in these areas (Mattsson, Jung, & Proykova, 2012).

In June 2018, the Scientific Committee on Emerging and Newly Identified Health Risks published its opinion on the potential human health risks of LEDs. The committee concluded that there is no reliable data to assess the risk to eye-safety or the effects on the skin of lifelong usage of LED light sources. It was, however, recommended that lower blue component LEDs be used for domestic light as blue range wavelengths are a risk factor for photochemical retinal injury. It was also recommended that artificial UV radiation from LEDs not be used to enhance vitamin D levels as UV-B is carcinogenic to humans (Scientific Committee on Health, 2018).

It is now evident that ipRGCs found in the eyes not only support vision but significantly contribute to the non-visual, eye-mediated effects of light; these influence several biological processes and systems in the human body, which are important to health and wellbeing, including pupillary constriction (Hattar, Liao, Takao, Berson, & Yau, 2002), light aversion (Mrosovsky & Hattar, 2009; Semo et al., 2010), learning (LeGates et al., 2012; Warthen, Wiltgen, & Provencio, 2011), memory (Tam et al., 2016) and mood (Milosavljevic et al., 2016), all of which are driven by the circadian rhythm (Goz et al., 2008; Guler et al., 2008; Hatori et al., 2008; Milner & Do, 2017; Pilorz et al., 2016) and the neuroendocrine and neurobehavioral systems. There is also compelling evidence that ipRGCs are essential in early eye development and in how sleep patterns are programmed for later life (Tufford et al., 2018).

Overall the effect of poor light quality on children is not well understood (Mattsson et al., 2012), though research has shown that the blink reflex in babies does not fully develop until age five (Tomita et al., 1989) and that a child's crystalline lens is more transparent to short wavelengths than an adult's. This, therefore, makes children more sensitive to the retinal effects of blue light (Point, 2018). Other research has shown the importance of natural light in the development of the eyes and the circadian system at this young age (Palumaa et al., 2018).

The effects of sound on human health

Research has shown that short term, noise-induced arousal may produce better outcomes when simple tasks are being done or in more creative, collaborative workspaces. Cognitive performance, however, deteriorates substantially for more complex mental tasks, e.g., those that require intense attention to detail, demand higher working memory or are analytically complex (Irgens-Hansen et al., 2015). The WHO has stated:

> "*Impairment of early childhood development and education caused by noise may have lifelong effects on academic achievement and health. Studies and statistics on the effects of chronic exposure to aircraft noise on children have found:*
>
> - *consistent evidence that noise exposure harms cognitive performance;*
> - *consistent association with impaired well-being and motivation to a slightly more limited extent;*
> - *moderate evidence of effects on blood pressure and catecholamine hormone secretion*." (World Health Organisation Regional Office for Europe, 2019, p. 2)

Research has indicated that the response in children to the Integration Time of Speech and the Lombard Effect is significantly different from that of adults. Reverberation in a space being potentially damaging to children's speech intelligibility and responses to background noise (Newman, 2005; J. Whitlock & Dodd, 2008).

Among teachers and children, stress, voice strain, fatigue and hearing loss have been identified as severe concerns (McLaren, 2008; Oberdörster & Tiesler, 2008; Tiesler & Oberdörster, 2008). Background and traffic noise negatively affect listening to consonant-vowel syllables (Dos Santos Sequeira, Specht, Moosmann, Westerhausen, & Hugdahl, 2010), and consonant identification has been shown to decrease in the presence of noise (Johnson, Stein, Broadway, & Markwalter, 1997).

There is also a direct link between health and noise, including stress-related illnesses, depression, speech interference, high blood pressure and noise-induced hearing loss (hearing impairment caused by excessive noise exposure) (Baliatsas, van Kamp, van Poll, & Yzermans, 2016; Basner et al., 2014; Beutel et al., 2016; Eze et al., 2018; Liu et al., 2013; Luetz et al., 2016; Moudon, 2009; Szalma & Hancock, 2011;

United States Environmental Protection Agency, 2017a). Those with a high sensitivity to environmental noise as defined by an 11-point Likert scale, are two times more likely to experience depression than those with low sensitivity to noise. They are also 1.9 times more likely to experience anxiety (Park et al., 2017).

Noise also affects sleep. Disturbed sleep is associated with several health impacts, including increased heart rate, arousal from sleep, sleep changes and awakening. Exposure to night noise has been shown to increase body movement and environmental insomnia. Noise-induced sleep disturbance also leads to further health consequences, such as hormone level changes, cardiovascular diseases, depression and other mental health issues and is summarised in Table 2-3 below.

The impact of $L_{night,\ outside}$ levels on a population's health are:

Table 2-3 Different night noise levels and their effects on the health of a population (World Health Organisation Geneva, 1999)

dB Level	Human health effect
< 30 dB	No substantial biological effects
30 - 40 dB	Several effects observed, but seem modest
40 - 55 dB	Adverse health effects, vulnerable groups most severely affected
> 55 dB	Increasingly dangerous with adverse health affects

Children do have a higher awakening threshold than adults; however, they spend more time in bed and, therefore, are exposed to more daytime and night-time noise levels. For this reason, the WHO considers children to be a risk group. For sensitive people, including children, a lower noise level limit should be considered (Basner, Griefahn, & Berg, 2010; Halonen et al., 2012; Halperin, 2014; World Health Organisation Geneva, 1999; World Health Organisation Regional Office for Europe, 2018).

2.4. New Zealand context

In NZ, there has been little research into IEQ in education (Taptiklis et al., 2017), with no research papers found on IEQ in ECE centres through a systematic review of IEQ academic journals.

This literature review will now focus on NZ, highlighting the health of NZ's population and it's building stock. It will then discuss in more detail NZ ECE services, in particular, the history, the building typology and ECE services today, including ECE centres and the ECE regulatory framework that influences the IEQ in ECE centres. Finally, it will focus on NZ's largest city, Auckland, examining its geography, climate and population.

2.4.1. The health of NZ's population

While NZ's parents rate their children's health as good, NZ's health statistics are some of the poorest across the Organisation for Economic Co-operation and Development (OECD) (Taptiklis et al., 2017). It has one of the highest asthma rates in the world. In 2015 and 2016, approximately 132,000 children, aged two to fourteen (17%), had asthma, and asthma was one of the three leading reasons children were admitted into hospitals. The cost of asthma in NZ is estimated to be over $7 billion per year (Ministry of Health, 2016).

In NZ, suicide is the second leading cause of death between the ages of 15 and 24, and the country has one of the highest youth suicide rates in the OECD (Stats NZ, 2013). In the 2015/16 Annual Update of Key Results published by Ministry of Health (2016), approximately 34,000 children (4.3%) aged 14 to 23 were diagnosed with emotional and/or behavioural problems at some time in their lives. This number has more than doubled since the 2006/07 report. Other high rates within the population include tuberculosis (TB), childhood pneumonia, hospitalisations from skin infections, rheumatic fever, chronic obstructive pulmonary disease and excess winter mortality (Taptiklis et al., 2017).

All of these statistics are at their highest in Auckland, predominantly due to the majority of the population being in Auckland, along with other factors, such as Auckland's maritime climate (Stats NZ, 2017).

2.4.2. NZ's building stock

It is estimated that approximately 6% of buildings in NZ's building stock are classed as leaky homes, along with numerous leaky schools and commercial buildings. Little to no insulation was put into buildings prior to 1978, with insulation building standards slowly being upgraded over the past 30 years. Dampness and mould growth in buildings is a commonly reported issue, and NZ's buildings are reported as being poorly maintained (Taptiklis et al., 2017).

2.4.3. Early childhood education in NZ

In NZ, it is not compulsory for children five years of age and under to attend an ECE service. For this reason, the Ministry of Education (MoE) does not administer this sector in the same way that it administers schools. ECE services operate independently of the MoE, either as commercial businesses or as not-for-profit organisations (MoE, 2019).

The MoE does, however, want to make ECE services accessible to all NZ families. Its primary mechanism to do this is to subsidise the sector by providing funding across six types of ECE services summarised in Table 2-4 below (MoE, 2017g).

.

Table 2-4 NZ ECE Services

	MoE Definition						
	Centre-Based		Hospital-based	Kohanga Reo	Play Centres	Play Groups	Home-Based
Childcare Model	ECE Centres *Including ECE Centres, Daycare, Preschool, Childcare*	Kindergartens *Including crèches*	Provide ECE services for those five years and under while in hospital	Maori culture and language centres run by Te Kohanga Reo National Trust	Provide parent-led care	Provide parent-led care	Provide home-based care
Operate from	Licensed to operate from a purposed facility or renovated premise	Licensed to operate from a purposed facility or renovated premise	Licensed to operate from within a hospital	Licensed to operate from a purposed facility or renovated premise	Licensed to operate from a purposed facility or renovated premise	Certified to operate from of a non-residential and non-purpose- built facility, e.g. a community hall	Licensed to operate from a residential home, often that of the parent(s) of one of the children
Educators	Teachers with an ECE teaching qualification	Teachers with an ECE teaching qualification	Teachers with an ECE teaching qualification	By parents specifically trained to instil the values of the Te Kohanga Reo National Trust	By parents and other educators often trained in the principles of the NZ Playcentre Federation	By parents	May or may not be a qualified ECE teacher; if they are not qualified, they will be under the supervision of a qualified ECE teacher.
Age of Children	From birth, but most only take from three months old to five years old	From two to five years old	From birth to five years old	From two to five years old	From birth to five years old	From two to five years old	From birth to five years old

	MoE Definition						
	Centre-Based		Hospital-based	Kohanga Reo	Play Centres	Play Groups	Home-Based
Operating Hours	Either all day or part day	Traditionally aligned with school terms and hours, 09h00 to 15h00	Part-day	Either all day or part day	Part-day, 2.5 hour to 4-hour sessions	Part-day, 2.5-hour to 4-hour sessions	Either all day or part day
Max number of children allowed under the license	From 20 to 250 children, though most operate with between 50 and 100 children.	Traditionally smaller centres with between 20 and 40 children	Small groups	From 20 to 40 children	From 20 to 40 children	Small groups	Up to 40 children
Ownership	69% Private	100% Community-Based	As part of hospital	100% Community-Based	100% Community-Based	100% Community-Based	90% Private
Sources of Funding	Ministry and parent funding	Predominantly Ministry funding	Ministry funding	Ministry funding	Ministry funding	Ministry funding	Ministry and parent funding

The number of ECE centres in NZ

In 2017 there were a total of 5,527 licensed and certified ECE services across NZ (MoE, 2017b). Of these 5,527 services:

- 2,558 (55.6%) were ECE centres, up by 804 services since 2005 (a 45.8% increase).
- 1,751 (68.5%) of the 2,558 ECE centres were privately owned, with the remaining 807 (31.5%) being community-based.
- 951 (37%) of the 2,558 ECE centres were in Auckland.

ECE centre income is sourced from a combination of government funding and parent fees (MoE, 2019).

The number of children attending ECE centres

In 2017, the official population eligible to attend ECE services in NZ was 309,576. Of this population 202,772 (65.5%) children were enrolled in ECE services. 132,221 children were enrolled in licensed ECE centres, 42.7% of all eligible children and 65.2% of those enrolled in ECE services. Of the children enrolled in licensed ECE centres, 54,503 were aged zero to two-years-old; 78,178 were aged three to five+ years old, or their ages were unknown. 49,927 (24.6%) of those children enrolled lived in Auckland with 18,872 (37.8%) of these children enrolled in Auckland ECE centres.

The average hours of attendance per week in 2017 were 20.7 hours across all ECE services, with children aged zero to three averaging 16.8 hours and children aged four averaging 21.7 hours. Children attending ECE centres averaged 22.8 hours, and those living in Auckland averaged 23.3 hours (MoE, 2017d).

The number of ECE teachers in NZ

In 2017, there were 30,674 ECE teaching staff members. ECE centres employed 25,755 (84%) of them, and 9,385 were employed in Auckland, 31% of all ECE teaching staff and 36% of those within ECE centres (MoE, 2017c).

NZ ECE curriculum and standards review

The Education Act of 1989 legislated the NZ ECE services curriculum (NZ Parliament, 2018). In 1996, a national curriculum was delivered in the '*He whāriki mātauranga mō ngā mokopuna o Aotearoa Early childhood curriculum*'. This document, also referred to as Te Whāriki, was one of the first national curriculum documents for early childhood education and is highly regarded internationally (MoE, 2017f).

Te Whāriki provides a framework of principles, standards, goals and learning outcomes to support children from a wide variety of cultures and values, recognising Māori as Tangata Whenua.

Using the metaphor of a woven mat, Te Whāriki expresses its vision:

"*children are competent and confident learners and communicators, healthy in mind, body and spirit, secure in their sense of belonging and in the knowledge that they make a valued contribution to society*" (MoE, 2017f, p. 6).

The Early Childhood Education Curriculum Framework lays out the criteria upon which to assess curriculum standards within a centre (MoE, 2016). Assessments are carried out by the Education Review Office (ERO). The ERO determines the frequency of reviews, which are dependent on the outcome of previous educational reviews, as follows (Education Review Office, 2016):

The next ERO review will be in:

- Four years for very well-placed centres that promote positive learning outcomes for children.
- Three years for well-placed centres that promote positive learning outcomes for children.
- Two years for those centres that require further development to promote positive learning outcomes for children.
- In consultation with the MoE for those centres not well-placed to promote positive learning outcomes for children.

2.4.4. The evolution of ECE centres in New Zealand

Kindergarten

Kindergartens built before 1958 tended to be purpose-built or repurposed community-based buildings (Kindergarten History, 2017). Examples (NZ Kindergartens inc.) include the following:

- The first purpose-built kindergarten, built in 1910, was established through the patronage of Sir John Logan Campbell (Te Ara NZ).
- The first purpose-built kindergarten in Wellington was the Berhampore Kindergarten. This centre was designed by prominent Wellington architect William Gray Young and opened in 1929 (Natalie Marshall, 2015).
- The NZ Centennial Kindergarten was set up as a model example of kindergartens at the NZ Centennial Exhibition, 1939 to 1940, Figure 2-13 (Alexander Turnbull Library).

Figure 2-13 The main room of the model kindergarten (Alexander Turnbull Library).

From 1958, kindergartens were required to be in purpose-built buildings according to government regulations, which were administrated through the regional education boards. During this time, kindergartens were generally on ¼ acre sections, giving them good indoor to outdoor flow (Kindergarten History, 2017). As the controlling agent of the kindergartens, the NZ Free Kindergarten Association operated the centres at a maximum enrolment of 40 children per centre. With 40 children, the centre would have a gross floor area of 168m^2 (Lindegan, 1982).

From the mid-1970s, kindergartens were permitted to occupy vacant primary school accommodations, including any vacant, prefabricated buildings (NZ Free Kindergarten Union, 1972). The Department of Education, through the regional boards, also began administering the design and building of any new or refurbishments of kindergartens, up until both the Department of Education and the regional boards were abolished in 1989.

Each year, the NZ Free Kindergarten Association and Playcentre Federation would submit its recommendation to the Department of Education concerning centres to be built or refurbished. Once the Department of Education had made its decisions, the relevant regional education board would administer the design and construction of the centre.

The design and construction were considered to be simple, residential constructions on par with residential housing across the region. Using a standard plan, the centres were mostly one big space, divided into smaller spaces. The construction was mainly either standard brick and tile or a timber frame clad in weatherboard with plasterboard or timber internal walls and either a concrete or timber floor. In the latter type, typically the roof was made of 0.4mm to 0.5mm corrugated steel, sitting on timber trusses as seen in Figure 2-14 below. The service content was considered low, and the finishes simple. On occasion, the roof design would be tailored to make it appear more playful. If the building was a new build, the expectation was that it could be removed from the site.

Expertise across the regional education boards produced mixed results, which led to the NZ Free Kindergarten Association seeking minimum space standards per child in 1983. They defined them as 2.7m^2, with an optimum gross area space per child of 4.2m^2 (B. Elliott, 1982; B. Elliott, 1982; Elliott, 1983, 1985; The McGuinness Institute, 2016).

Figure 2-14 Doris Nicholson Kindergarten, Upper Hutt, 1974 (R. Anderson, 1974).

Crèches and nurseries

As the history of crèches and nurseries reflects, they tended to be based in repurposed community buildings or purpose-built centres drawing inspiration from kindergarten building typologies (Jemmett & The NZ Ministry of Culture and Heritage, 2018). Examples include the following.

- The first crèche in Auckland was in a former library on High Street, opening in 1887 (Jemmett & The NZ Ministry of Culture and Heritage, 2018).
- In 1914, architect John Swan designed a purpose-built crèche for the Compassion Crèche in Wellington (Ministry for Culture and Heritage, 2017).
- The Women's National Reserve Residential Nursery in Newtown, Wellington, opened in 1920 to look after children whose mothers were in the hospital. The nursery also ran a drop-in service where women could leave their children while shopping or running errands (NZ History Online).

Unfortunately, due to high maintenance costs, including bringing the building up to the current building code standards and removing the asbestos used in many building products up until the 1990s, few of these centres remain. Those that do remain have been converted into daycare or ECE centres (Jemmett & The NZ Ministry of Culture and Heritage, 2018).

Daycares and ECE centres

Historically, private centres were smaller operations in converted private homes or similar in size to kindergartens until the mid-1970s. In the mid-1970s the first larger, commercial providers began to emerge. In 1978, Kindercare opened its first large-scale centre in Auckland. From 1978 onward, there has been a significant increase in the number of childcare centres. By early 2011, Kindercare had opened 36 centres across Auckland, Hamilton, Wellington and Christchurch, with the Australian provider, ABC Learning Centres, opening six centres in 2003 and operating 127 centres by 2011. These centres can be either purpose-built or repurposed buildings. The purpose-built buildings are commonly constructed from a timber frame structure and cladded with timber or blockwork that is then rendered in plaster or brick or cladded in timber. Those buildings that are repurposed range from timber-framed villas to blockwork commercial properties to repurposed public buildings, e.g. old churches and halls (B. Elliott, 1982; Elliott, 1985; Pollock, 2012; The McGuinness Institute, 2016).

2.4.5. ECE centres regulatory framework

The current education regulatory framework for ECE centres is divided into three tiers, as defined and administered by the MoE in Figure 2-15 below (MoE, 2017e):

- First-tier: The Education Act of 1989.
- Second-tier: the regulations for ECE services and playgroups, which were both updated in 2008 and again in 2016.
- Third tier: the criteria, which are the standards with which services must comply.

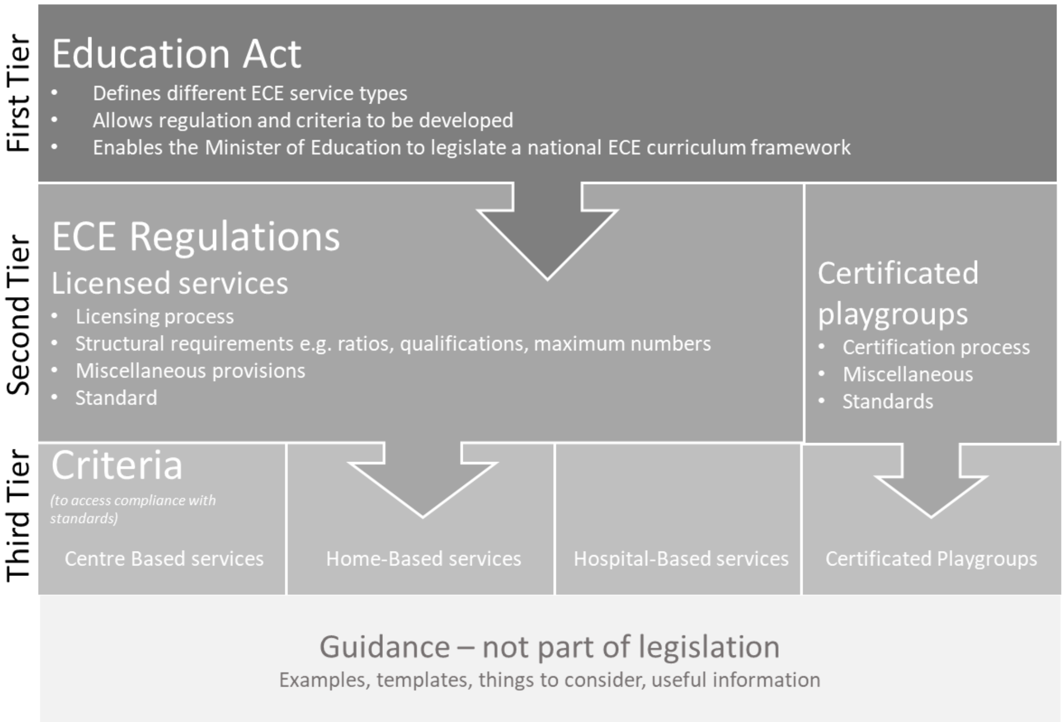


Figure 2-15 ECE centres' regulatory framework (MoE, 2017e).

Legislation relevant to building or renovating an ECE centre

When renovating an existing centre or building a new one, the four primary regulatory documents with which builders must comply are (MoE, 2017e):

- The Education Act of 1989
- Education (Early Childhood Services) Regulations 2008
- The licensing criteria for centre-based education and care services 2008 (updated May 2016)
- The Building Act 2004, which includes:

  - The NZ Building Regulations.
  - The NZBC.
  - Building standards, including the Access Standard NZS 4121:2001 Design for Access and Mobility Buildings and Associated Facilities.

These regulatory documents reference a series of other documents that must also be considered, including:

- The Resource Management Act
- Building Research Association of New Zealand (BRANZ)
- The Regional Health Board regulations
- The Health and Safety at Work Act 2015
- The Fire and Emergency NZ Act 2017
- The Food Act 2014
- The Vulnerable Children's Act 2014

Currently, all regulations, standards and guidelines that apply to an ECE centre either do not define a level, or only define a minimum level that must be obtained. This level can be improved upon but cannot fall below the requirements defined.

The Education Act of 1989

Part II, Miscellaneous Section 139B, of the Education Act of 1989 (reprinted 2018) (NZ Parliament, 2018) requires that all early childhood services comply with The Building Act 2004 (NZ Parliament, 2018).

Education (Early Childhood Services) Regulations 2008

The Education (Early Childhood Services) Regulations 2008 (NZ Parliament, 2008) defines and regulates the administration of early childhood services. This includes defining the minimum ratios of staff to children, the minimum indoor and outdoor space standards and the maximum number of children per centre (NZ Parliament, 2008). Specifically:

- The premise must provide facilities to suit the age and range of children who will attend the centre, including activities, food preparation, storage, eating, sleeping, toileting and washing and suitable heating, lighting, noise control, ventilation and equipment that supports the curriculum.

- Each licenced provider must take reasonable steps to promote the health and safety of the children, including preventing accidents and the spread of infection; keeping the premises, facilities and equipment in good repair, ensuring that they are regularly maintained and safely used; and putting procedures in place to deal with emergencies.
- Minimum adult to child ratios for all ECE services, except for those that are home-based, is 1:5 for children under two-years-old and 1:10 for children aged two and above. For home-based services, a minimum ratio of 1:4 is required across all ages.
- Unless approved by the Secretary, a single centre will have no more than:
    - 150 children two-years-old and over attending at any one time.
    - 25 children under-two-years of age attending at any one time.
    - 50 children in total if those attending are under two and over two in one centre.
- Minimum activity space:
    - Early childhood education and care centres:
        - Indoor: 2.5 m^2 per child (excluding spaces occupied by all fittings, fixed equipment and stored goods, as well as passageways, toilet facilities, staff rooms, sleeping area for children under two and any other area not available for play).

The licensing criteria for centre-based education and care services 2008 (updated May 2016)

This document outlines the criteria for assessing the standards of ECE service premises and facilities, as well as any documentation required to meet the minimum standards (MoE, 2016). The criteria topics include:

- Criteria to assess curriculum standards:
    - C1 - C4 Professional practice.
    - C5 - C6 Culture and identity.

- C7 - C10 Children as learners.
- C11 - C13 Working with others.

- Criteria to assess premises and facilities standards:
  - PF1 - PF14 General.

    Including PF12 '*Parts of the building or buildings used by children have: lighting (natural or artificial) that is appropriate to the activities offered or purpose of each room; ventilation (natural or mechanical) that allows fresh air to circulate (particularly in sanitary and sleep areas); a safe and effective means of maintaining a room temperature of no lower than 16°C; and acoustic absorption materials if necessary to reduce noise levels that may negatively affect children's learning or wellbein*g.' (MoE, 2016, p. 14)
  - PF15 - PF17 Food preparation and eating spaces.
  - PF18 - PF23 Toilet and handwashing facilities.
  - PF24 - PF28 Other sanitary facilities.
  - PF29 - PF38 Sleep.

- Criteria to assess health and safety practices standards:
  - HS1 - HS3 Hygiene.
  - HS4 - HS8 Emergencies.
  - HS9 - HS11 Sleep.
  - HS12 - HS18 Hazards and excursions

    Including HS15 Noise, stating that '*All practicable steps are taken to ensure that noise levels do not unduly interfere with normal speech and/or communication, or cause any child attending distress or harm.'* (MoE, 2016, p. 22)
  - HS19 - HS23 Food and drink.
  - HS24 - HS30 Child health and wellbeing.

    HS24 Thermal comfort, which states that '*Rooms used by children are kept at a comfortable temperature no lower than 16°C (at 500mm above the floor) while children are attending*.' (MoE, 2016, p. 24)
  - HS31 - HS33 Child protection.
  - HS34 Notification.

The Resource Management Act

The Resource Management Act of 1991 (RMA) (Ministry for the Environment, 1991a) introduced NZ's primary piece of legislation for managing the country's environment. It considers the effects of activities on an environment, now and in the future, based on sustainable principles. Local city and regional councils administer the RMA on behalf of the Ministry for the Environment. The mechanism they use to do this is their specific local or regional district plans (Ministry for the Environment, 2018).

In Auckland, the district plan was revised in 2016 to form the Auckland Unitary Plan. The Unitary Plan is intended to help Auckland meet its economic and housing needs by delineating (Auckland Council, 2018):

- What can be built and where
- How to create a higher quality and more compact Auckland
- How to provide for rural activities
- How to maintain the marine environment

It is broken into zones, which are applied across Auckland to define the status of a particular activity in that zone.

The zones also layout restrictions that may apply to an activity in that zone. If an activity might break a restriction, a resource consent will be required. In most zones, ECE is considered a 'restricted discretionary' or 'discretionary activity', as it's triggering traffic and noise affects the relevant zone's conditions. Depending on how severe the effect may be, the Council may proceed with a limited notification to the direct neighbours or an unlimited notification to the broader public. If there is no objection, the Council will grant the consent; however, if there are objections, the project will proceed to a hearing for a decision to be made (Auckland Council, 2017).

Environmental noise limits

NZS 6802:2008 Acoustics environmental noise (Standards NZ, 2008b) addresses environmental noise in NZ. Local councils can reference this standard in an ECE centre's resource consent though the application of the standard is inconsistent across councils and within councils. This standard even includes an ECE example of environmental noise with the noise limits of:

- 55 dB $L_{Aeq,(15min)}$ Daytime 0700 h - 1900 h

Another reference that has been included in an ECE centre's resource consent is the WHO Community Guidelines 1995, which define environmental or reverse sensitivity levels for land use and residential (outdoors) at any point within the boundary (World Health Organisation Geneva, 1999). These define the same levels as those in NZS 6802:2008 Acoustics – Environmental noise.

- 55 dB $L_{Aeq,(15min)}$ daytime 0700 h - 2200 h
- 45 dB $L_{Aeq,(15min)}$ night-time 2200 h – 0700 h the following day
- 75 dB L_{AFmax} night-time Lmax

The Building Act 2004

All building work in NZ must meet minimum standards. These standards are regulated by the Ministry of Business, Innovation and Employment (MBIE) and laid out in legislation and regulations which include the Building Act 2004, the Building Regulations and the NZBC as depicted in Figure 2-16 below (MBIE, 2016c).

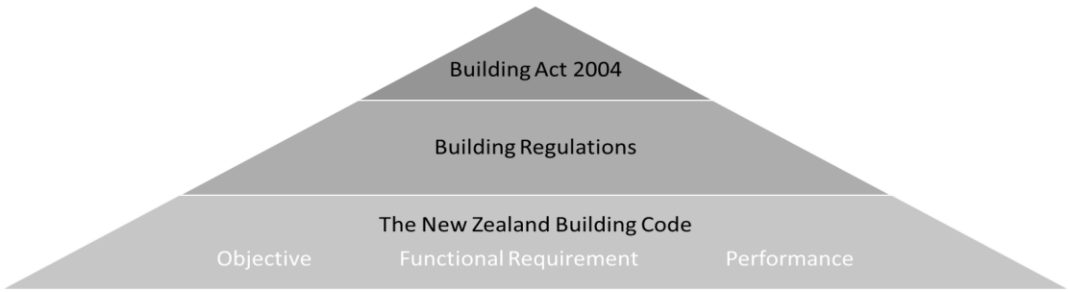


Figure 2-16 NZ's building legislative structure Code (MBIE, 2014c).

The Building Act 2004 is the primary legislation governing building and construction in NZ. The Building Regulations define specific building controls, and the Building Code sets the minimum performance standard buildings must meet.

Forty specific codes are delineated in the Building Code. Of these forty, ten either directly or indirectly reference the indoor environment of an ECE building, and five have specific requirements for ECE centres (MBIE, 2014c).

Standards NZ, a unit within the MBIE, sets specific standards and standard-based solutions. The standards are voluntary unless cited in an act, legislation or regulation (Standards NZ). An example is the Access Standard NZS 4121:2001 Design for Access and Mobility - Buildings and Associated Facilities (Standards NZ, 2001).

If there is an area of concern relating specifically to ECE, the MBIE will issue a determination. For example, if there is a concern that door handle height is too accessible for children and, it should be raised but, this contradicts the Access Standard NZS 4121:2001. In such a case, the MBIE will issue a determination to provide further guidance (MBIE, 2016a).

BRANZ

BRANZ is an independent research body that provides independent advice to the building and construction industry in partnership with the MoE and the MBIE. This advice is often relied on by councils and the industry at large. Examples include:

- MoE Designing Quality Learning Spaces (DQLS): Lighting (MoE & BRANZ, 2007);
- BRANZ IAQ in NZ Homes and Schools (Taptiklis et al., 2017).

NZ IAQ regulations and standards relevant to IEQ

Within the NZBC, clause G4 Ventilation, an acceptable solution for natural ventilation requires a net openable area of windows to the outside of no less than 5% of the floor area (MBIE, 2016b). The DQLS - IAQ and thermal comfort provide further guidance for schools, stating that minimum natural ventilation rates should be nominally equivalent to four air changes per hour, totalling approximately eight litres per second per person as seen in Figure 2-17 below (MoE, 2017a). Any mechanical ventilated system must provide minimum flow rates, according to NZS 4303:1990. For acceptable IAQ, ventilation should be 8L/s/person (Standards NZ, 1990).

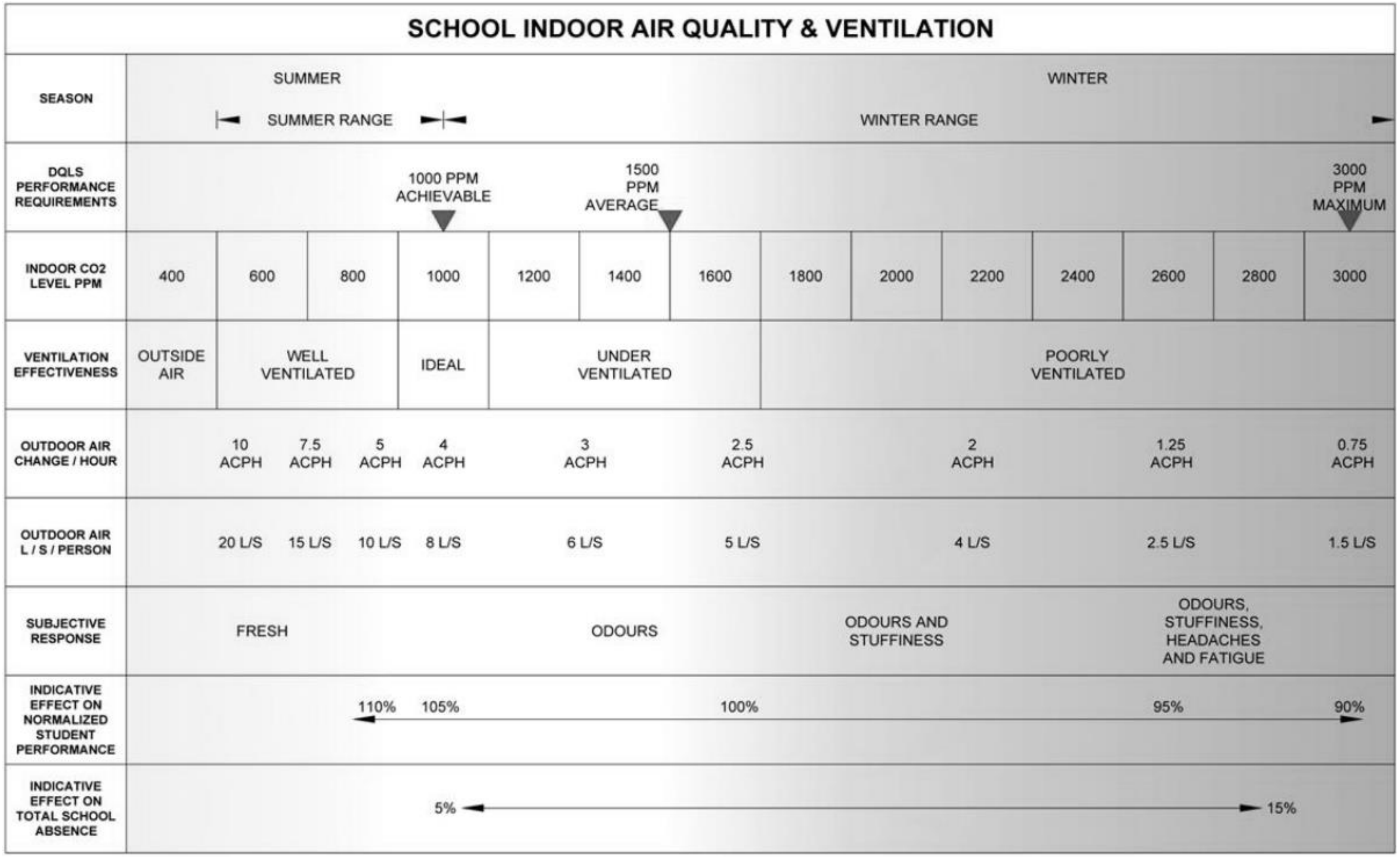


Figure 2-17 School IAQ, ventilation and performance outcomes (MoE, 2017a).

In NZ, adequate ventilation for a school classroom is also defined by the MoE, which states that the average concentration of CO_2 should not exceed 1,500 ppm when measured at a seated head height of 1.2m, during the continuous period between the start and finish of teaching each day. An average of 1,200 ppm or lower is required; a maximum peak of 3,000 ppm should not be exceeded; and the space should be able to be purged to reach 1,000 ppm in ten minutes, with a purging threshold of 800 ppm or lower. It is also required that a CO_2 monitor with direct reading display is located in each learning area (MoE, 2017a). The ASHRAE 62.1-2016 Ventilation Standard recommends an indoor concentration of no greater than 700 ppm above outdoor air CO_2 levels (ASHRAE, 2016).

It is recommended that entry/exit mats be placed at principle entries and exits to mitigate the tracking in of dust and dirt from the outside (J. Bennett et al., 2018; MoE, 2017a; Trompetter et al., 2018).

There is no specific ventilation standard for ECE centres or sleep rooms within centres. There are also no specific particulate matter exposure levels or cleanliness standards set.

NZ thermal comfort regulations and standards relevant to indoor environment quality

ASHRAE (ANS/ASHRAE Standard 55 (2013)) and CIBSE (CIBSE TM52) have both developed thermal comfort models to consider these factors. In NZ, Typical Meteorological Year (TMY) files are commonly available, rather than the Design Summer Year (DSY), on which CIBSE TM52 relies. For this reason, the MoE requirements have a modified version of more established standards given in CIBSE Guidebook A and the UK Building Bulletin 101 - Ventilation of School Buildings. The modifications model is different for NZ locations to determine locally appropriate hours of exceedance values. Instead of using variable adaptive temperatures, it uses fixed air temperatures (MoE, 2017a).

G5 Indoor environments (Department of Building and Housing, 2011) requires an internal temperature to be maintained at no less than 16°C measured at 0.75m above floor level with the space being adequately ventilated. The 2008 licensing criteria for ECE centres and care services, requires a safe and effective means of maintaining a room temperature no lower than 16°C (MoE, 2016). However, it does not specify a height above the floor level, and there are no maximum limits set.

Indoor air temperatures are expected to be within a range of 18°C to 25°C for the majority of the year, as seen in Figure 2-18 (MoE, 2017a). In classrooms, a temperature of 18°C is to be maintained during normal occupancy periods at 1m from floor level (MoE, 2017a).

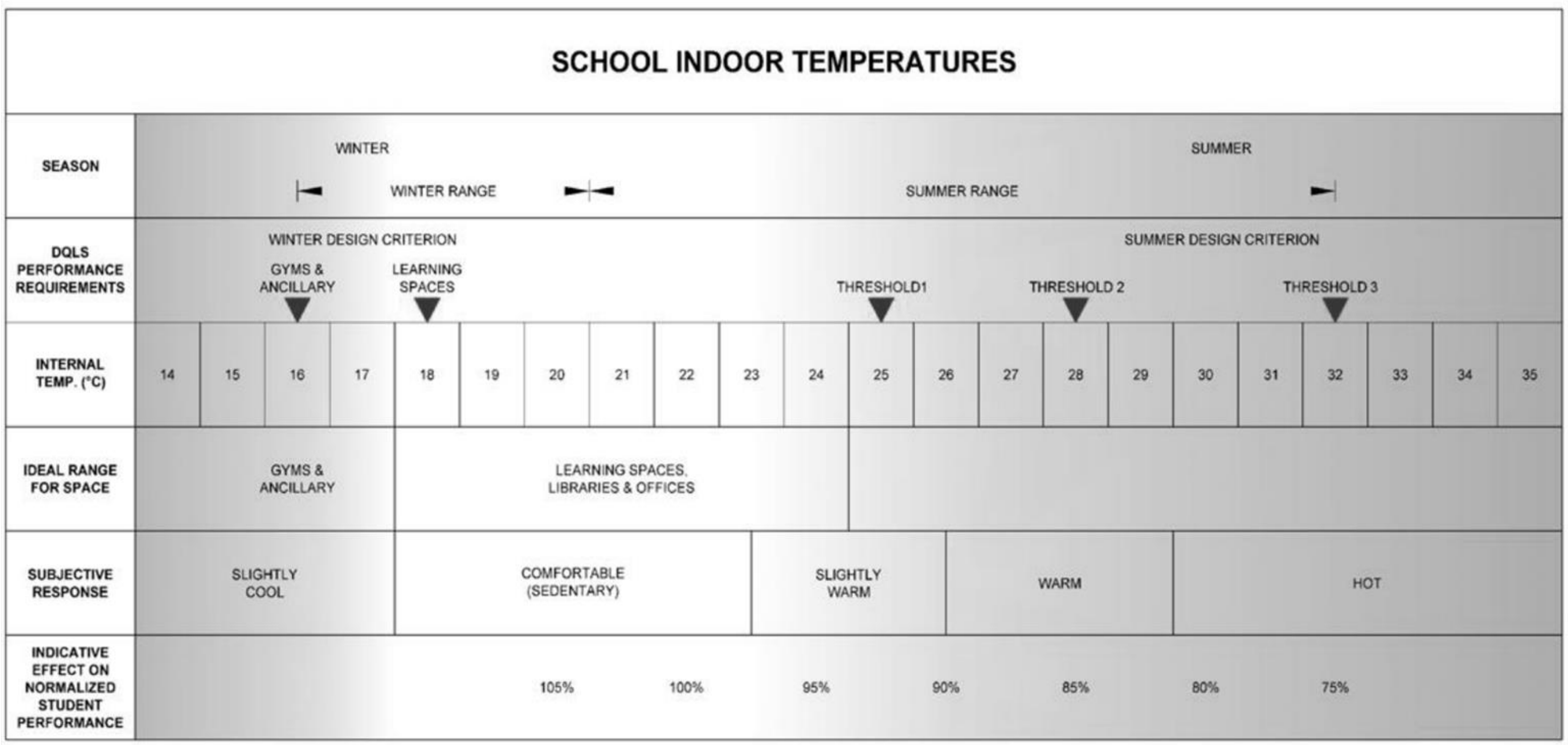


Figure 2-18 School indoor temperature parameters (MoE, 2017a).

In terms of maximum internal temperature, schools are required to meet two of three criteria:

- Temperatures in schools should not exceed 25°C and 28°C for a certain length of time as defined by MoE while occupied between 09h00 and 15h30, from Monday to Friday, between 10 October to 20 December and between 1 February to 15 April;
- The average internal temperature should not exceed the average external temperature by 5°C during hours of occupancy and
- The internal air temperature should not exceed 32°C when occupied.

The DQLS - Indoor air quality and thermal comfort (schools) follow the guidelines set by ASHRAE Standard 62.1-2016, Ventilation for acceptable IAQ in terms of a RH level of 65% or less to reduce the risk of creating an environment conducive to microbial growth. However, no minimum level is set in NZ though ASHRAE (ASHRAE, 2016; MoE, 2017a). The EPA does, however, recommend minimum RH of 30% (United States Environmental Protection Agency, 2017b).

Buildings are also expected to achieve a minimum building resistance level, R-value, according to NZBC H1 and NZS 4218:2009. Insulation requirements to meet these standards can be calculated using three methods, depending on the construction type and glazing area. They include the schedule method, the calculation method or the modelling method (MBIE, 2014c).

NZ lighting regulations and standards relevant to IEQ

Relevant NZBC regulation requirements include:

- G7 Natural lighting (MBIE, 2014a)
  - Habitable spaces should provide adequate openings for natural light and visual awareness of the outside environment to safeguard against illness and provide amenity.
    - Natural light shall provide an illuminance of no less than 30 lux at floor level for 75% of the standard year (between 08h00 and 17h00 each day, compensating for daylight savings). This is equivalent to the Commission

Internationale de l'Eclairage's (CIE) overcast sky (Commission Internationale de l´Eclairage, 1996) according to NZ Standard NZS 6703:1984 Code of practice for interior lighting design (Standards NZ, 1984).

    - Openings to give awareness of the outside shall be transparent and provided in a suitable location.
  - Included in the G7 Natural light is an acceptable solution of (MBIE, 2014a):
    - A window area of no less than 10% of the floor area.
      (This is equivalent to approximately 33 lux at floor level for 75% of the standard year),
    - A glazing transmittance of no less than 0.7,
    - A combined window head height that covers at least half of the room or in larger rooms 10% of the floor area,
    - Increased total window area or added internal reflectance if natural light is restricted by external obstacles,
    - At least 50% of the glazed area for natural light in habitable spaces located in a zone of 0.9m and 2m from the floor level.
- G8 Artificial lighting (MBIE, 2014b)
  - Artificial lighting should be no less than 20 lux at floor level in exit ways, access routes and common spaces within buildings to enable safe movement. An installation will, however, be deemed to be Building Code compliant at 18 lux, due to the difficulties in measuring the illuminance of an installation.

In addition to these requirements, several recommendations are relevant. These are defined via the recommended average illuminance on the following planes, below which levels are not allowed to fall.

- Interior and workplace lighting
  - The Licensing criteria for centre-based education and care services 2008 (updated May 2016) statement in section PF12:

> *'Parts of the building or buildings used by children have lighting (natural or artificial) that is appropriate to the activities offered or purpose of each room.'* (MoE, 2016, p. 14)

- AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series, Section 3.2 provides a special consideration for young observers:

> '*While not strictly a lighting matter, it must be noted that the visual system of very young observers (i.e. up to about 6 to 8 years of age) cannot achieve the acuity (the ability to detect fine detail) that older observers can: this is the reason for large print in children's books. Consequently, it is important that designers of visual tasks for the very young are aware of the limits of the visual system and that lighting designers are aware of which characteristics of tasks can be significantly affected by lighting decisions and which are user-dependent.' (*Standards NZ, 2008a, p. 8*)*

- AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series, Appendix D includes the following illuminance levels:

  General use classrooms should be at 240 lux (maintained) at the working plane and reading rooms at 320 lux (maintained) at the working plane, both with a colour rendering of 1B,2 and a maximum glare index of 19. All lux values are the minimum, maintained values at which the average illuminance should stand.
- NZS 6703:1984 Code of practice for interior lighting design, recommends a standard of service illuminance lux (i.e. not maintained lux) in general teaching spaces of 300 lux at the working plane with a limiting glare index of 19. Illuminance may be reduced to 150 lux in spaces lit by tungsten lamps, e.g. nurseries and infant schools. It must be noted that this is the only specific ECE interior lighting design requirement across all the NZ regulations and standards.

- MoE DQLS: Lighting (MoE & BRANZ, 2007) recommends for classrooms 300 to 500 lux at the working plane of 0.8m above finished floor level (AFFL).

Regional health boards

On behalf of the MoE, the Ministry of Health carries out health and safety assessments of centres, if a centre is looking to apply for an operating licence or if a concern has been raised about a centre. These assessments are carried out in accordance with the health and safety standards, sections 45 and 46 of the Education Regulations 2008 (NZ Parliament, 2008).

The Ministry of Health delegates the completion of these assessments to the regional health boards, e.g., the Auckland Regional Public Health Service (Auckland Regional Public Health Service, 2018a). The local health protection officers represent the regional health board and carry out the assessments.

Each public health unit has health and safety guidelines specific to its region, which interpret the intentions of sections 45 and 46 of the Education (Early Childhood Services) Regulations 2008. Health Protection Officers will follow these guidelines when completing an assessment of a centre. Overall, centres must comply with the Building Act 2004, though the health protection officer may comment on areas of this act if any deficiencies are observed (Auckland Regional Public Health Service, 2018b, 2018c).

The assessment areas include (Auckland Regional Public Health Service, 2018c):

- Play Areas:
  - Lighting
  - Ventilation
  - Heating
  - Noise
  - Art sinks
  - Animals
- Kitchen and dining area:
  - Drinking water
  - Nutrition
  - Food safety
  - Kitchen facilities and dishwashing
  - Refuse storage and disposal
  - Pest and vermin control
- Toilet/handwashing:
  - Toilet hygiene
- Nappy change/body wash area:
  - Nappy changing
  - Body wash facilities
- Child health:
  - Disease prevention and control
  - Immunisation
- Sleep area:
  - Sleeping facilities and bedding
- The whole of premises:
  - General cleaning
  - Water temperature
  - Laundry facilities
  - Sewage disposal

- General public health information:
  - Lead paint
  - Asbestos
  - Sun care
  - Smoke-free policy

Health and Safety at Work Act 2015.

This act (MBIE, 2015) applies to employees and contractors. It does not include children. It requires that all workers be given the highest level of protection from workplace health and safety risks, as far as reasonably practicable. This includes risks to both physical and mental health (Work Safe, 2019).

NZ occupational noise regulations and standards relevant to IEQ

With excessive exposure to sound, causing noise-induced hearing loss, the legal limits of noise are addressed in the 1995 Health Safety and Employment Regulations, Regulation 11 (MBIE, 1995). These guidelines state that 'every employer must, so far as *reasonably practicable*, ensure in relation to every workplace under the control of that employer, that no employee is exposed to noise above the following levels:

- 85dB $L_{Aeq,8h}$ (100% dose or 1.0 Pa^2h exposure) and 140 dB L_{Cpeak},
- Or equivalent, e.g., 88dB $L_{Aeq,4h}$, 91dB $L_{Aeq,2h}$, 94dB $L_{Aeq,1h}$. (MBIE, 1995)'

NZS 6802:2008 sets limits on compatibility within human activities, land use and health protection and amenities (Standards NZ, 2008b). This includes defining levels at timeframes across the day and night. AS/NZ 2107:2016 recommends designing sound levels and reverberation times for building interiors, as well as measurements for compliance assessments (Standards NZ, 2016). AS/NZS 1269.1:2005 provides recommended best practices for measuring and assessing occupational noise immissions and exposure (Standards NZ, 2005). AS/NZ 2460:2002 Acoustics Measurement of the Reverberation Times in Rooms includes classrooms and lecture rooms, though not ECE centres (Standards NZ, 2002). It must be noted that there are no specific criteria for protecting children's hearing.

Fire and Emergency NZ Act 2017.

From 1 July 2018, the Fire and Emergency NZ Act 2017 (Ministry of Internal Affairs, 2017) replaced the Fire Service Act 1975 and the Fire Safety and Evacuation of Buildings Regulations 2006, bringing together all fire and emergency services for the first time. This new act places compliance obligations on building owners, occupants and all persons. It also requires all commercial, public and industrial buildings to have evacuation procedures and schemes in place. For any new building, the evacuation procedures and schemes must be approved 30 days before the building's opening. In most cases, the council will require a scheme to be included with the building consent documentation (Comply with.com, 2018; Fire and Emergency NZ, 2017, 2018).

Food Act 2014

All ECE services that meet the Food Act 2014 (Ministry for Primary Industries, 2014) criteria must register with the Ministry of Primary Industries and have their premises and procedures verified by a food verifier every two years (Ministry for Primary Industries, 2019; Ministry of Primary Industries, 2017).

The requirements under this act are referenced in the 2008 licensing criteria for ECE education and care services and the ECE education curriculum framework, as amended in May 2016 (MoE, 2016). They are also part of the local health unit guidelines, e.g., health and safety guidelines for early childhood education centres (Auckland Regional Public Health Service, 2018c).

Vulnerable Children's Act of 2014

Introduced on 1 July 2014 the Vulnerable Children's Act 2014 aims to protect and improve the wellbeing of vulnerable children and to strengthen the child protection system across NZ. The implication for ECE centres is that they are required to implement child protection policies and safety checking. The child protection policies are to ensure children are safe, and any potential abuse or neglect is identified and addressed (MoE, 2014).

Building requirements that have resulted include:

- No visibility into any bathrooms from the outside.

- All areas within bathrooms and sleep rooms must be visible from within the main playroom.

2.4.6. Building or renovating an ECE centre.

Most cities and district councils are building consent authorities (BCA), which may sometimes be contracted out. BCAs approve resource consent (if applicable), as well as building consent documentation, before any building work commences, with site inspections carried out by the local council during, and at the end of, the build (MBIE, 2016c).

The MoE and the Ministry of Health do not require any approvals before or during the building of a centre. An ECE centre is only inspected by the MoE and the Ministry of Health once it is complete (MoE, 2016).

If a centre fails to pass any of its building inspections, its MoE inspection or its Ministry of Health inspection, it will not obtain its:

- Code of compliance certificate from its local council, which confirms that the building meets minimum building standards.
- ECE license, which confirms that the centre meets minimum MoE standards.
- Approval from the Ministry of Health, which confirms that the centre complies with minimum health standards.
- Building insurance, upon which bank financing of construction work will often depend.

2.4.7. Auckland, NZ context

Population

In the 2013 Census, NZ's resident population was 4,242,051 of which 1,415,550 (33%) were resident in Auckland. Of the Auckland resident population 102,882 children between the ages of zero and four years old, 7.27% of Auckland's population. Of those children aged zero to four, 65% live in Auckland (Stats NZ, 2017).

In this census, across Auckland, 249 territorial authorities were defined, with an average of 3,370 residents per authority. By the end of 2017, NZ's estimated resident population was 4,796,000 people, a 13% increase since the 2013 Census. Of the estimated resident population 1,657,200 (34%) people were estimated to be living in Auckland (Stats NZ, 2017), a 17% increase since the 2013 Census.

Geographical

Located in the South Pacific Ocean, Auckland, NZ, lies at a latitude of 36° 51' S and a longitude of 174° 47' E. This is in the northern part of NZ as seen in Figure 2-19. Auckland is the largest city in the country and is dissected by two plateaux, the Waitakere and Hunua Ranges (New World Encyclopaedia, 2019).

Auckland is one of the few cities in the world to have harbours on two individual bodies of water: the Pacific Ocean and the Tasman Sea. Auckland is built across a narrow isthmus, spreading out to cover 5,600 km^2 across a very diverse, volcanic terrain (New World Encyclopaedia, 2019).

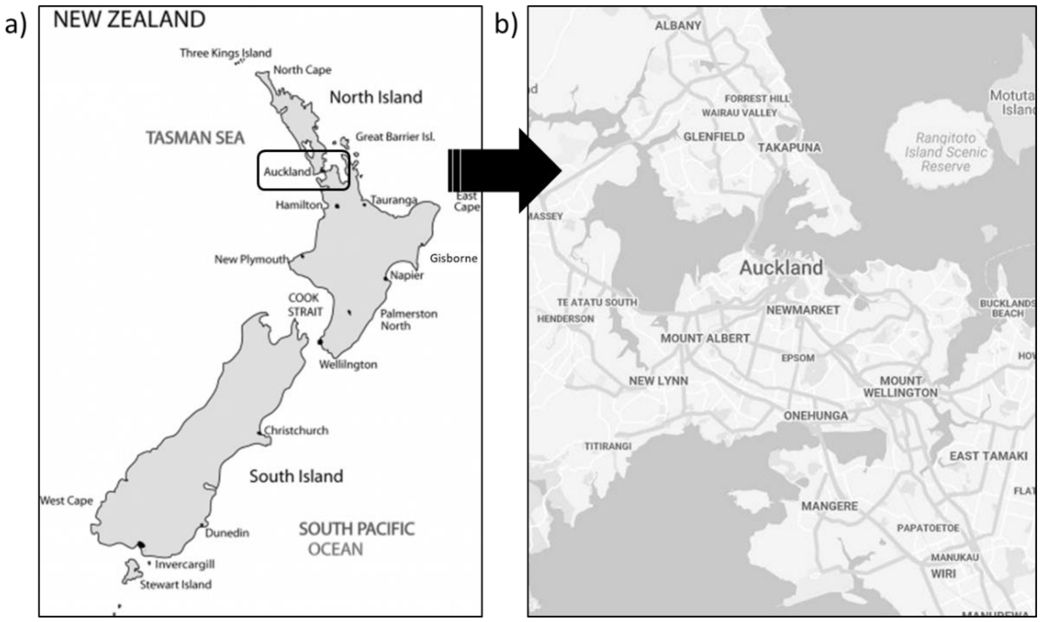


Figure 2-19 a) NZ, highlighting Auckland (Creative Commons & Unknown Author, 2018) b) Central Auckland (Google Maps, 2018)

Climatic conditions

Auckland’s climate is considered subtropical, with warm and humid summers (December to February) and mild and damp winters (June to August). Rainfall occurs all year round with predominantly northerly winds. While Auckland can experience very high, sporadic rainfalls throughout the year, 32% of the annual rainfall occurs in winter and 20% in summer as seen in Figure 2-20. Summer may also experience infrequent, short, dry spells. The lower urban areas receive an average rainfall of between 1,100 mm to 1,200 mm per year, with the higher ranges experiencing levels about 50% greater. The land and sea breezes have a moderating influence on Auckland’s climate, with a predominate southwestern airflow, though the proportion of northeast winds do increase in summer (Chappell & National Institute of Water and Atmospheric Research, 2014).

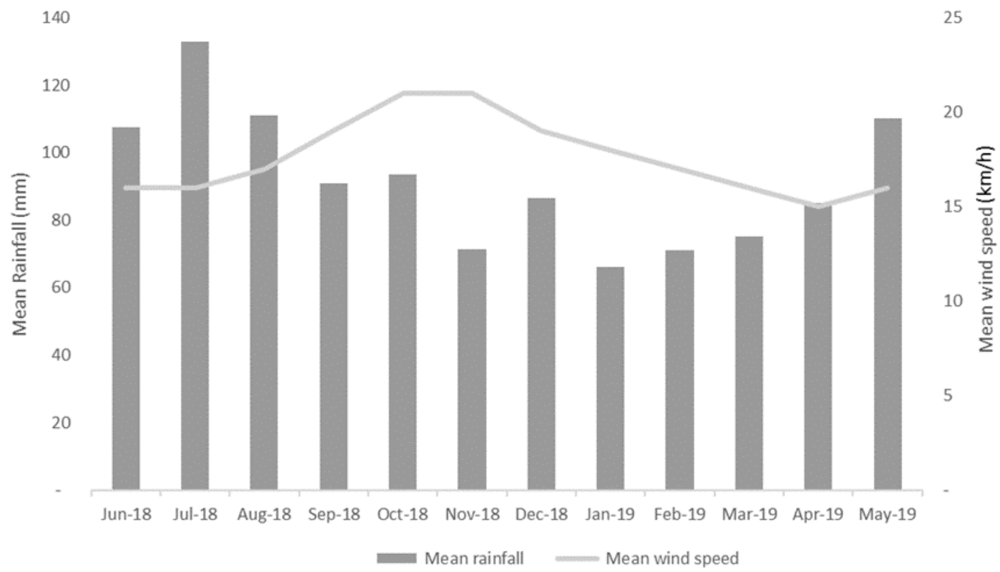


Figure 2-20 Mean rainfall (mm) and mean wind speed (km/hour) by month at Auckland Airport from June 2018 to May 2019 (Chappell & National Institute of Water and Atmospheric Research, 2014)

As depicted in Figure 2-21 Auckland's annual mean temperatures vary between 14°C and 16°C and are tempered by the relatively low latitudes and elevations in the region, as well as the surrounding ocean. High temperatures can reach into the early thirties, and low temperatures drop to just below zero. The annual mean daily temperature range is, however, considered small, at an average of 7.9°C (Chappell & National Institute of Water and Atmospheric Research, 2014) as seen in Figure 2-22.

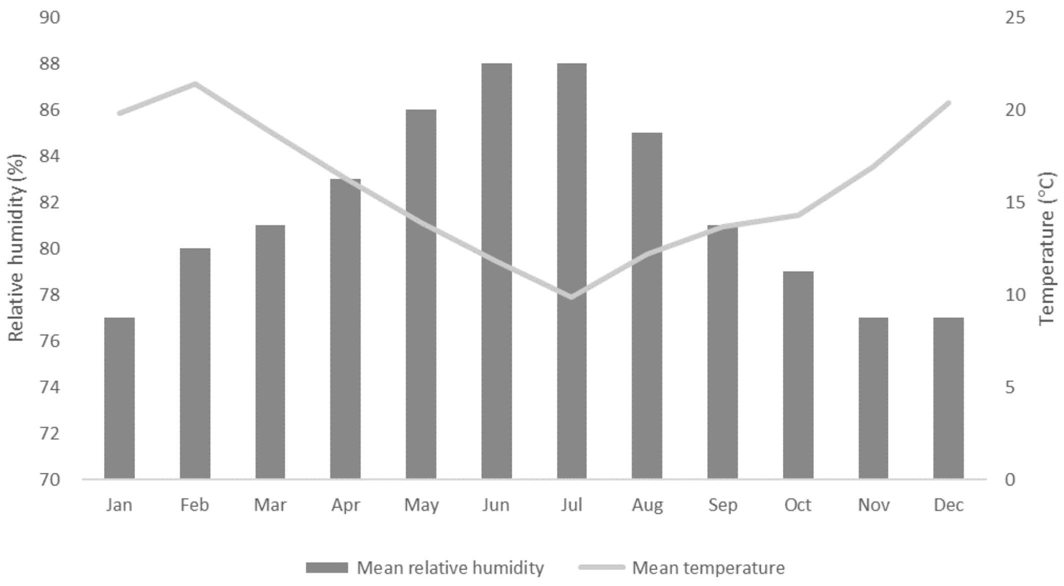


Figure 2-21 The mean monthly relative humidity (%), mean monthly maximum and minimum temperatures (℃) at Auckland Airport in New Zealand (Chappell & National Institute of Water and Atmospheric Research, 2014)

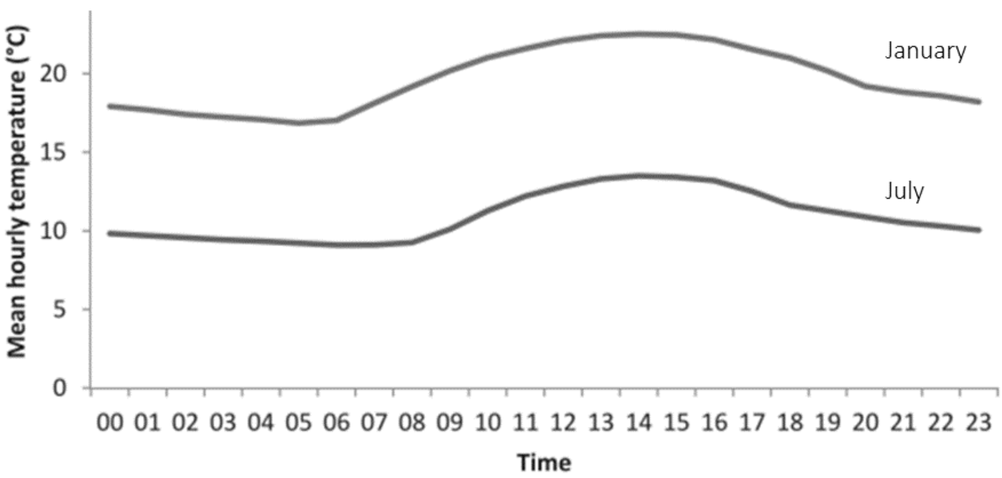


Figure 2-22 Mean hourly temperature (℃) at Auckland Airport, January and July (Chappell & National Institute of Water and Atmospheric Research, 2014).

Since it is surrounded by sea and has no significant mountain ranges, Auckland's vapour pressure and RH are considered high. Both are reasonably consistent throughout the year, with an annual mean vapour pressure of 14.2 hPa and an RH of 82% at the Auckland Airport. Vapour pressure can reach a monthly mean high of 17.9 hPa in February and a low of 11 hPa in August, with RH reaching a monthly mean high of 88% in July and a low of 77% from November to January. Auckland is considered to feel more humid in summer than other centres due to its higher water vapour pressure and an increase in temperature, despite its lower RH at that time of the year. Auckland experiences extreme weather events that can cause flooding and wind damage (Chappell & National Institute of Water and Atmospheric Research, 2014).

Auckland experiences local onshore daytime sea breezes, with examples shown in Figure 2-23. These are generated on clear days when the land surface has warmed more than the sea. They tend to be less than 20km/hr and contribute towards the sea breeze convergence zone. This is a cloud band that can contain scattered showers. The location of this zone is influenced by the direction of large-scale winds.

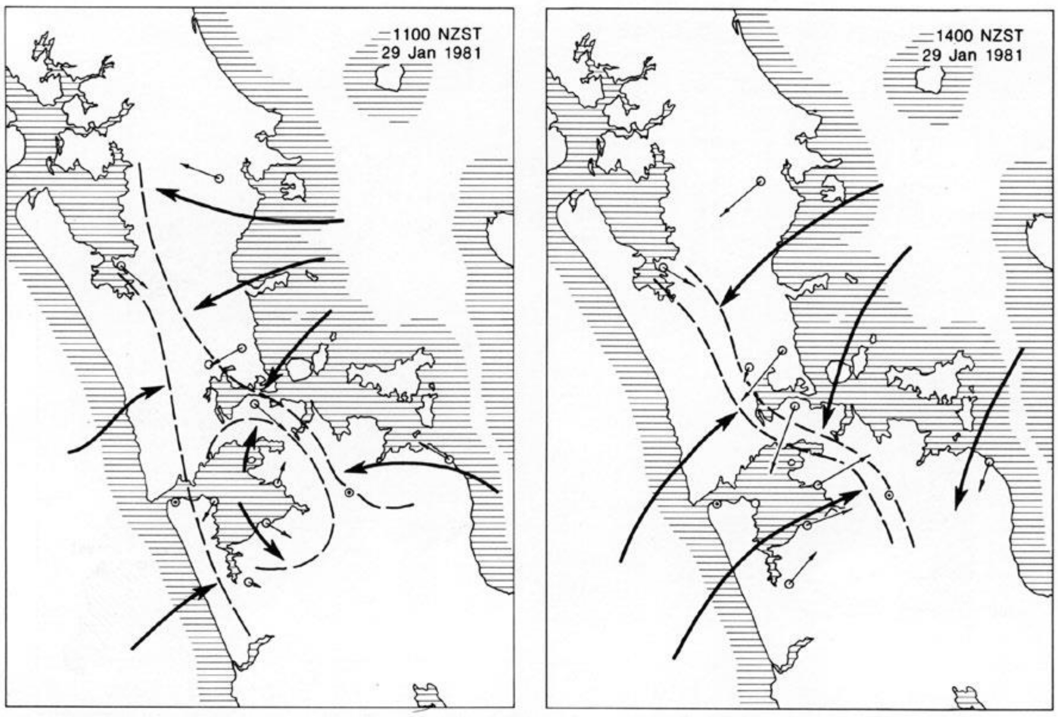


Figure 2-23 An example of a typical sea breeze convergence zone. On the left, are the harbour breezes at 11h00 and on the right are the mature breezes at 14h00 with the sea breeze convergence zone having developed (Chappell & National Institute of Water and Atmospheric Research, 2014).

Most of Auckland receives approximately 2,000 hours of bright sunshine per year, with UV sun protection advised from October to March between 09h00 and 17h00, as the UV index climbs to an extreme level (12) (Chappell & National Institute of Water and Atmospheric Research, 2014)

2.5.The literature review summary

The literature review showed a low number of studies relating to ECE indoor environments. Of the studies found only a few studies were undertaken in NZ, and only one other currently underway in Auckland. The international ECE IEQ studies reviewed identified IEQ environments that fell below that country's standards and focused on either IAQ, particulate matter or chemical air pollutants with very few investigating light or sound.

The literature review then explored three key factors of IEQ are IAQ, light and sound and each of these key factor's characteristics within an indoor environment. This included how these factors could be managed and the impact they can have on human health. Research indicates that IEQ in terms of IAQ, light and sound can negatively impact a person's health, especially younger children. In NZ, it has been found that there is also a growing concern for the health of the NZ population, with NZ having one of the highest asthma rates in the world. NZ has also seen increases in tuberculosis (TB), childhood pneumonia, hospitalisations from skin infections, rheumatic fever and chronic obstructive pulmonary disease.

It also highlighted a 46% increase in the number of ECE centres between 2005 and 2017 and in 2017, 66% of NZ's children under five years old were enrolled in early education services with 38% of these children living in Auckland. These centres have been built in an environment where the ECE IEQ factors within NZ building regulations and educational guidelines can be complex and set minimum standards. The building regulations and education guidelines are also more specific to the school environments and less specific to ECE environments. Approximately 6% of buildings in NZ's building stock are classed as leaky homes, along with numerous leaky schools. Dampness and mould growth in buildings is a commonly reported issue, and NZ's buildings are reported as being poorly maintained. The estimated population of Auckland increased by 17% between the 2013 and 2017 census and the climate in Auckland was found to be subtropical, with warm, humid summers and mild, wet winters. It is surrounded by sea and has no significant mountain ranges; therefore, it's RH is high and reasonably consistent throughout the year.

Bringing together the impact IEQ can have on young children, the concerns relating to the health of the NZ population, the growing population size of Auckland and the localised climatic challenges as well as the increase in ECE centres in a complex building compliance framework that sets minimum standards, there is a research knowledge gap in the understanding of the NZ ECE IEQ, particularly in Auckland.

2.6.The objective of the thesis

As concluded in the literature review, there is a research knowledge gap in NZ ECE IEQ, particularly in Auckland. The objective of this thesis was to, therefore, begin to fill this research knowledge gap. It does this by being the first to investigate NZ ECE IEQ, particularly in Auckland through the following three research questions:

4. What is the NZ education facilities environment, and is there an interest for IEQ research, particularly in ECE?
5. How can ECE centres be safely and sensitively monitored?
6. What is the IEQ in Auckland ECE centres and how does it compare with local regulations, standards and guidelines?

To answer these research questions the objective of:

- Research question one was to gather industry feedback regarding the local NZ education facilities environment from ECE to schools and see if there is was an interest for IEQ research, particularly in ECE.
- Research question two was to determine the scope and appropriate materials and methodology to measure the IEQ of an ECE centre safely and sensitively in NZ. The planning for the symposium began in June 2016 with the four cases studies starting shortly after that.
- Research question three was to measure the IEQ within four urban ECE centres in Auckland over a year and to assess these results against current NZ building regulations and educational guidelines. Nine classrooms and four sleep rooms were monitored in total.

The design of this study is presented in Figure 2-24 below.

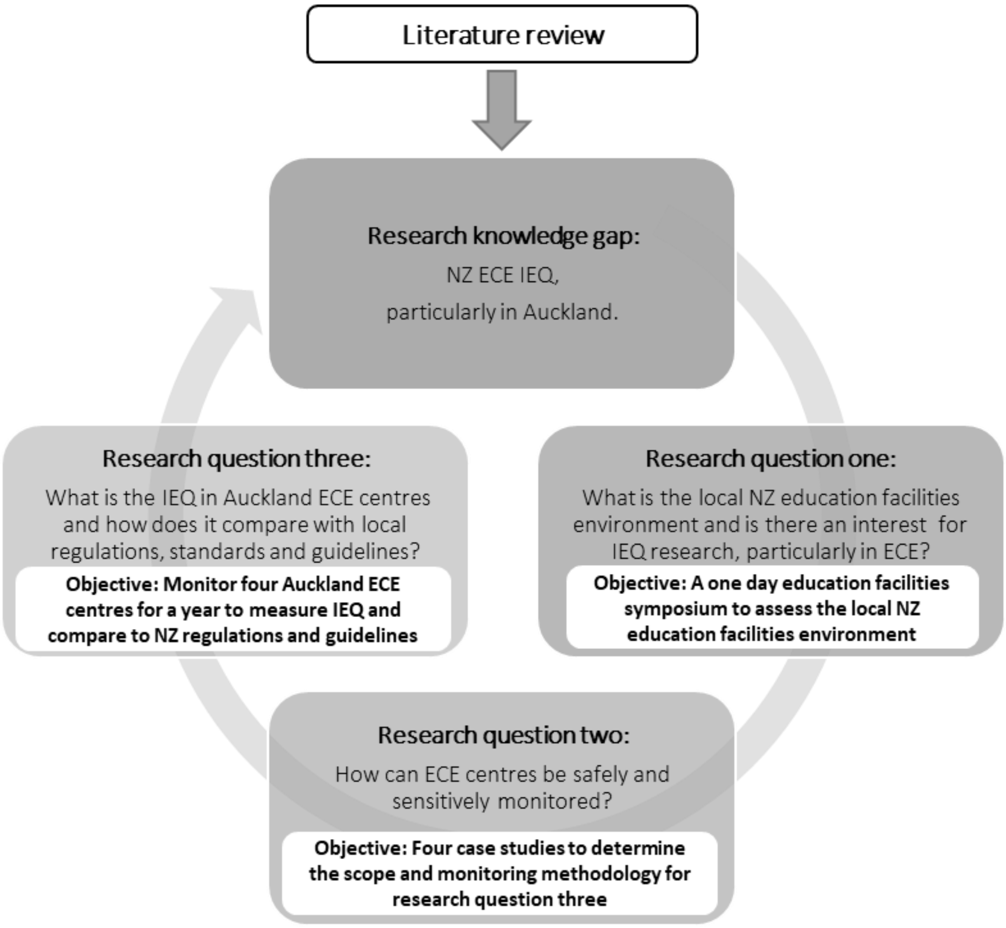


Figure 2-24 The research knowledge gap identified in the literature review was addressed through three research questions and their respective objectives.

The literature review, commenced in April 2016, found that the NZ building regulations and educational guidelines can be complex and set minimum standards. The building regulations and education guidelines are also more specific to the school environments and less specific to ECE environments. To, therefore, better understand the local education facilities environment and why this may be, schools were included in the scope of research question one along with ECE. With the research gap identified as NZ ECE IEQ, particularly in Auckland, this thesis focuses predominately on research questions two and three. The summary and conclusion from research question one are presented in this thesis in the context of the research knowledge gap and how it informed and enabled research question two and three. The full methodology, results and discussion used for research question one are presented in appendix 8.1.

The rest of this thesis is composed of four chapters. Chapter three summarises the conclusions from research question one, a facilitated day-long education facilities symposium, in the context of research question two and three. Chapter four addresses research question two in order to determine the scope and appropriate materials and methodology to measure the IEQ of an ECE centre safely and sensitively in NZ. The planning for the symposium began in June 2016 with the four cases studies starting shortly after that.

Chapter five presents research question three. It begins with the methodology used to monitor and assess the IEQ factors within four urban ECE centres in Auckland, NZ and summarises the ethics approval of this study. It then quantifies the results of the IEQ factors measured. Following this, it discusses the results and assesses them against current NZ building regulatory requirements and any NZ educational IEQ guidelines. The chapter then closes with the limitations of investigating research question three and the recommendations drawn from the discussion. The monitoring of the four centres started in June 2018 and was completed in July 2019.

Chapter six concludes this study by summarising the key findings and key recommendations for policymakers and future research. After the references, the appendix presents the full methodology, results, discussion, challenges and recommendations from research question one and concludes with the challenges faced during the investigation of research question three.

3. Research question one

To answer the first research question "What is the local NZ education facilities environment and is there an interest for IEQ research, particularly in NZ?", a one-day education facilities symposium was designed with the objective of gathering industry feedback regarding the local NZ education facilities environment from ECE to schools and see if there is was an interest for IEQ research, particularly in ECE.

The literature review found that there were few standards and guidelines for ECE in NZ though there were standards and guidelines for schools. To, therefore, better understand the local education facilities environment and why this may be, schools were included in the scope of research question one along with ECE.

The researcher facilitated the organisation of the one-day education facilities symposium, Figure 3-1. This symposium was hosted by Massey University on 5th September 2016. It was the first of its kind in NZ, bringing together over 90 industry-wide representatives including educators, designers, policymakers, medical doctors, manufacturers, builders and researchers to discuss issues and share experiences.

Figure 3-1 Opening Mihi at the Education Facilities Symposium from Professor Chris Cunningham, Director of Massey University's Te Pumanawa Hauora Māori Health Research Centre and Massey University staff

Education facilities in this context were indoor and outdoor spaces from ECE to high school, including building products, materials and systems and ongoing operations, e.g., energy budgets, maintenance and refurbishments.

A symposium committee of four people was established. The members included the researcher, Mikael Boulic and Professor Robyn Phipps from Massey University, and David Waters as an industry representative. The committee was also assisted by Shona Alo, School of Engineering and Advanced Technology Administrator at Massey University.

The researcher facilitated and coordinated the development of the symposium, including the agenda, the questions and the list of participants, as well as securing their attendance. The full methodology, discussion and results of the symposium are presented in detail in appendix 8.1.

In answer to the first research question 'What is the local NZ education facilities environment and is there an interest for IEQ research, particularly in ECE?' the symposium highlighted how dominant the school environment was over ECE within the education and building sectors. It also highlighted potential inconsistencies and uncertainties in the education facilities regulatory framework, a possible breakdown in the education facilities design, procurement, building and maintenance process and education facilities may not be meeting building code, and other guidelines set out by the MoE. Feedback from the symposium confirmed the conclusion of the literature review with the symposium concluding that further research into the IEQ of NZ education facilities was valid in both schools and ECE. Subsequent to the symposium MoE and BRANZ went on to support and finance a similar study in 100 school classrooms across New Zealand.

4. Research question two

Following on from the answers to the first research question in that the education facilities environment was complex with many concerns raised, and there is an interest in ECE IEQ research, four case studies were commenced to address research question two. To answer the second research question, the case studies were designed with the objective of determining the scope and appropriate materials and methodology to measure the IEQ of an ECE centre safely and sensitively in NZ.

4.1.Materials and methodologies

To determine the scope, appropriate materials and methodology to measure the ECE centres in Auckland, NZ, four case studies were carried out. The criteria used to evaluate the activities were:

- Ensuring that an ECE centre could be safely and sensitively measured over a year,
- Understanding what the occupants' potential involvement could be and
- Evaluating what was achievable within the scope of a solo part-time master researcher.

Case study one: Short term measurement of IAQ in an ECE centre

The first field activity was a short trial undertaken by a Massey research group. The objective of this trial was to understand the best installation to measure the RH, CO_2 and temperature in three ECE centres. The researcher acted as an assistant to the research group and documented installation observations.

Two commercial, indoor, IAQ monitors (TSI Q-TRAK 7575) were installed in six classrooms across three centres while the centres were closed (two rooms per centre). These monitors are annually calibrated by Massey University.

Various attachment methods and locations in the rooms were tested. This included installing the monitors in protective cages and placing those cages within the breathable zone of the children, securing the monitors to the walls near a power outlet and securing them to the walls at a distance from a power outlet. Tested installation materials included nail type hanging hooks, double-sided tape hanging hooks, 3M Velcro removable hanging strips, nail and 3M removable cable hooks, electrical tape, duct tape along with a staple gun, extension leads and power boards.

Case study two: Short term measurement of IAQ in three school classrooms

To test the observations gathered from the first activity and to further develop the methodology for the third research question of this study, a short field trial was conducted in three classrooms of a primary school local to the researcher. This second field activity involved installing two commercial, indoor, IAQ monitors (TSI Q-TRAK 7575) in each classroom, which, as mentioned above, are annually calibrated by Massey University.

The teachers were asked to log when the doors or windows of the classroom were opened or closed. This was done by leaving a data sheet on a clipboard next to each window or door for easy record keeping.

Installation materials tested in the previous field activity were again tested in the classrooms. This trial was run for two weeks, with daily observations of the installed equipment and interviews with the teachers to assess if the monitors were impacting their lessons and how they had used and found IEQ in the room that day.

Case study three: A research study surveying the durability of hardware and safety of doors and windows in ECE centres

The third activity was to observe and advise a Massey student on his research report undertaken in partial fulfilment of his degree of Bachelor of Construction in Quantity Surveying (Staveley, 2016). The purpose of the study was to evaluate naturally ventilated ECE centres to see if they were being ventilated correctly and to see if the doors and windows were considered fit for purpose and safe in New Zealand's unregulated window and door manufacturing environment.

Data was mainly collected through an email survey of headteachers and managers of ECE centres. The researcher reviewed the draft survey questions, supported the student in trialling the survey with a small sample of headteachers and assisted in recruiting ECE centres.

Case study Four: A day observing in an ECE centre

A day was spent observing and documenting an ECE centre that was not one of the centres participating in investigating the third research question. The aim was to use this centre as a trial to ensure there was no unintended intervention in the participating centres. This ECE centre of 40 children was within the vicinity of the participating centres and had an ERO rating of ‘very well-placed to promote positive learning outcomes for children’.

The objective of this day was to:

- Observe how teachers and children used the centre and gain an understanding of their routines. This was done through informal interviews with each teacher and sitting in the occupied rooms to observe activities.
- Become familiar with the building characteristics of the centre and test a draft building inspection checklist. This was done by completing a full building site measure while the children were out to play, consulting a draft checklist and making adjustments where necessary. The draft checklist was initially created based on other similar studies (J. Bennett et al., 2018; Gaspar et al., 2018; Ramalho et al., 2013; Salleh, Salim, & Kamaruzzaman, 2016; Viegas et al., 2015; Zuraimi & Tham, 2008).

4.2. Discussion and conclusions

Each activity was evaluated against the following key criteria:

- Ensuring that an ECE centre could be safely and sensitively measured over a year,
- Understanding what the occupants' potential involvement could be and
- Evaluating what was viable for a solo part-time master's student to complete.

Case study one: Short term trial measuring IAQ in an ECE centre

The observations drawn from this trial indicated that long term monitoring in an ECE space must be discreet, secured and temporary. Children at these ages are curious and love to climb. Monitors placed in protective cages require constant supervision and, therefore, are not an option going forward. Within two hours of the children being in the room with the cage, the researcher was called back to site as they had tried to climb on top of it, pushed small toys through the ventilation slots, and almost knocked it over. It was therefore concluded that, for a longer-term study, researchers would need to be on standby to swiftly remove the equipment if necessary.

Concerning installing the monitors on the wall, it was concluded that, for the safety of the children and the equipment, any equipment (including all cabling) should be installed above 1.2 m. The children could easily reach anything below this height and pull it off the wall.

Commercial indoor IAQ monitors (TSI Q-TRAK 7575) were a concern in an early learning environment. They are difficult to temporarily install in appropriate locations due to the weight of the probe stand and the variations in wall materials, e.g. pinboard, whiteboard, painted plasterboard, brick or concrete. They are also challenging in terms of how far the probe protrudes from the wall and how difficult the probe is to see, even when white marking tape is applied to the end of the probe.

In terms of installation methodology, 3M hanging strips and cable hooks were by far the most secure, non-invasive and discreet. It was concluded that cable runs should be kept as short and discreet as possible. Electrical tape and staples from a staple gun used in the trials to secure extension cables and sensor holders easily came away from the walls. Duct tape and any form of nail caused too much permanent damage. Extension cables were too heavy to run over long distances, were not easy to secure and were not in keeping with a good quality children's environment. Plugs also needed to be secured into the plug sockets with electrical tape to prevent them from being unplugged or turned off.

During the trial, one monitor had been unplugged, another accidentally turned off and two others just stopped storing data. As these monitors do not transmit the data, this was only discovered at the end of the field activity.

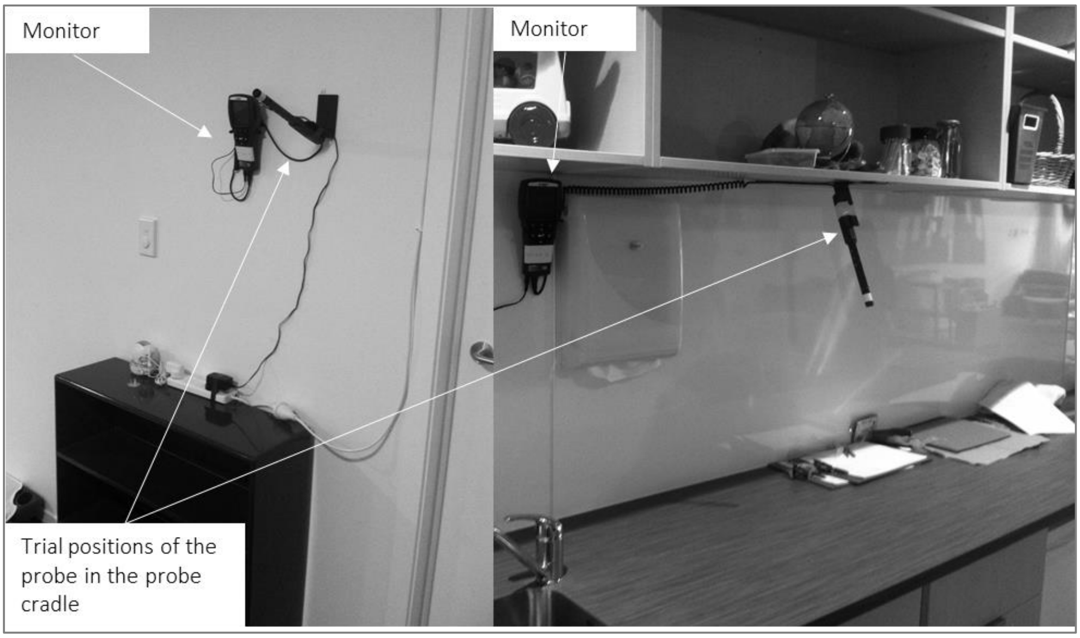
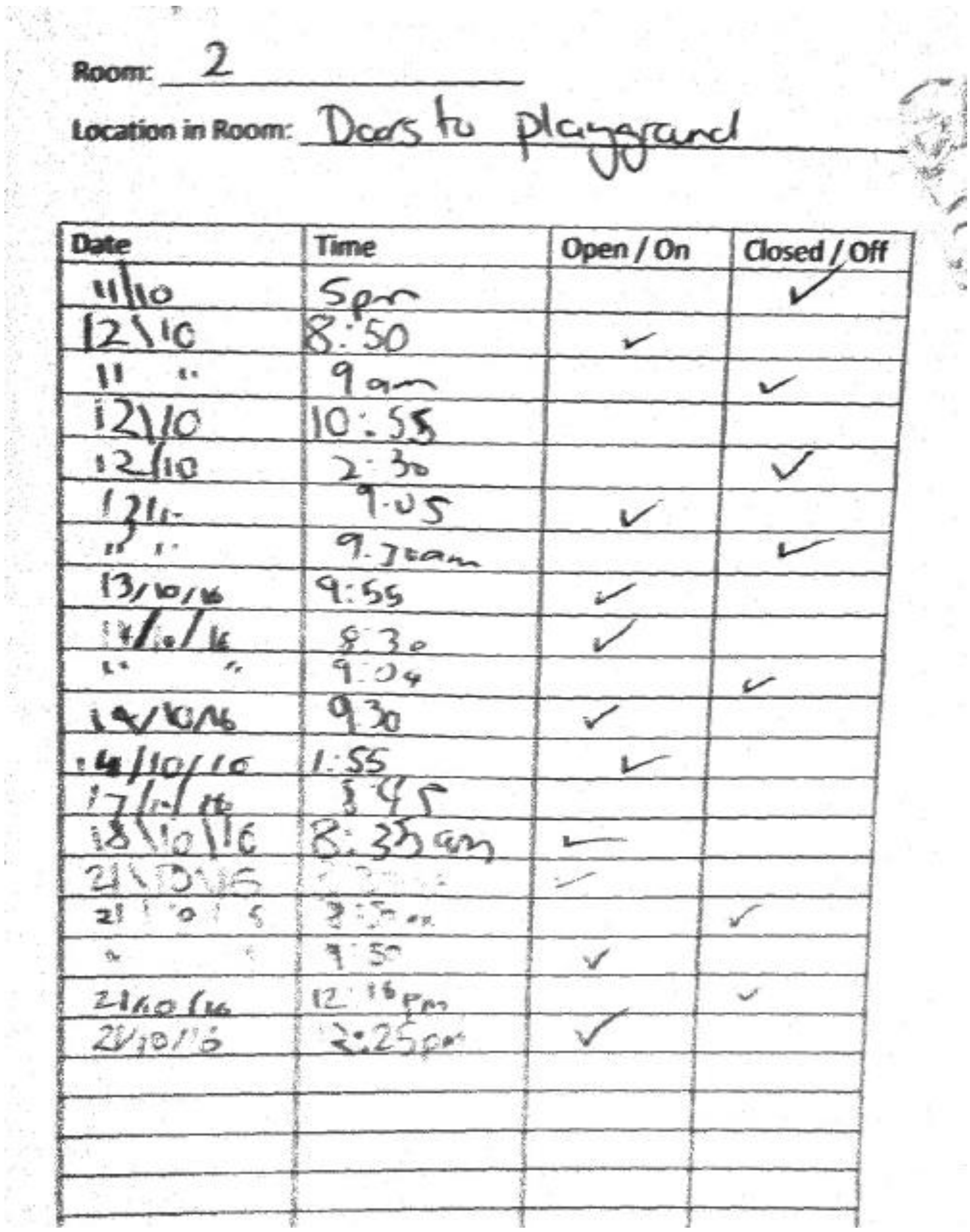


Figure 4-1 Examples of the installed IAQ monitor trialled in various locations and positions

The time taken to install the monitors and conduct the tracer-gas decay tests were also material for each centre, taking at least 1.5 to 2 days to install two monitors per room and run four tracer-gas decay tests in two classrooms. Examples of the installations can be seen in Figure 4-1 above.

Case study two: Short term measurement of IAQ in three school classrooms

The data sheets were poorly completed, and when they were completed, they were inconsistently completed. For example, in the first room, only the first three days were logged and a mix of logs in the second room. In the third room, as seen in Figure 4-2, while there was a log for each day it was mostly for when the door was opened in the morning and not when it was closed again, which when crosschecked against the teacher's daily routine of opening and closing the doors and windows at break times was inconsistent.


Room: 2

Location in Room: Doors to playground

Date	Time	Open / On	Closed / Off
11/10	5pm		✓
12/10	8:50	✓	
" "	9am		✓
12/10	10:55		
12/10	2:30		✓
13/10	9.05	✓	
" "	9.30am		✓
13/10/16	9:55	✓	
14/10/16	8:30	✓	
" "	9:04		✓
14/10/16	9 30	✓	
14/10/16	1:55	✓	
17/10/16	8 45		
18/10/16	8:35am	✓	
21/10/16	[illegible]	✓	
21/10/16	8:50 am		✓
" "	9:50	✓	
21/10/16	12:16pm		✓
21/10/16	2:25pm	✓	

Figure 4-2 Example of a door log sheet that accessed onto the school playground. While there was a log for each day, not all logs were captured with most break times missing and this door being their main access to the playground twice a day.

Commercial indoor IAQ monitors (TSI Q-TRAK 7575) were used in the trials, and, while they are good quality monitors, they were not viable for a long-term study. The sensor is too easily damaged and too heavy to secure to the wall without a nail as seen in Figure 4-3. It also sticks out from the wall too much to be considered safe over a longer-term study. One sensor was accidentally knocked off the wall, and another was damaged when it pulled away from the wall on its own during a test to determine how best to secure it to a pinboard wall. These types of monitors are also too expensive a resource for a larger scale, longer-term study, and data cannot be remotely accessed.

Securing the plugs and power switches with electrical tape and writing across them “Do not unplug” did result in no instances when the monitor was either turned off or unplugged.

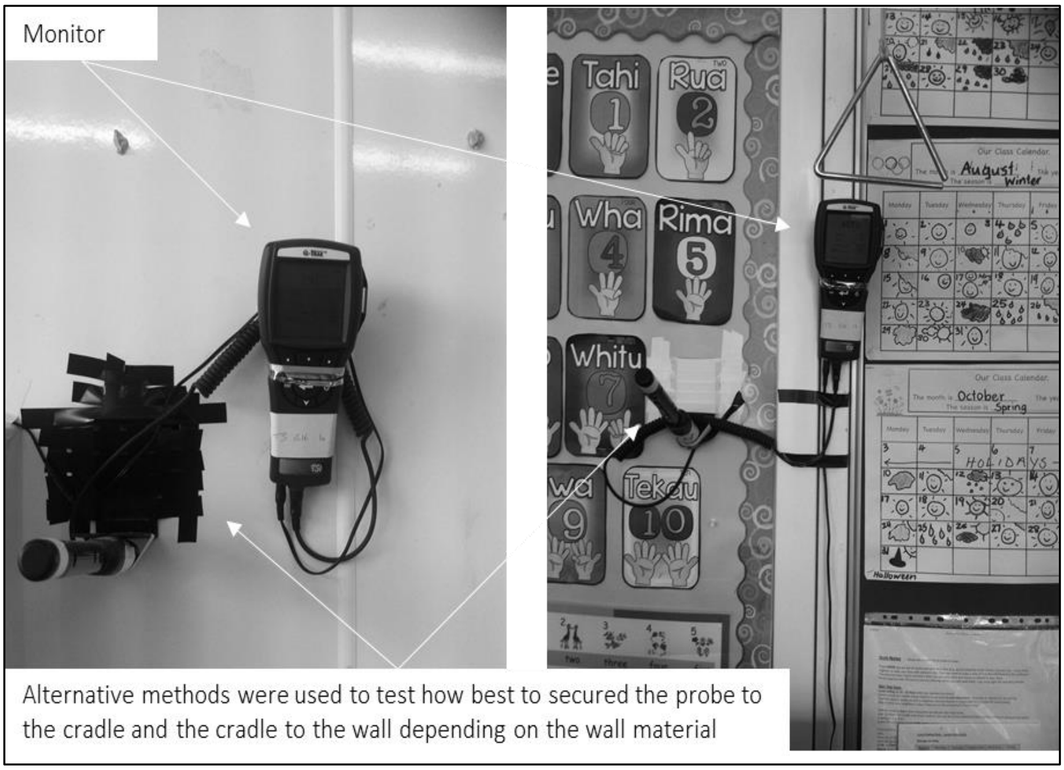


Figure 4-3 The IAQ monitors were difficult to temporarily install due to the weight of the probe stand and the probe were intrusive and not always easy to see.

Case study three: A research study surveying the durability of hardware and safety of doors and windows in ECE centres

After assisting in the refinement of the survey questions, facilitating a trial of the survey questions within a centre and assisting in the recruitment of centres’ observations drawn included the following:

- Recruiting ECE participation and obtaining the appropriate authority is a long, complicated and time-consuming process. Most staff within a centre work ‘on the floor’ and are, therefore, challenging to contact.

- Staff access to email is limited, with most not having an email account.
- Staff time to complete the survey was limited, with most staff only having approximately one hour of non-contact a day when they are not required to be observing the children.
- Survey questions must be very clear to prevent misunderstandings and misinterpretations.

Case study four: A day observing in an ECE centre

- Children's curiosity was reinforced, even in terms of who the researcher was and what she was doing there. However, this interest in the researcher quickly waned as they settled into their daily routine.
- The classroom routines were regular from day to day, as they seek to teach the children routine and self-management.
- Further items to include in the building checklist were identified, and those already identified were refined examples included carpet versus hard floor surfaces measurements, type of wall and ceiling materials used and breakdown of the cleaning routines including shelves and under moveable furniture.

4.3. Summary

In answer to the second research question 'How can ECE centres be safely and sensitively monitored?' the four case studies demonstrated that any long-term monitoring must be discreet, secured and temporary. The program must be clearly communicated to the members of the staff, with no participation from staff or children. Any participation by the staff or children would dramatically increase the complexity of the study in terms of the reliability of data and the scope of the project. This was further validated through the initial ethics applications, as presented in appendix 8.2. Any equipment and plugs used must be clearly labelled and secured. The monitors need to be lightweight with no protrusions into a room and installed near a power outlet and at a height that children under five years old cannot reach. The monitors also need to be frequently checked to ensure they are still taking measurements.

5. Research question three

With research questions one and two answered as seen in Figure 5-1 below, work on the third research question commenced, 'What is the IEQ in Auckland ECE centres and how does it compare with local regulations, standards and guidelines?' The objective of research question three was therefore to measure the IEQ within four urban ECE centres in Auckland over a year and to assess these results against current NZ building regulations and educational guidelines.

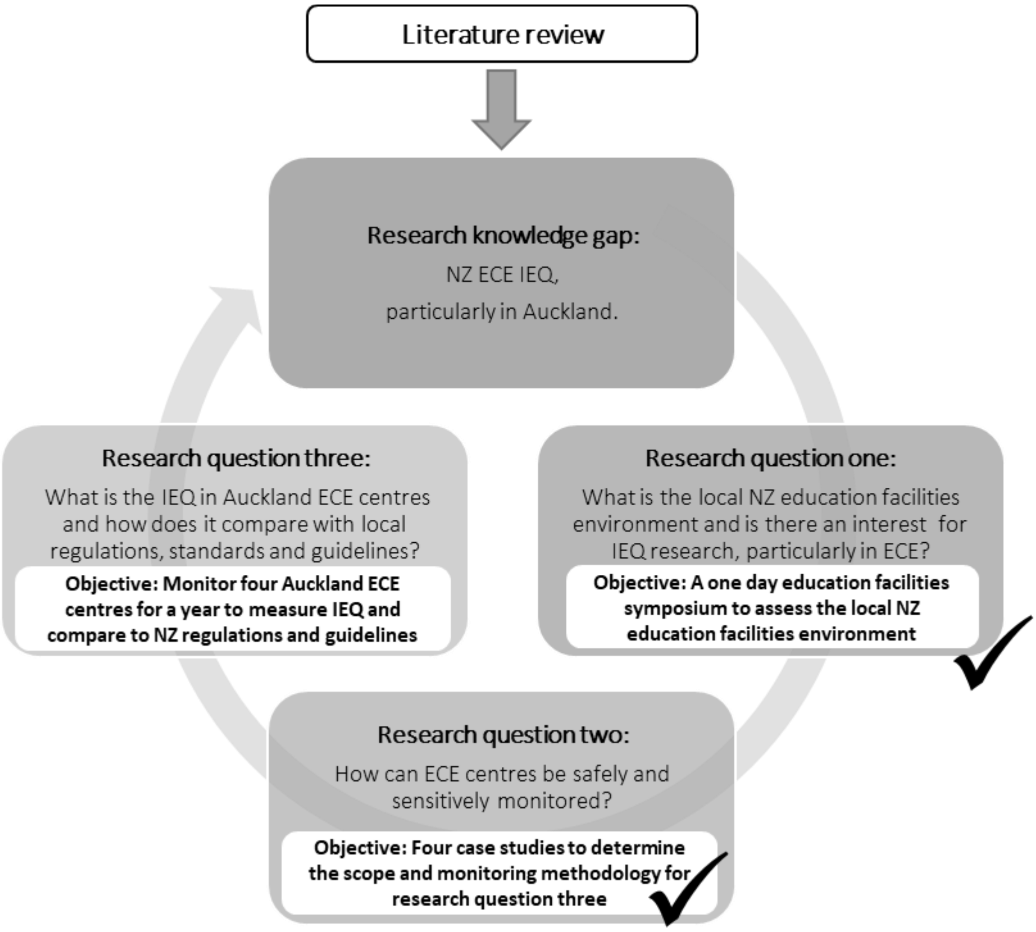


Figure 5-1 The study design to address the research knowledge gap identified in the literature review through three research questions and the objectives of these research questions. With the first two research questions addressed the investigation into the third research question began.

5.1.Scope

Using the information gathered in the literature review and the conclusions drawn from research questions one and two of this study, the scope of research question three focused on the IEQ of four ECE centres based in a localised area of Auckland, NZ. ECE centres in the context of this study, are privately owned centres that provide early childhood education and care. These centres care for infants, toddlers and pre-school children up to five years of age.

Measuring IEQ was a critical step in understanding if local building code, standards and guidelines continue to be met once the construction of a building is complete and deciding on mitigating measures that could be taken to support under five-year-old children's health.

The scope of this study focused specifically on four ECE centres that met four specific criteria. The first criterion was selected to ensure a similar localised weather pattern across all centres, and the next two criteria were selected as indicators that the centre meets the current MoE and Ministry of Health standards and NZ's building code regulations. The fourth criterion was selected to ensure typical ECE building types were represented as highlighted in the literature review. The criteria for participating in the study were as follows:

1. The centres are located in the ECE Centre eligibility zone;
2. Centres achieved an ERO of or above 'well-placed to promote positive learning outcomes for children',
3. Centres hold a current building warrant of fitness,
4. Centres' construction types that can be classified as:
   - Timber (i.e. timber-framed and cladding) or non-timber construction (i.e. concrete 'tilt slab' or block)
   - Naturally or mechanically ventilated
   - A retrofitted centre or purpose-built centre

The IEQ factors included in the scope of research question three were IAQ, light and sound (de Waard & Zeiler, 2014). The scope of IAQ was been limited to temperature, RH and CO_2 as an indication of ventilation rates and the presence of dust. VOCs and other chemicals were excluded from this study due to scope, time and financial constraints. The measurements taken were both real-time and calculated.

5.1.1. Timeline and time frames monitored

The timeline considered for research question three was a full year of continuous monitoring, with no intervention. The timeframes considered within the study included seasons, months, days of the week and hours of the day.

5.1.2. Design

The design of the study consisted of the following steps:

1) Identifying the ECE centre eligibility zone as described in the methodology below and recruiting participating centres.
2) Sourcing outdoor environment data.
3) Undertaking building audits.
4) The measurement of IAQ, including:
    a. Continuous, 24/7 monitoring of IAQ in real-time.
    b. Short term CO_2 tracer-gas decay testing in one centre to obtain reference values for comparisons with the monitored data of those centres and
    c. The calculating of thermal comfort
5) Measurement of light, including:
    a. Computer simulation of natural light illuminance and daylight factors and
    b. Real-time measurement of artificial light.
6) Measurement of sound, including:
    a. The calculation of reverberation within the classrooms.

5.2. Methodology

5.2.1. ECE centre identification and recruitment methodology

Two forms of purposive sampling were used to identify and recruit participating ECE centres. Purposive sampling was selected because it is a non-probability sampling method, with selection based on the research question and the characteristics of the ECE centre population.

Critical case purposive sampling was initially used to identify an area within which potential participating ECE centres could be located, i.e. centres that might reveal insights applicable to other, similar centres. Typical case purposive sampling was then used to identify typical ECE centres according to a set of criteria listed below (Crossman, 2019).

In terms of this study, these sampling methodologies looked to achieve a balance between identifying typical centres that could reveal insights and the centres' proximity to the researcher. As presented in appendix 4 the case studies in research question two revealed the need to be able to get to the centre quickly where children or staff had tampered with the equipment, to ensure child safety was never compromised.

Determining the ECE centre eligibility zone

The ECE centre eligibility zone was determined using critical case purposive sampling. This began with selecting the city of Auckland, which was chosen because 36% of all children eligible to attend ECE services in NZ live in Auckland (Stats NZ, 2017), and the researcher is based there.

Auckland is one of the few cities in the world with harbours on two individual bodies of water (the Pacific Ocean and the Tasman Sea) and is built across a narrow isthmus, spreading out to cover 5,600 km^2 across a very diverse, volcanic terrain (New World Encyclopaedia, 2019). This typology causes Auckland's weather to be localised and influenced by daily sea breezes (Chappell & National Institute of Water and Atmospheric Research, 2014). To, therefore, minimise the variable impact the outdoor environment has on the indoor environment (J. Bennett et al., 2018; Trompetter et al., 2018), the NZ Virtual Climate Station Network (VCSN) was selected from which to obtain the most localised weather data available for the participating eligibility zone. Outdoor monitoring equipment at each site was not economically viable for this study. The two nearest weather stations are located just under 6 km away from the researcher in a south-westerly direction and northeasterly direction respectively. However, the location of the first weather station placed an elevated volcanic ridge between the station and the researcher and therefore,the readings were inhabited by two different sea breeze zones. Eligible centres would therefore not necessarily experience similar localised weather. The positions of these weather stations also placed the eligibility zone across a more diverse urban environment, which partly included the Auckland central business district, a large retail area and a light industrial area. While the second station had the same sea breeze as the reseacher's location, the area between the station and the researcher was mostly water due to an inlet. Therefore, this station captured few centres. In addition to this, the centre did not provide constant daily information. For example the daily RH was not available at the first centre and was difficult to extract at the second.

The VCSN has over 11,000 data points covering the whole of NZ on a regular ~5 km grid and it is managed by the National Institute of Water and Atmospheric Research's (NIWA), an NZ Crown Research Institute established in 1992.

The outdoor environment data was obtained from the VCSN at https://data.niwa.co.nz/#/registration. Climate data is not measured at these points but calculated by NIWA using the ANUSPLIN software. This is done by interpolating measurements made at actual monitoring stations located in surrounding areas. The Australian Bureau of Meteorology uses a similar interpolation process to estimate weather data at similar resolution across Australia, also using the ANUSPLIN software (National Institute of Water and Atmospheric Research, 2016). Each virtual weather station provides daily interpolated data on rainfall, wind speed, maximum and minimum temperatures and the temperature at 10cm from the ground at 9 am, RH, mean sea level pressure, vapour pressure and global solar radiation. A mean daily temperature was not available; therefore, this was calculated based on a mean of:

- The mean between the daily maximum temperature and the temperature at 09h00,

- The mean between the daily minimum temperature and the temperature at 09h00.

The virtual climate station selected was based on two criteria. The first being that the area was exposed to the same sea breeze and the second being its close proximity to the researcher. It was therefore determined that the most appropriate virtual weather station was located at 36.8725°S and 174.8229°E. The eligibility zone identified and selected as seen in Figure 5-2 was between the researcher's location and this weather station, forming a half-circle. The half-circle was kept to a 3km radius remain within the same sea breeze.

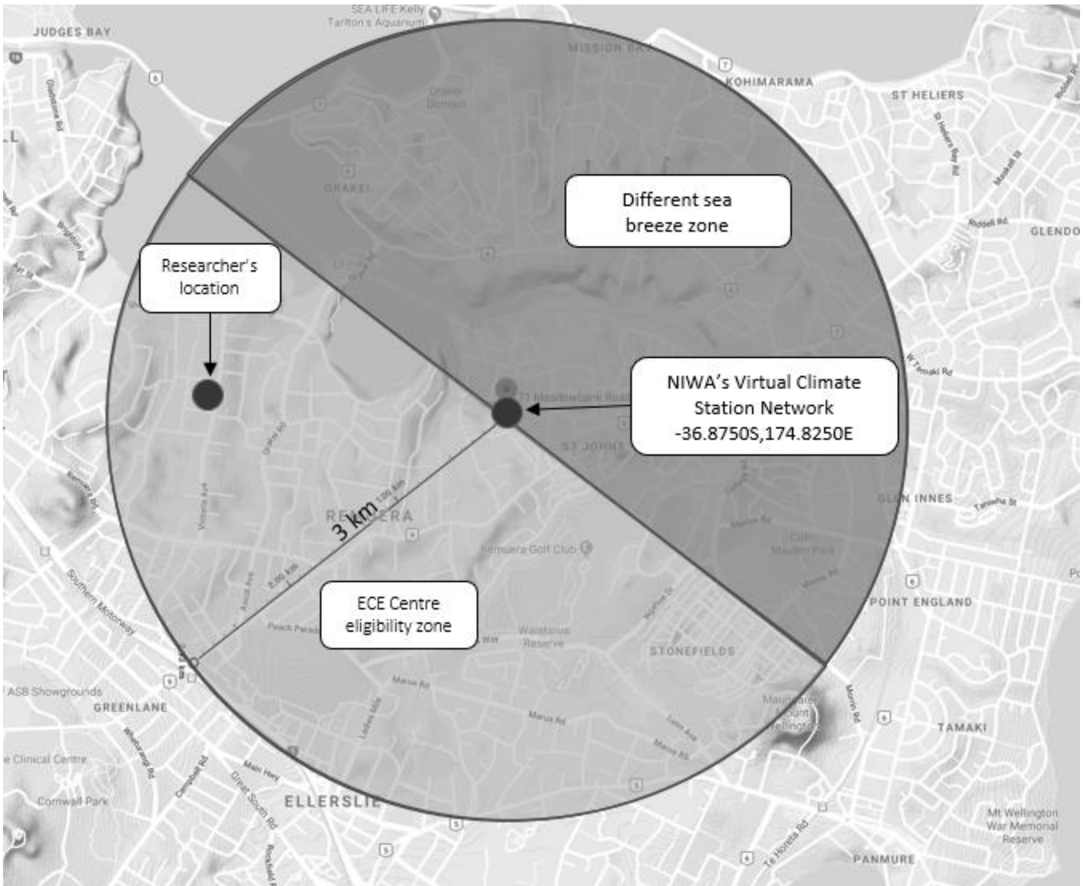


Figure 5-2 A terrain map of Auckland including the virtual weather station, the location of the researcher and the resulting ECE centre eligibility zone (Google Maps, 2018)

Selecting and recruiting the ECE centres

With the ECE centre eligibility zone identified, typical case purposive sampling was used to identify potential eligible centres within this zone. This was done using the following criteria:

1. The centres are located in the ECE centre eligibility zone;
2. Centres achieved an ERO of or above 'Well-placed to promote positive learning outcomes for children',
3. Centres hold a current building warrant of fitness,
4. Centres' construction types can be classified as:
   - Timber or non-timber construction;
   - Naturally or mechanically ventilated;
   - Retrofitted or purpose-built centre.

Using google maps ECE centres were identified within the eligibility zone. Only ECE centres were considered for this study because, of the 5,527 early education services available in NZ, 2,558 (55.6%) are ECE centres – an increase of 804 (45.8%) services since 2005 with little change in the numbers of other services.

To minimise the impact of poor management or teaching practice within a centre, only those centres that achieved the highest ERO of or above 'Well-placed to promote positive learning outcomes for children', according to the Education Review Office database (https://www.ero.govt.nz/review-reports/), were shortlisted.

Centres were then evaluated in terms of the variety of their construction to represent typical construction types. These types included a refurbished villa, a refurbished public use building, a refurbished commercial building and a purpose-built ECE centre. Publicly available council records were used to verify if the centre had a current warrant of fitness though it must be noted that without this in place the MoE would not permit the centre to operate.

5.2.2. Indoor environment quality measurement methodology

The real-time IEQ environmental factors measured throughout the study were CO_2 (as an indicator of ventilation rates), RH and temperature, with one-off artificial light measurements taken in the classrooms of three centres.

To eliminate environmental variables, natural light was calculated using modelling software with accurate computer models built from measured data. Reverberation calculations were also undertaken using software for the same reason, using measured areas of acoustic materials from each applicable space being studied.

A building audit of the monitored rooms was completed to capture activities within the rooms, as well as building characteristics, occupancy, dust observations and cleaning routines.

Monitoring equipment

Indoor air quality monitor

As part of a more extensive IAQ study, Massey University developed a low powered, low-cost, indoor environment monitoring instrument. This instrument, called a SKOMOBO (SKOol MOnitoring BOx) as seen in Figure 5-3, was used to assess the IAQ in this study. Its sensors include CO_2, temperature, RH and particulate matter ($PM_{2.5}$ and PM_{10}). It was built using the open-sourced hardware Arduino Pro Mini, with test results showing a high correlation to their commercial equivalents (Wang et al., 2017). The units were calibrated in October 2017 by Massey University.

The monitors were also assessed and peer-reviewed (Dong, Prakash, Fen, & O'Neill, 2019). However, further research was being conducted at the time of this thesis regarding the accuracy of the PM sensor Plant Tower PM3003. This sensor was 1.5% the cost of a commercial grade PM sensor. Early indications of this research undertaken by Massey University is that when calibrated against a commercial-grade PM sensor, it may be constantly over measuring at 400 $\mu g/m^3$ at PM_1, $PM_{2.5}$ and PM_{10}. At the time that this thesis was submitted this further study had not yet been published. Therefore, due to the possible technical constraints of the PM sensor, the PM data has been removed from this thesis.

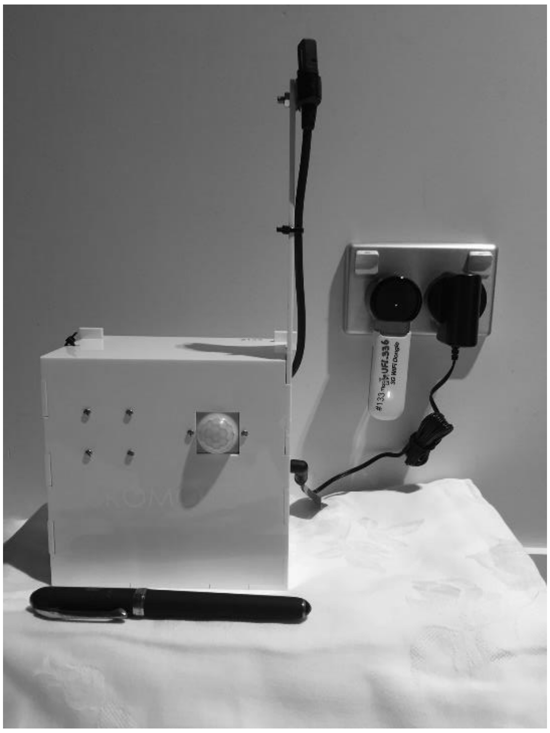


Figure 5-3 SKOMOBO, low-cost IAQ monitoring instrument with a data transmitting device

To further understand the mechanical ventilation conditions in one of the two mechanically ventilated centres, tracer-gas decay testing was successfully performed. The SKOMOBO boxes recorded the data. Three standard domestic fans were used to mix the air well. Compressed, beverage grade CO_2 was used in the testing with CAS No. 124-38-9 and a content of 7% to 11%.

Pre-fieldwork, completed before installing the monitors, included checking equipment integrity and determining if each monitor was measuring and reporting to the Massey database.

Artificial light meter

Illuminance measurements were taken across all centres with a calibrated Testo 540 Lux Meter. This sensor can be used to measure both artificial light and natural light and complies with the NZ Standards:

- NZS 6703:1984 Code of Practice for Interior Lighting Design, Section 11, Measurement of illuminance (Standards NZ, 1984).

- AS/NZ1680.1:2006: Interior and Workplace Lighting, Part 1: General principles and recommendations, Appendix B, Calculation and measurement of illuminance (Standards NZ, 2006).

The requirements of these standards include :

- The photoreceptor should be able to take account of the effects of light falling on it at oblique angles (i.e., a cosine-corrected photocell);
- The photoreceptor should be colour corrected to be able to measure both natural light and artificial light,
- The sensor must have been calibrated within the last 12 months.

A summary of the sensors used in the study and their specifications are presented in *Table 5-1*.

Table 5-1 A summary of the sensors used in the study and their specifications (Wang et al., 2017).

Features	Sensors		
	Within the SKOMOBO		Separate device
	T9602-3-D-1	K30 STA	Testo 540 Lux
Measurement	Temperature and Relative humidity	Carbon Dioxide (CO_2)	Illuminance
Method used	Non-dispersive infrared (NDIR)	Celsius	A cosine-corrected photodiode cell based on the spectral sensitivity of a human eye
Resolution	Temperature: 1 °C Relative humidity: 1%	1 ppm	1 lux (lm/m^2)
Range	Temperature: -20 °C to 70 °C; Relative humidity: 0 to 100 %	0 to 5000 ppm$_{vol}$	0 to 99999 lux
Accuracy	Temperature: ± 0.5 °C Relative humidity: ± 2 %	± 30 ppm or ± 3 % of reading	Accuracy level of ±3 Lux
Response time	Temperature: <= 116 sec; Relative humidity: <= 29 sec	20 sec	0.5 sec
Manufacturer	TELAiRE	SenseAir	Testo

The SKOMOBO installation methodology

The SKOMOBOs were installed when the centres were closed, i.e. either in the evening during the week or over a weekend. This was to ensure the safety of the children and to enable free movement around the centre. µ

To ensure all health and safety concerns were considered, the centre manager's approval was obtained for the final installation position of the units, and staff members were debriefed, either at a staff meeting the night of installation or the following Monday morning post-installation. The primary drivers included:

1. Children's safety;
2. Ensuring the installation was in keeping with the look and feel of the centre and appeared non-invasive;
3. Mitigate, by all actions necessary, any property damage that would require remediation.

Detailed placement considerations for each unit included the following considerations:

- The children could not reach the cables, and the cables were installed neatly, safely and as invisibly as possible—i.e., no long runs of cable.
- Cable runs were kept as short as possible and secured using 3M removable cable holders.
- When securing equipment, 3M Velcro removable hanging strips were used on all surfaces.
- All plugs and switches were secured with electrical tape.
- Power outlets are a scarce resource in an ECE centre. Therefore, additional multiplug boards were provided when using a centre's power outlet.
- All plugs, cables and equipment were at least 1.2m above floor level, so the children could not reach them.
- The units were within the occupancy zone, i.e. no higher than 1.5m from the floor.
- The units had a clear, 50 mm of space around them so that there was nothing obstructing airflow.
- The units were not in direct sunlight.

- The units were not in any direct draught including:
  - Openable external and internal windows or doors
  - Under or in the direct line of any ceiling ventilation or extractor fan.
  - Under or in the direct line of a heat pump or other heating/cooling device.

Note: it was not always possible to install the monitors where the presence sensor could sense movement across the entire room. For this reason, the presence sensor and any associated data were disregarded in the study.

Ventilation rates using the tracer-gas (CO_2) decay methodology

Short term tracer-gas decay testing and analysis were used to obtain ventilation reference values for comparison to the monitored ventilation data, i.e. air changes per hour and litres per second per person. The methodology applied is defined in "The Procedure for the Concentration Decay Test Method" in ASTM Standard E741 (ASTM Standards, 2006). Tracer-gas decay analysis has been widely used to estimate the ventilation rate of a space - i.e., the air exchange rate within a room. The methodology used in this study is consistent with that of other similar studies (J. Bennett et al., 2018; Boulic, 2012; Viegas et al., 2015).

The tracer-gas decay testing began with placing monitors at different locations around the room, all within the occupancy zone of the children, between 0.5m and 1m from the floor. Calibration checks were completed on the SKOMOBOs prior to the tests being run. This was done using a commercial indoor IAQ monitor (TSI Q-TRAK 7575) hired from Tech Rentals, a local monitoring equipment supplier. The monitor was calibrated prior to pick up.

The CO_2 was then released into the room. Three fans were moved around the room while the initial CO_2 was being released to obtain a homogeneous mixture of CO_2. Continuous measurements were being taken by a commercial indoor IAQ monitor (TSI Q-TRAK 7575) that was also moved around the room. When 2000 ppm or above, at least four times the baseline of 500 ppm, was constantly obtained across the room, the CO_2 supply and fans were turned off. Each scenario was then run, with the occupants leaving the room once the relevant scenario was set. The test sequence was stopped when the baseline of 500 ppm was reached, or there was no change in the concentration level over a 15-minute period.

The first scenario was designed to test the minimum level of ventilation within the room. This was with any mechanical ventilation turned off, and all doors and windows shut for the full duration of the test. The second scenario was designed to test the normal operating setting of the mechanical ventilation within the room. This was done by firstly closing all doors and windows and turning off any mechanical ventilation. Then, when the CO_2 level across the room stabilised at 2,000 ppm, all doors and windows remained closed and the mechanical ventilation was turned on to its normal operating setting.

Light testing methodology

The methodology used to measure the illuminance of the classrooms in this study was based on the verification methodologies in the following NZBC and standards. The results of these measurements were also evaluated against these standards.

- G7 Natural lighting verification methods one (MBIE, 2014a);
- G8 Artificial lighting (MBIE, 2014b), which also references the NZ Standard NZS 6703:1984 Code of practice for interior lighting design Section 11 Measurement of illuminance (Standards NZ, 1984);
- The NZ Standard Interior and Workplace Lighting, AS/NZ 1680.2.3:2008: Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series. (Standards NZ, 2008a) refers to AS/NZ 1680.1:2006: Interior and Workplace Lighting, Part 1: General Principles and Recommendations, Appendix B, Calculation and Measurement of Illuminance (Standards NZ, 2006).

Natural light illuminance and daylight factor measurement methodology.

Measuring the natural light illuminance within a building is difficult and complex. This is due to the influence the weather and the time of year has on how much sun or cloud there is, as well as the location of the sun and external and internal reflective elements. For this reason, the light simulation computer programme, Velux Daylight Visualiser, was used to calculate the illuminance and daylight factors in the monitored rooms. The Daylight Visualiser is a simulation tool that analyses the natural light conditions within a building (Velux, 2019a).

The CIE, developed a validation approach to assess the accuracy of a lighting computer programme and to identify its weaknesses: CIE 171:2006 (Ashdown et al., 2006; Maamari et al., 2005). The CIE produced several test cases, against which its software could be assessed, and the Daylight Visualiser passed all the test cases (Labayrade, Jensen, & Jensen, 2009).

As stated by the software developers, the Daylight Visualiser can simulate the following relevant aspects of natural light transport, with an average error lower than 1.29%:

- Luminous flux conservation.
- Directional transmittance of clear glass.
- Light reflection over diffuse surfaces.
- Diffuse reflection with internal obstructions.
- Sky component and external reflected component for a façade glazed opening for CIE sky types 1-15.

Within the standard CIE S003:1996, the CIE has defined the sky type to be used when calculating Daylight Factors - CIE Standard Overcast Sky (Commission Internationale de l´Eclairage, 1996). The global horizontal illuminance under this sky set at 21st March is equivalent to the global horizontal illuminance requirements as set out in NZS 6703:1984 Code of practice for interior lighting design of 11,500 lux for the outdoor illuminance level for 75% of the standard year in Auckland, NZ.

The methodology developed below considered the proposed workflow designs/scenarios in the study, ‘Validation of Velux daylight Visualiser 2 against CIE 171:2006 test cases’ (Labayrade et al., 2009) and the Daylight Visualiser User Guide (Velux, 2019b).

The following methodology was used for measuring the illuminance and natural light factors of the natural light within the centres.

- Each centre was modelled in ArchiCAD version 22, an industry-standard architectural design tool, using the Auckland Council building consent documentation and information gathered from site visits. The model included any outdoor objects that may impact the light, e.g. fences, neighbours' buildings, canopies etc.
- An Sketchup file was generated for each centre and imported into the Daylight Visualiser software.
- The imported model was checked to ensure it was complete and materials applied from within the Velux standard materials library which has applicable present reflectances.
- The cameras were positioned at floor height and at a bench height of 0.8 m.
- The daylight factor as per the Daylight Visualizer with the default sky and date settings of CIE Standard Overcast Sky and 21st September at midday. Note: 21st of September and 21st March at midday are the same points in the sky therefore used interchangeably. This date was also used to calculate the lux levels.
- Illuminance was also measured using the CIE Standard Overcast Sky set to a scale of
    - 0 to 30 lux
    - 0 to 500 lux

A further compliance check against G7/AS1 Natural Lighting was completed where the window area was no less than 10% of the floor area, and there was approximately equivalent to 33 lux at floor level for 75% of the standard year (MBIE, 2014a).

Artificial light installation illuminance measurement methodology.

The following methodology was used to measure the illuminance of the artificial light installations within the centres and was developed from the following NZ Build Code and Standards:

- G8 Artificial lighting (MBIE, 2014b) which references the NZ Standard NZS 6703:1984 Code of practice for interior lighting design Section 11 Measurement of illuminance (Standards NZ, 1984) and
- The NZ Standard Interior and Workplace Lighting, AS/NZ 1680.2.3:2008: Specific Application, Education and Training Facilities (Standards NZ, 2008a) which refers to AS/NZ 1680.1:2006: Interior and Workplace Lighting, Part 1: General Principles and Recommendations, Appendix B, Calculation and Measurement of Illuminance (Standards NZ, 2006).

To assess the artificial lighting levels against the above, the measurements were taken at the following levels:

- Floor level as required by G8 Artificial light;
- 0.5m AFFL as recommended by AS/NZ1680.2.3:2008 that requires a maintained illuminance in the plane of the task. Within ECE, the plane of the task was determined by the height of the children's art desks.
- 0.8m AFFL as recommended by the MoE DQLS Spaces: Lighting guidelines section 2.

The following criteria were applied when taking the measurements to ensure accuracy:

- The area can be divided into squares with sides of approximately 1 m, with no more than a 10% variance; the illuminance measurements should be taken on the centre of the square at the height of the working plane and then averaged.
- For general, overhead lighting systems, the number of measuring points can be reduced, if an accuracy of +/- 10% is considered enough, then averaged according to the following calculations:
- If a room is less the 25 m2 and has four or more luminaires, a smaller area can be measured of 9 m2. However, if the room is greater than 25 m2, the whole room must be measured, with a minimum of nine measurement points.
  - Within working interiors, the illuminance can be measured at each workstation, then averaged.

- No measurement point should be within 0.5m to 1m of a vertical surface, e.g., a wall.
- The measurements should be made in areas unobstructed by objects that are likely to affect the readings and should, therefore, be removed.

Before going on site, the plan of each room to be measured was reviewed by applying the above methodology. An appropriate grid was then drawn up for each room with each point allocated a reference number. Once on site:

- The position of the grid was delineated using a tape measure and masking tape on the floor to mark each measurement point. Each point was then numbered in accordance with the grid plan.
- Measurements were to be taken on the horizontal plane at floor level and at 0.5m and 0.8m AFFL according to the working plane set in a school classroom (MoE & BRANZ, 2007; Standards NZ, 2008a).
- The instrument was to be held horizontally to the floor with the light sensor facing upwards.
- Portable transparent stackable boxes were used at 0.5m and 0.8m to ensure the correct height and position over the relevant point on the floor marked out by the masking tape grid.
- Before taking any reading, the photocell was exposed to the illuminance to be measured until the reading was stable, approximately five to fifteen minutes.
- Care was taken not to cast a shadow over the photocell when taking a reading.
- Measurements of the artificial lighting system illuminance were taken after dark.
- Before measurements of the artificial lighting were taken, lamps were turned on and their output allowed to stabilise. For discharge lamps, e.g., fluorescents, at least 20 minutes were allowed to elapse before any readings were taken. If fluorescent lamps were mounted within an enclosed luminaire, the stabilisation took longer.
- At least 100 hours of operation for fluorescent lamps and 20 hours for incandescent lamps were required to have elapsed before measurements were taken.
- Ventilation systems were run as usual.

Measurement conditions to be considered and gathered where available:

- Lamp type and age.
- State of maintenance included when last cleaned.
- The possible occurrence of non-visible flicker as may be witnessed through a 1080-pixel high definition video recorder at 30 frames per second. Note: This is a very rudimentary test, which only indicates that more investigation is required. The further investigation that could be carried to validate if this was in fact flicker of some kind would need to be to use an Oscilloscope.

Sound testing methodology

Noise immissions and exposure.

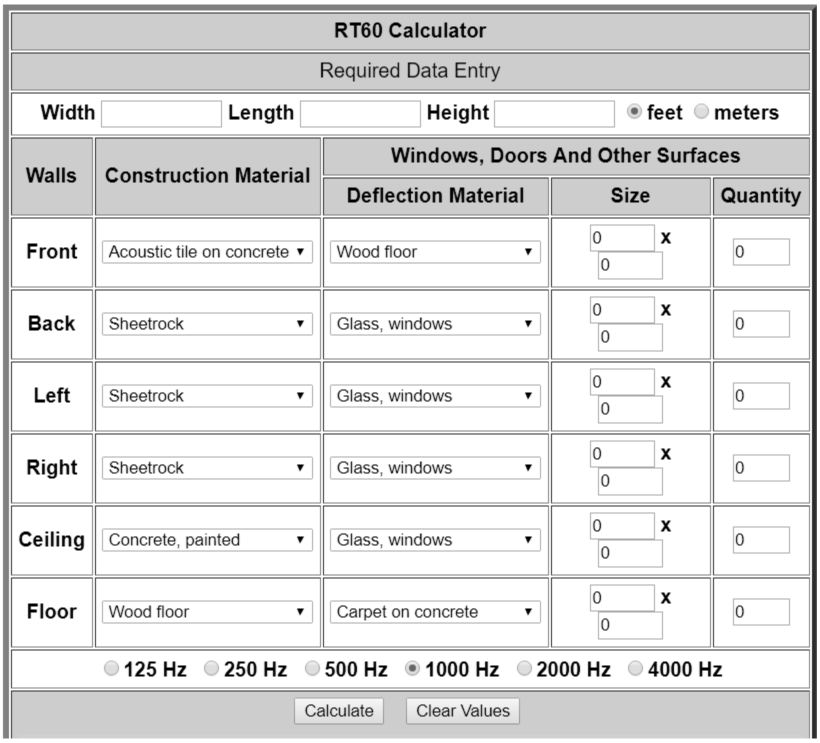
AS/NZS 1269.1:2005 recommends best practices for measuring and assessing of noise immissions (sound received at a particular location over a time interval) and exposure (Standards NZ, 2005).

The assessment of the occupant's noise immissions and exposure within the rooms was, unfortunately, removed from the scope of this study. This was a result of the equipment to measure this not being included in the final design of the SKOMOBO boxes due to timing and cost constraints, as well as to the added complexity and limited scope of the wider schools' research study for which the SKOMOBOs were used. Sourcing alternative equipment was not viable due to costs and resource constraints within the scope of this Master's study.

Reverberation

AS/NZ 2460:2002 Acoustics Measurement of the Reverberation Times in Rooms includes classrooms and lecture rooms, though not ECE centres (Standards NZ, 2002). Completing a full reverberation test of the rooms in accordance with this standard was not economically viable within the scope of this master's study.

Therefore, to give an approximate reverberation time for each room at different frequencies, an RT_{60} Acoustic Reverb Calculator was used (CSG Network, 2019) as shown in Figure 5-4. The basis of the calculator is Sabine's formula. RT_{60} is the reverberation time (a drop of 60 dB); V is the volume of the room; C_{20} is the speed of sound at 20°C (room temperature); and Sa is the total absorption in sabins. Each room was assessed according to the calculator's required inputs. In addition, the Noise Reduction Coefficient of the primary surfaces within the room was referenced to assist with interpreting the calculator's results.



RT60 Calculator				
Required Data Entry				
Width	Length	Height	feet	meters
Walls	Construction Material	Windows, Doors And Other Surfaces		
		Deflection Material	Size	Quantity
Front	Acoustic tile on concrete	Wood floor	0 x 0	0
Back	Sheetrock	Glass, windows	0 x 0	0
Left	Sheetrock	Glass, windows	0 x 0	0
Right	Sheetrock	Glass, windows	0 x 0	0
Ceiling	Concrete, painted	Glass, windows	0 x 0	0
Floor	Wood floor	Carpet on concrete	0 x 0	0
125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz				
Calculate, Clear Values				

Figure 5-4 RT60 Acoustic Reverb Calculator (CSG Network, 2019).

The NZ standards to which the results were compared to were those set in AS/NZS 2107:2016, Appendix A (Standards NZ, 2016).

ECE centre building audits

A full site audit was completed using a standardised evaluation form specifically drafted for this study. A draft checklist was initially designed during research question two based on other similar studies (J. Bennett et al., 2018; Gaspar et al., 2018; Ramalho et al., 2013; Salleh, Salim, & Kamaruzzaman, 2016; Viegas et al., 2015; Zuraimi & Tham, 2008). It was then refined, focusing on those characteristics that impacted the IEQ factors within this study or are critical inputs in evaluating NZ regulation requirements as defined in the literature review. The draft checklist was tested and refined during research question two, with further inputs added.

Inputs included building characteristics and the activities within the rooms, particularly those relevant to IAQ, light and sound. The following building characteristics were noted to assist in the understanding of the IEQ results and to give them context:

- Ventilation and heating/cooling systems,
- Year of construction,
- Building materials,
- Occupant density,
- Floor finishes,
- When last renovated,
- The closest type of road,
- Signs of visible dust on various surfaces or on the air extract grates,
- Visible dirt or dust on the heating/cooling system and
- Cleaning routines, in particular:
    - How frequently the floors, surfaces and shelves were cleaned and
    - How often any heating/cooling or ventilation systems were inspected.

Activities in the rooms were noted from the daily routines set out by each centre. Building characteristics were cross-referenced with the building documentation obtained from the Auckland Council for each centre, including approved building consent documentation submissions.

Room occupancy

In the monitored rooms, occupancy was considered due to the impact this can have on the indoor environment. This was accomplished in two ways:

1. The SKOMOBO monitors included a passive infrared sensor to indicate if there was movement in the room.
2. The number of children and teachers per room as mandated by MoE and noted in the building consent documentation:
    - at 2.5 m^2 per child plus 10% additional floor area
    - plus the number of required teachers for those children as per the mandated child to teacher ratios.

5.3.Data management and analysis

5.3.1. Centre and room type referencing

Each participating centre was allocated a reference number, from 1 to 4, for each room type, i.e. the sleep room and classroom were allocated room type references number of 1 and 2, respectively.

5.3.2. Indoor air quality measurements

The IAQ factors were monitored every 20 seconds, 24-hour a day for a year. This data was recorded using two storage systems. The primary storage was an SD card in the Arduino board. After data was saved to the SD card, it was sent to a remotely hosted, secure database at Massey University, which was also backed up at regular intervals. This was done through a WIFI hot spot device plugged in nearby. The data could then be remotely downloaded in a .csv file format via secure URLs.

Real-time light measurements were taken once onsite and recorded in an Excel spreadsheet.

The following factors were considered when interpreting the results of the measurement surveys, according to AS/NZS 1680.1:2006.

- The accuracy and calibration of the sensors.
- The errors inherent in the measurement processes.

Additional variables, date formatting and the initial data integrity review was completed using Microsoft Excel power queries.:

- Formatting of the time received and time sent variables to d/mm/yyyy h:mm.
- Duplicating the time sent field and splitting it in separate date and time variables then format both to d/mm/yyyy h:mm.
- Adding in additional variables to be used in filtering and referencing the data: e.g. centre and room references, monitor activity, season, day of the week, weekend vs weekday, month, opened vs closed and NIWA outdoor weather data.
- The presence sensor data was removed from the data analysis. It was determined that the recording of a presence in the room was not always reliable as the sensor

could not always be placed where they were able to sense movement across the entire room.

- If a zero value was recorded, i.e. no measurement was recorded, then that measurement was excluded from the analysis. This was done by adding a variable to exclude those cases.
- Check for:
    - Duplicate measurements which were then removed.
    - Time measurements that were not in sequence though received by Massey University in sequence, the time stamp was corrected by taking the mean between the last and the next time measurement.

A second data integrity test was completed using SPSS graphs and descriptive statistics with data interrogation done in Microsoft Excel on any anomalies seen in SPSS, such as extreme outliers.

Microsoft Excel was then used to identify patterns to be explored of the individual monitor data sets. The data sets combined, however, exceeded the number of rows in Microsoft Excel; therefore, the SPSS software package version 25 procedures were used to perform the statistical analysis. The statistical analysis undertaken in this study follows other similar studies (J. Bennett et al., 2018; Gaspar et al., 2018; Ramalho et al., 2013; Salleh, Salim, & Kamaruzzaman, 2016; Viegas et al., 2015; Zuraimi & Tham, 2008).

SPSS was firstly used to audit the data with excel used to interrogate it. The IAQ variables measured were evaluated from a building character perspective and a time series variable perspective. The primary building character perspective used was the room type, i.e. a classroom and a sleep room. These types were then analysed by:

- Construction type: timber frame and non-timber frame and
- Ventilation type: natural and predominantly mechanical.

The time-series dimension analysed included:

- The duration of study split by seasons as defined by NIWA;

- Spring: September, October and November
- Summer: December, January and February
- Autumn: March, April and May
- Winter: June, July and August.

- by day of the week
- over a 24-hour period.

The starting point of the analysis used SPSS graphs and classic descriptive statistics to identify patterns to be explored. These included calculating arithmetic medians, means, minimums, maximums, and associated dispersion measures including variances, standard deviations with corresponding confidence intervals and quantiles of the distributions of measured indoor and outdoor levels. Adjustments for confounders were made when necessary.

Pearson's correlation coefficient (r), was the bivariant parametric test used to determine the statistical significance of selected variables among the means of various groups with the level of significance considered to be $\alpha = 0.01$ and p-values less than 0.01. The variable relationships tested were:

- The indoor temperature and outdoor temperature,
- The indoor RH and outdoor RH,
- The indoor temperature and indoor RH,
- The indoor temperature and CO_2 concentration,
- The indoor RH and CO_2 concentration.

The groups were:

- Classroom,
- Sleep room,
- Timber-framed buildings that were naturally ventilated,
- Non-timber-framed buildings that were predominantly mechanically ventilated.

It must be noted that CO_2 concentrations are can be measured in mg/m^3 to account for the influence the temperature has on CO_2 concentration levels. To convert CO_2 measured in ppm to mg/m^3 the following formula is used:

Equation 1 CO_2 mg/m³ equation

$C_{(mg/m^3)} = C(ppm) \times ((M/V_m) \times (T/273.1))$

Where

M = molecular weight of gas (M_{CO2} = 44g/mol)

V_m = standard molar volume of an ideal gas. V_m = 22.7L/mol (1bar, 273.1K)

T = temperature in the Kelvin scale (K). $T_{(K)} = T_{(°C)} + 273.15K$

While all data in this study were converted to mg/m³, the results are presented in ppm to be consistent and comparable to international guidelines provided in ASHRAE (ASHRAE, 2016) and by the MoE (MoE, 2017a) as well as other studies focused on IEQ and IAQ found during the literature review (Araújo-Martins et al., 2014; J. Bennett et al., 2018; Branco et al., 2015; Carreiro-Martins et al., 2014; de Waard & Zeiler, 2014; Hwang et al., 2017; Kabir et al., 2012; Kolarik et al., 2016; Lin et al., 2016; Michelot, Marchand, Ramalho, Delmas, & Carrega, 2013; Oliveira et al., 2017; Ramalho et al., 2013; Salleh, Salim, & Kamaruzzaman, 2016; Salleh, Salim, Kamaruzzaman, et al., 2016; Viegas et al., 2015; Zuraimi & Tham, 2008).

5.3.3. CO_2 tracer-gas decay measurements

The CO_2 tracer-gas decay measurements were used to calculate ventilation reference values, i.e. the air changes per hour and the litres per second per person. The average method, as defined by ASTM Standard E741 (ASTM Standards, 2006), was used to calculate the air changes per hour. According to ASTM Standard E3741, the CO_2 concentration within a room is determined by:

Equation 2 CO_2 concentration within a room

$$V\frac{\partial c}{\partial t} = VFc$$

Where

V = the room volume (m³)

c = the CO_2 concentration above the background level (mg/m³)

t = the time (hours)

F = the air change (hours^{-1})

Therefore a solution to finding *c* is:

Equation 3 A solution to finding c, the CO_2 concentration above the background level

$$c = c_o e^{-Ft}$$

Where c_0 is initial CO_2 concentration after it has been released in the room

The log of this equation is:

Equation 4 The log of the above equation

$\ln c = \ln c_0 - Ft$

A solution to finding *F* is, therefore:

Equation 5 The air changes per hour

$F = [\ln(c) - \ln(c_0)] / t$

The above assumes the room is unoccupied, that there was a homogenous concentration of CO_2, and that the air exchange rate was proportional to the CO_2 concentration in the air.

To convert air changes per hour to litres per second per person, the following formula was used:

Rp = ((*F* * V * 1000) / 3600) / number of occupants of the room

Where Rp is the ventilation rate per person (L/s/person)

This methodology and the CO_2 unit of measure is aligned with other ventilation studies completed in Portugal, Japan, France and Great Britain (Almeidaa, Barreiraa, & Moreira, 2017; Hori, Soma, & Mizoguchi, 2005; Ramalho et al., 2013; Sherman, 1990).

5.3.4. Lighting

The output from the natural light modelling in the Velux Daylight Visualizer was captured as plan diagrams that show the illuminance and daylighting factors. The actual artificial light measurements taken on-site were recorded in an excel spreadsheet. Additional building characteristics relevant to light were also documented during the building inspection or noted from the council documentation.

Both the natural light diagrams and artificial light measurements were then assessed against the following standards:

- G7 Natural lighting (MBIE, 2014a),
- G8 Artificial lighting (MBIE, 2014b),
- The NZ Standard Interior and workplace lighting AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series. (Standards NZ, 2008a),
- MoE DQLS: Lighting (MoE & BRANZ, 2007)

5.3.5. Sound

The output from the RT_{60} Acoustic Reverb Calculator was captured in an excel spreadsheet. Additional building characteristics relevant to sound documented during the building inspection or noted from the council documentation were also taken into consideration.

The measurements were then assessed against the following standards:

- Health Safety and Employment Regulations 1995, Regulation 11 (MBIE, 1995). It states that "every employer must, so as *reasonably practicable*, ensure in relation to every workplace under the control of that employer, that no employee is exposed to noise above the following levels:
    - 85dB $L_{Aeq,8h}$ (100% dose or 1.0 Pa^2h exposure) and 140 dB L_{Cpeak}
    - Or equivalent e.g. 88dB $L_{Aeq,4h}$, 91dB $L_{Aeq,2h}$, 94dB $L_{Aeq,1h}$
- AS/NZ 2460:2002 Acoustics measurement of the reverberation times in rooms include classrooms and lecture rooms though not ECE (Standards NZ, 2002). It must be noted that there are no specific criteria for the protection of children's hearing.

5.4. Ethical approval

This study was carried out in accordance with Massey University Human Ethics and was approved by the Massey University Human Ethics Committee on 3rd October 2017 (Ethics Notification Number 4000018524). The study was peer-reviewed and judged to be low risk.

The ECE centres were only included in the study after written consent was obtained from the owners of the centres and the centre managers. The consent was given with the understanding that:

- Inclusion in the study was completely voluntary and completely confidential. Approval may be withdrawn from the study at any time up to the commencement of data analysis.
- There is no direct participation or interaction with any teachers, parents, children or Whānau of the centre in the actual project itself and
- They may request an oral and/or written summary of findings to be presented to interested parties.

Informed consent was provided through an information sheet supplied to all staff members and parents. All consent forms templates are in appendix 8.3

5.5. Results

Eleven centres were identified in the eligibility zone. Remaining criteria below as defined in the methodology was then applied which of these eleven centres were appropriate centres:

- Centres that achieved an ERO Education Review of 'Well-placed to promote positive learning outcomes for children' or above;
- Centres that hold a current building warrant of fitness and
- Centres' construction types can be classified as:
  - Timber or non-timber construction;
  - Naturally or mechanically ventilated;
  - Retrofitted or purpose-built centre.

Five centres were identified, and the owners were approached. Four approved the study; however, one was unable to proceed as they were due to temporarily close for refurbishment. Auckland council records show that the final four buildings held a current building warrant of fitness. In the centres' last ERO reports two centres achieved a 'very well-placed to promote positive learning outcomes for children' and the other two achieved 'well-placed to promote positive learning outcomes for children' (Education Review Office, 2016).

Of the final four, three were monitored from June 2018, with the fourth centre delayed until August 2018. This delay was caused by constraints on the researcher and the centre manager's availability and accessibility considerations. All four centres were monitored until the end of May 2019 with the artificial light measurements taken in June 2019.

5.5.1. Local outdoor conditions

During the monitoring period from June 2018 to May 2019 the VCSN weather point was calculated to a mean temperature and RH for June 2018 to 2019 at 15.61°C and 82.63% respectfully, as presented in Figure 5-5. July had the highest mean RH at 91.08% and the lowest mean vapour pressure of 11.16hPa, while January had the lowest RH of 75.47% and highest mean vapour pressure of 18.73hPa. The annual mean sea level air pressure was 1,017hPa. The mean wind speed during this same period was 14.8km/h.

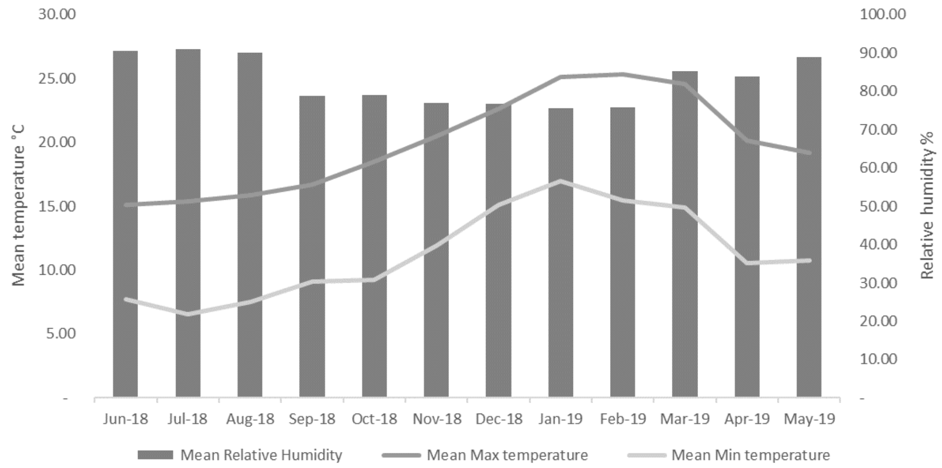


Figure 5-5 The monthly mean maximum and minimum temperatures (°C)and relative humidity (%), at the VCSN weather data point from June 2018 to May 2019.

The annual rainfall was 1,002mm, and there were 118 wet days. In December the highest mean rainfall of 184mm was calculated, though January had the highest number of wet days at 17.3, 1.5 days higher than December. May had the lowest mean rainfall of 22.30mm with April having the driest month with 12 wet days, 1.5 days more than May as can be seen in Figure 5-6 below.

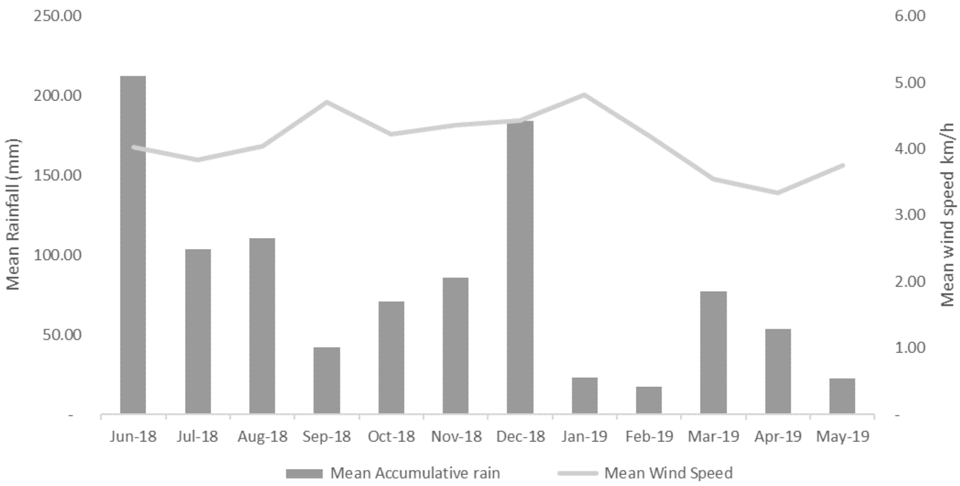


Figure 5-6 The monthly mean rainfall (mm) and mean wind speed (km/h), at the VCSN weather data point from June 2018 to May 2019.

The annual weather calculated at VCSN weather point is summarised in Table 5-2 below.

Table 5-2 The monthly and annual mean weather conditions calculated at the VCSN weather data point.

		2018							2019					
		Jun-18	**Jul-18**	**Aug-18**	**Sep-18**	**Oct-18**	**Nov-18**	**Dec-18**	**Jan-19**	**Feb-19**	**Mar-19**	**Apr-19**	**May-19**	**Annual**
Mean Accumulative rain	*mm*	212.10	103.70	110.40	42.10	70.70	85.50	184.00	22.80	17.40	77.20	53.80	22.30	1,002.00
Rainfall	*% of annual rainfall*	21%	10%	11%	4%	7%	9%	18%	2%	2%	8%	5%	2%	100%
Wet days	*1mm of rain*	17.00	14.00	16.00	10.00	9.00	12.00	12.00	3.00	3.00	8.00	9.00	5.00	118.00
Mean Wind Speed	*km/h*	4.02	3.83	4.04	4.71	4.21	4.36	4.42	4.82	4.19	3.54	3.34	3.76	4.11
Mean Relative Humidity	*%*	90.63	91.08	90.06	78.86	78.99	77.00	76.72	75.47	75.73	85.14	83.83	88.97	82.63
Mean Vapour pressure	*hPa*	11.57	11.16	11.75	11.72	13.00	14.79	17.16	18.73	17.66	18.63	13.83	13.99	14.50
Mean Max temperature	*Celcius*	15.10	15.41	15.86	16.70	18.50	20.53	22.64	25.13	25.31	24.59	20.14	19.20	19.92
Mean Min temperature	*Celcius*	7.72	6.52	7.50	9.08	9.25	11.91	15.10	16.98	15.45	14.94	10.53	10.74	11.31
Mean temperature	*Celcius*	11.41	10.96	11.68	12.89	13.88	16.22	18.87	21.05	20.38	19.76	15.34	14.97	15.61
Mean Sea level air pressure	*hPa*	1,016.11	1,017.58	1,012.08	1,016.44	1,019.40	1,013.24	1,014.27	1,016.41	1,016.14	1,023.37	1,020.51	1,023.34	1,017.29
Mean Solar radiation	*MJ/m2*	6.04	7.59	9.96	13.21	18.43	20.11	21.45	24.75	21.64	16.08	13.03	8.80	15.20

5.5.2. ECE centres' building characteristics and activities

This study included thirteen rooms across four ECE centres, nine classrooms and four sleep rooms. Four of the classrooms were occupied by children under two-years-old with the other five classrooms accommodating children two-years-old and over. An example of a centre can be seen in Figure 5-7.

Figure 5-7 An example of a classroom included in the study

The building characteristics of the four centres that participated in the study are summarised in Table 5-3 below. These characteristics were documented to assist in the understanding of the IEQ results and to give them context.

The centres were licensed for a total of 340 children from 3 months to 5 years old and 49 teachers. Of the 340 children and 49 teachers across the four centres, 197 children were licensed to occupy the rooms included in this study, requiring 33 teachers to care for these children.

Centres one and four are renovated, timber-framed buildings that are over 50 years old. Centre two is an eleven-year-old purpose-built precast concrete panel building, and Centre three is just over 50 years old and is a converted single-storey office building built from concrete block. None of the centres were renovated in the last five years, and during the study Centre, two and three had their interior walls repainted in December 2018. All carpet and furnishings are the original carpets and furnishings from when the centres were last renovated.

Three of the four centres' buildings are leased buildings. This is where the building is owned by a property investor and leased on a long-term lease to the centre operator. Centre one is owned by the operator of the centre. The most recently renovated building was six and a half years ago with the next most recently renovated building over nine years ago.

Centres one and two open every day at 07h00 with Centres three and four opening at 07h30. All centres closed by 17h30.

Table 5-3 Summary of the key characteristics of the four centres

Building Characteristics	1	2	3	4
Latest ERO assessment	Well placed	Very well placed	Very well placed	Well placed
Age range of children	3 months to 5 years old	3 months to 5 years old	3 months to 5 years old	3 months to 5 years old
Size of centre: Total number of children as per last ERO report	45	100	145	50
Total number of teaching staff (Excl administration)	5	14	25	5
Operation time	07h00 to 17h30	07h00 to 17h30	07h30 to 17h30	07h30 to 17h30
Repurposed building or purpose built	Repurposed	Purpose Built	Repurpose Built	Repurpose Built
Construction type	Timber frame and cladding	Concrete tilt slab	Brick	Timber frame and cladding
Original purpose of building	Public use	Not applicable	Commercial offices	Residential
Age of building	54	11	52	98
Date last renovated	2012	2008	2010	2004
Operating model	Building owner & operator of centre	Leased building	Leased building	Leased building

The room occupancy, space per child and sleep room layouts are summarised in Table 5-4 below. The mean square meters per child within the classrooms across all four centres was 3 m^2 and in the sleep rooms 1.8 m^2. The mean volume per cubic meter was 8.5 m^3 and 4.9 $m^{3,}$ respectively.

In the sleep rooms, there was a mix of stacked, single-level and portable day beds for those children under two-years-old with all children over 2 sleeping on portable day beds. The use of these cot types determines the layout to the sleep rooms as can be seen in Figure 5-8 below.

Table 5-4 A summary of the occupancy of the rooms monitored and the space per child including the sleep room layouts

Building Characteristics		1	2	3	4
Age range within room	Under twos	0 to 2 years	0 to 1 years old	0 to 2 years old	0 to 2 years
	Over twos (Toddlers)	2 to 3.5		2 to 3 years old	3 to 5 years old
	Over twos (Preschool)	3.5 to 6	3 to 4 years old		
Max. number of children per classroom	Under twos	12	12	30	10
	Over twos (Toddlers)	16		30	40
	Over twos (Preschool)	17	30		
Min. number of teachers per classroom as per MoE requirements	Under twos	3	3	8	3
	Over twos (Toddlers)	2		3	4
	Over twos (Preschool)	3	4		
Classroom size (m^2)	Under twos	34.9	40.0	90.8	32.7
	Over twos (Toddlers)	43.0		101.9	117.0
	Over twos (Preschool)	43.0	75.0		
Classroom: Max. m^2 per child	Under twos	2.9	3.3	3.0	3.3
	Over twos (Toddlers)	2.7		3.4	2.9
	Over twos (Preschool)	2.5	2.5		
Classroom: Volume (m3)	Under twos	125.6	108.0	272.4	88.3
	Over twos (Toddlers)	116.1		305.7	315.8
	Over twos (Preschool)	116.2	202.5		
Classroom: Volume per child at maximum capacity (m3)	Under twos	10.5	9.0	9.1	8.8
	Over twos (Toddlers)	7.3		10.2	7.9
	Over twos (Preschool)	6.8	6.8		
Sleep room size (m^2)	Under twos		13.0	55.0	9.7
	Over two years old			34.3	
Sleep room: Max. m^2 per child	Under twos		1.4	2.9	1.4
	Over two years old			1.6	
Sleep room: Volume (m3)	Under twos		35.1	148.5	26.3
	Over two years old			92.5	
Number of cots/sleep beds	Under twos		9	19	7.0
	Over two years old			22	
Sleep room: Volume per child at maximum capacity (m3)	Under twos		3.9	7.8	3.8
	Over two years old			4.2	
Sleep room: Type of cots	Under twos		Predominantly stacked	Single level costs & Portable day bed	Single level cots
	Over two years old			Portable day bed	

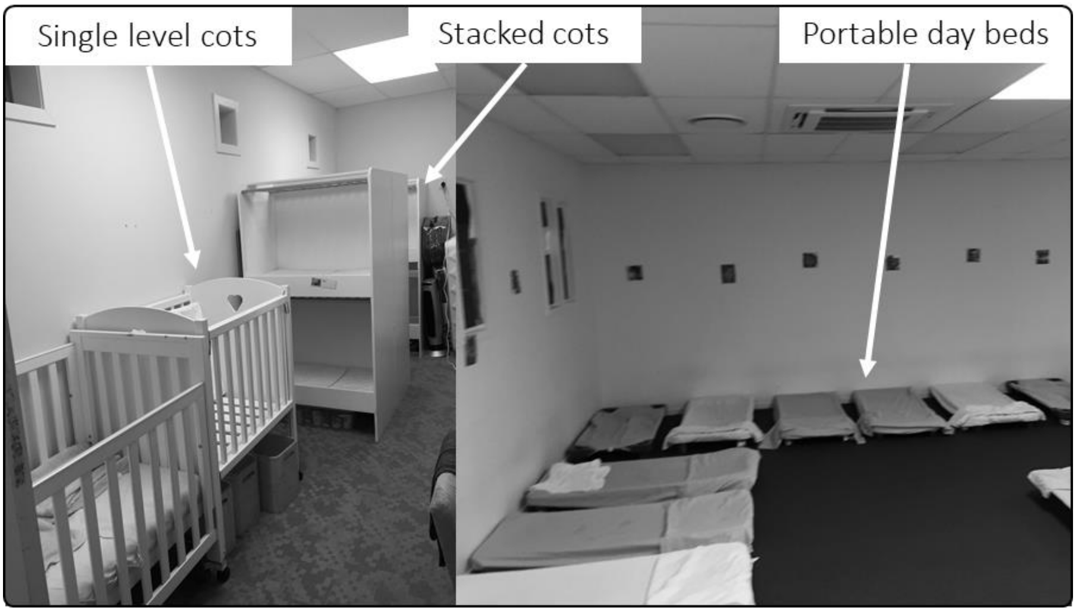


Figure 5-8 ECE cot types found in the sleep rooms

All four centres have a similar regular routine that is set out for the children each day. This routine does not vary unless the over two-year-old children have an excursion which may be between two to three times a year. For example, the under two-year old’s daily routine in Centre two is:

- Open 07h00
- 08h00 open the doors throughout the centre if weather is fine
  (Activities are set up inside and outside, walking children free to play outside or inside, as long as weather is fine)
- 09h30 to 10h00 Morning tea
  (Morning sleep for babies)
- 11h30 to 12h00 Lunch
  (Babies are then taken outside if weather is fine)
- 14h30 to 15h30 Afternoon tea
  (Afternoon sleep for babies)
- 17h30 the centre closes.

5.5.3. Indoor air quality

The thirteen SKOMOBOs were installed as defined in the methodology. An example can be seen in Figure 5-9 below. The monitors were left in place until the end of May 2019 with the data being successfully collected in June 2019.

Figure 5-9 Installation of a SKOMOBO monitor in one of the centres

The monitors installed are summarised in Table 5-5 and were in the following rooms:

- Centre one: The under two-year-old's classroom and both the over two-year-old's classrooms.
- Centre two: The under two-year-old's classroom and the adjoining sleep room as well as an over two-year old's classroom.
- Centre three: The under two-year-old's classroom and the adjoining sleep room as well as an over two-year old's classroom and the adjoining sleep room.
- Centre four: The under two-year-old's classroom and the adjoining sleep room as well as the over two-year-old's classroom.

Table 5-5 A summary of the rooms monitored.

	Number of rooms				
	Centre one	Centre two	Centre three	Centre four	Total
Classroom					
Under two-year-old's	1	1	1	1	**4**
Over two-year-old's	2	1	1	1	**5**
Sleep room					
Under two-year-old's		1	1	1	**3**
Over two-year-old's			1		**1**
Total	3	3	4	3	**13**

The plans of the four centres are laid out in the appendix 8.4 Figure 8-5, Figure 8-6, Figure 8-7 and Figure 8-8, including a key to the plans in Table 8-1. The plans depict where the monitors were placed, and the key considerations taken into account when installing the monitors.

Thermal comfort

Centre two's heating and cooling were integrated into the mechanical ventilation system with all other centres relying on high wall mounted heat pumps.

The sun orientation of the buildings was mixed with Centre one facing West, Centre two facing South-West, Centre three North West and Centre four facing East. The external facades of the rooms monitored were also mixed and are included in Table 5-6 below.

Table 5-6 A summary of the building and rooms monitored sun orientations

Building Characteristics		1	2	3	4
Centre's source of heating		Heat pump	As part of the mechanical ventilation	Heat pump	Heat pump
Orientation of the building		West	South &	North West	East
Classroom: Orientation of predominate external façade/s	Under twos	South	North	North West	South &
	Over twos (Toddlers)	South		North West	North
	Over twos (Preschool)	North	North		
Classroom: Orientation to the playground	Under twos	South	No direct	North West	North
	Over twos (Toddlers)	West		North West	East
	Over twos (Preschool)	West	West		
Sleep room: Orientation of predominate external façade/s	Under twos		North	No external	North & East
	Over two years old			No external	

The results of the temperature and RH measurements are presented in Table 5-7 below. During operating hours across all room types, the median and mean temperature and RH were 21.4°C (SD = 2.3°C) and 60.9% (SD = 8.2%), respectively. The minimum temperature and RH experienced were 9.3°C and 22.8%, and the maximum was 34.9°C and 96.9% respectively.

Table 5-7 Temperature (°C) and relative humidity (%) by room type and centre during the operating hours of 07h00 to 17h30 Monday to Friday.

	Mean	Median	Std. Deviation	Minimum	Maximum	Mean	Median	Std. Deviation	Minimum	Maximum
Classroom	Indoor temperature					Indoor relative humidity				
Centre one	21.4	21.5	1.6	11.6	27.9	62.6	62.4	6.9	37.5	87.9
Centre two	21.4	20.9	2.5	13.2	34.9	58.9	59.8	9.6	22.8	93.9
Centre three	21.3	21.4	2.1	11.6	30.9	59.5	59.1	8.0	33.7	87.1
Centre four	21.4	21.5	2.0	10.9	29.6	61.3	60.4	8.9	33.4	86.5
All Classrooms	21.4	21.3	2.1	10.9	34.9	60.7	60.7	8.6	22.8	93.9
Sleep room										
Centre two	20.7	21.3	2.9	10.8	27.9	62.8	62.8	6.2	42.1	85.0
Centre three	20.4	20.6	1.7	11.4	25.9	59.9	60.2	6.7	40.1	80.9
Centre four	19.9	19.5	2.5	9.3	34.9	60.1	59.3	8.8	40.8	96.9
All Sleep rooms	20.4	20.6	2.5	9.3	34.9	61.3	61.5	7.1	40.1	96.9
All rooms	21.1	21.2	2.3	9.3	34.9	60.9	60.9	8.2	22.8	96.9

The temperature 75% and 95% percentile were 22.4°C and 23.6°C respectively and the RH were 66.5% and 71.3% respectively, as presented in Table 5-8 below.

Table 5-8 The temperature (℃) and relative humidity (%) weighted average percentiles of all classrooms and sleep rooms during the operating hours of 07h00 to 17h30 Monday to Friday.

Percentiles	5%	10%	25%	50%	75%	90%	95%
Indoor temperature	17.5	18.5	19.9	21.2	22.4	23.6	24.4
Indoor relative humidity	47.7	50.7	55.6	60.9	66.5	71.3	73.8

During operating hours, the temperature and RH from Monday to Friday are constant across both the classrooms and the sleep rooms. This can be seen in the box plots below for the classrooms temperature and RH during operating hours from Monday to Friday in Figure 5-10 and Figure 5-11, respectively.

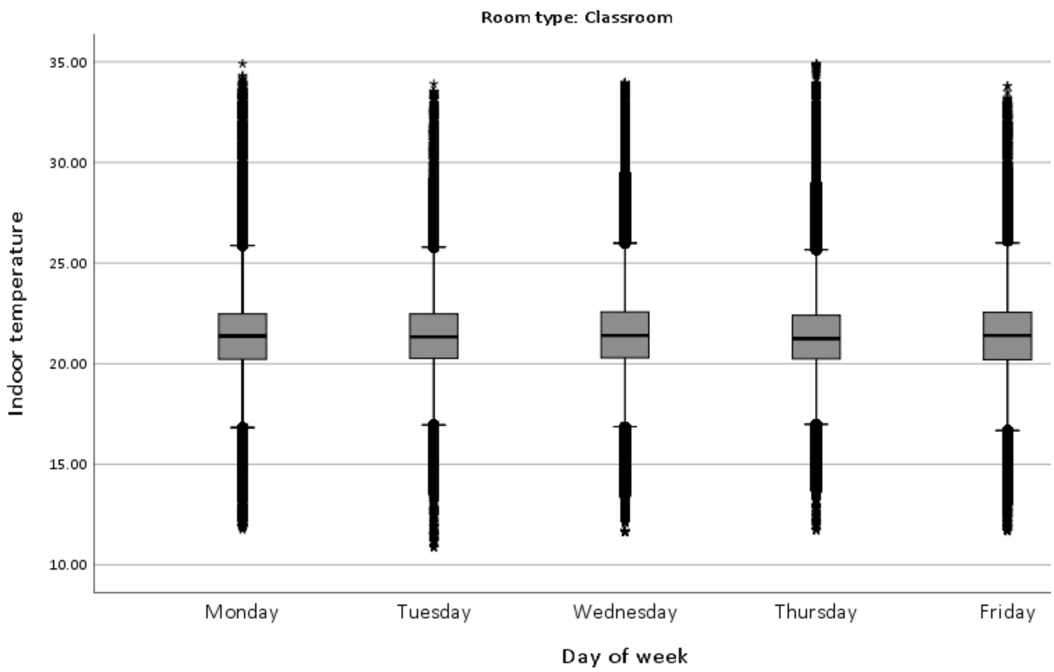


Figure 5-10 A box plot of the indoor temperature in the classrooms by the day of the week during operating hours of 07h00 to 17h30 from Monday to Friday.

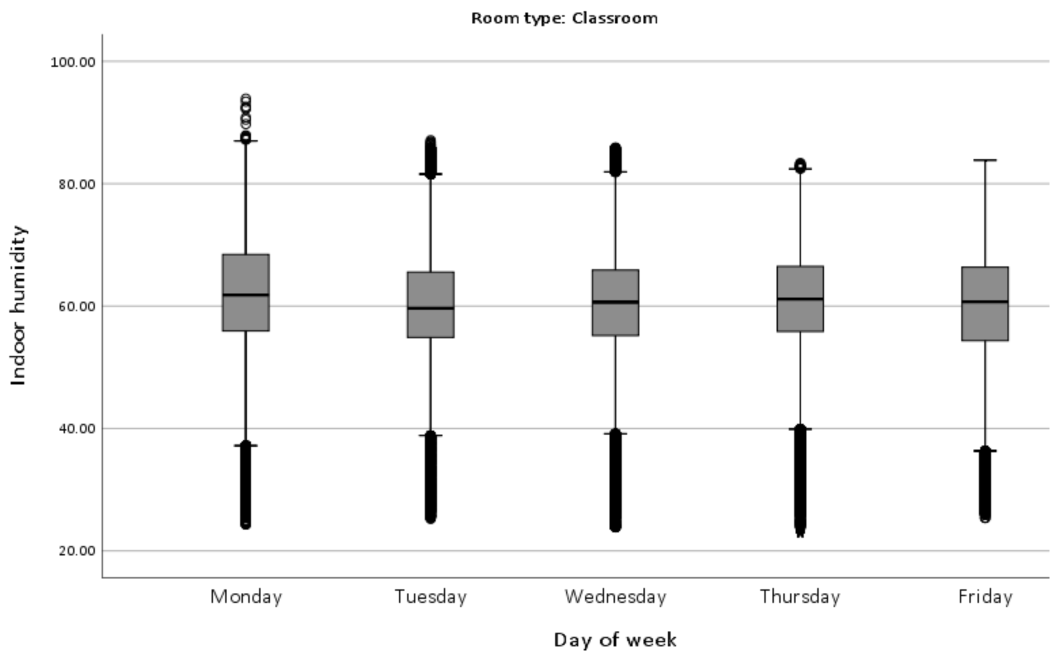


Figure 5-11 A box plot of the indoor relative humidity (%) in the classrooms by the days of the week during the operating hours of 07h00 to 17h30 from Monday to Friday.

During the week, the mean temperature over a twenty-four-hour period is cyclical in nature as can be seen in Figure 5-12 below. The temperature is rising through the day then falling at night when the centres are closed, and the mechanical ventilation is off in those centres with mechanical ventilation. During operating hours, the temperature is fairly constant with a mean of 21.1° and a 2.3°C difference between the highest and lowest mean temperatures. Outside of operating hours, the mean temperature is 19.4°C and less constant with a 3.5°C difference between the highest and lowest mean temperatures. This can be seen in the broader range of temperatures measured within 75th percentile during the night than during the day, as seen in Figure 5-10 above. The highest mean temperature recorded at 21.7°C was between 14h00 and 17h00 in the afternoon, and the lowest mean temperature recorded at 18°C was at 05h00 in the morning.

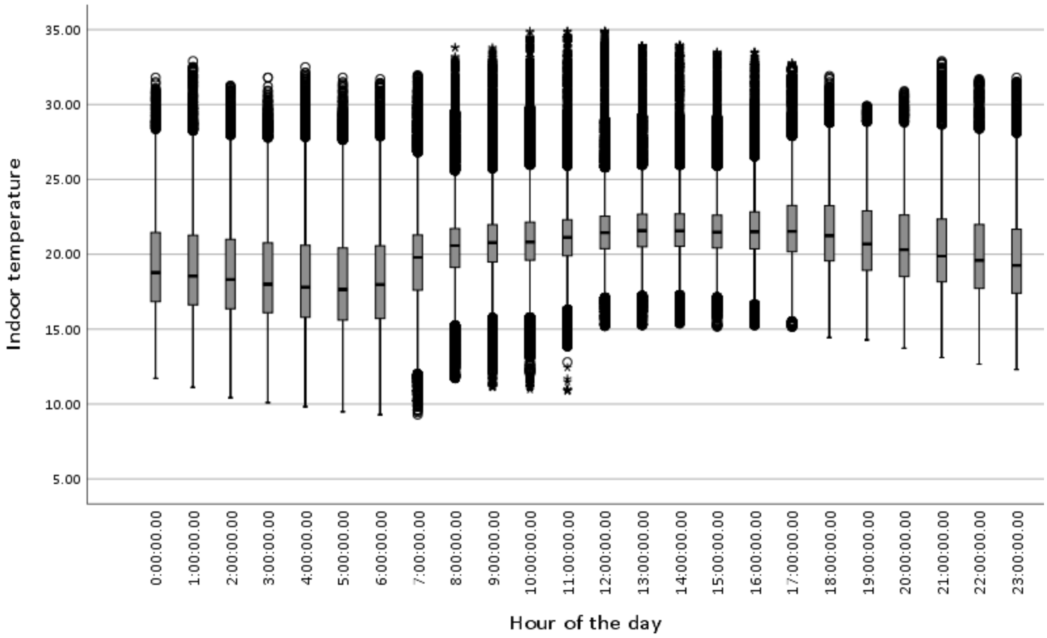


Figure 5-12 Box plot of indoor temperature (℃) over a twenty-four-hour period across all rooms Monday to Friday.

As can be seen in Figure 5-13, the mean RH over a twenty-four-hour period is also cyclical in nature though inverse and less constant than the temperature cycle. The RH is lower during operating hours at a mean of 60.9% and can change by an RH of 4.4%. Out of hours, the mean increases by 6.5% to a mean of 64.8% and can change by an RH of 4.7%. The highest mean RH recorded of 66.2% at 05h00 and the lowest mean RH recorded of 58.9% was between 15h00 and 16h00.

The centres open at 07h00 when any mechanical ventilation comes on, with the heat pumps turned on manually during the day if needed. From 17h00 the centres are closed with any mechanical ventilation and heating turned off.

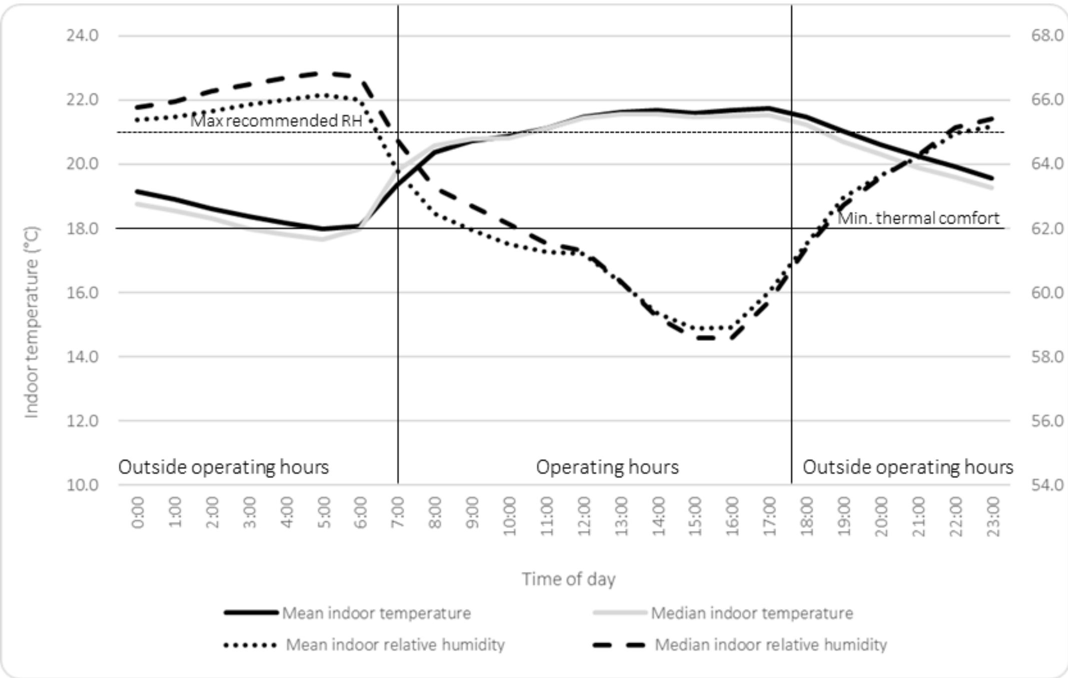


Figure 5-13 A line chart of the mean hourly temperature (℃) and relative humidity (%) for all the classrooms and sleep rooms over twenty-four-hours by days of the working week, Monday to Friday.

The mean daily temperature across all centres over a twenty-four-hour period from Monday to Friday was a constant 20°C, which drops by almost 1°C over the weekend. Similarly, though conversely, the daily mean RH for the same period was reasonably constant during the week and increased by at least 3% over the weekend. These changes in the daily temperature and RH across the week can be seen in Figure 5-14 below.

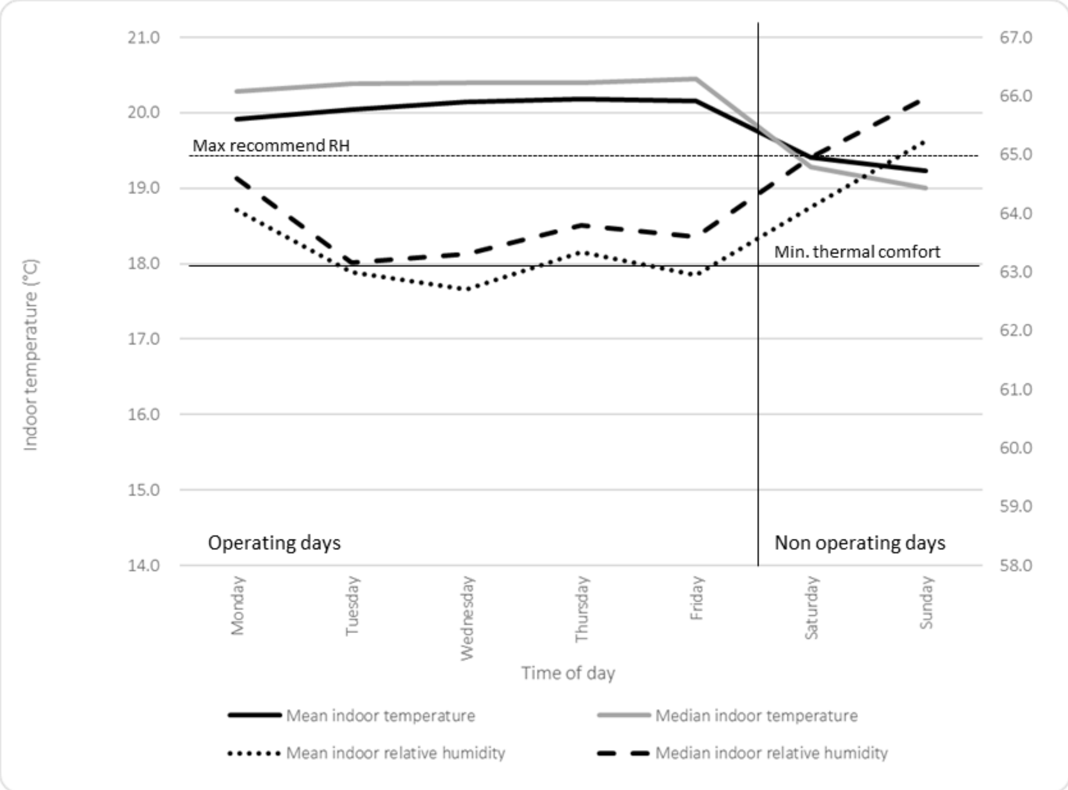


Figure 5-14 A line chart of the mean and median indoor daily temperature (°C) and relative humidity (%) of all the classrooms and sleep rooms over twenty-four-hours across by the days of the week, Monday to Sunday.

Figure 5-15 summarises the percentage of time thermal comfort, RH comfort and comfort cone were achieved across all rooms over the duration of the study. It shows that during operating hours, the classrooms and sleep rooms achieved a thermal comfort of 88% and 80% of the time, respectively. Thermal comfort is the temperature between 18°C and 25°C as defined by DQLS: Indoor air quality and thermal comfort (MoE, 2017a). The classrooms and sleep rooms achieved RH comfort of 74% and 66% respectively over the same period. The RH comfort is the RH between 30% and 65% as defined by the EPA minimum recommend RH level (United States Environmental Protection Agency, 2017b) and the maximum RH level as defined DQLS: Indoor air quality and thermal comfort (MoE, 2017a). The combination of the thermal and RH comforts is the comfort zone (ASHRAE, 2017), which was achieved 66% of the time in the classrooms and 55% of the time in the sleep rooms.

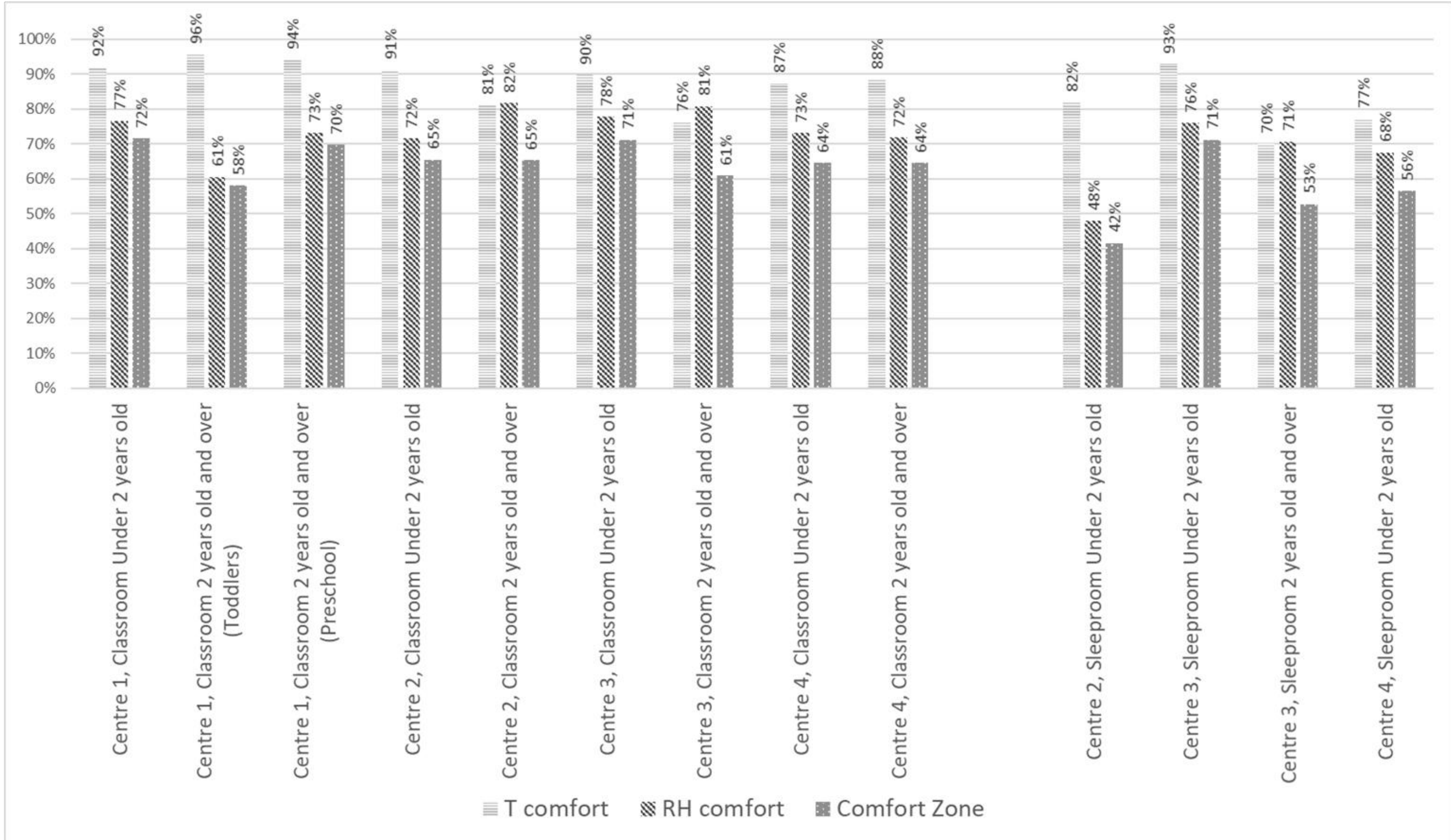


Figure 5-15 The percentage of time thermal comfort, relative humidity comfort and comfort zone were achieved across all rooms over the duration of the study.

.

During operating hours, the classrooms remained above 16°C for 99% of the time and the sleep rooms 97% of the time as can be seen in Table 5-9. Both the timber-framed with natural ventilation and non-timber framed with mechanical ventilation classrooms achieved the comfort zone 66% of the time. Winter had the lowest comfort zone achieved across all the room types at 51% of the time closely followed by Autumn at 52% with Spring the highest the comfort zone achieved of 71% of the time.

Table 5-9 The percentage of time the classrooms and sleep rooms achieved a temperature greater or equal to 16°C and less or equal to 25°C, the temperature comfort, relative humidity (RH) comfort and comfort zone by room type, construction type and by season.

Description	≥ 16°C	≤ 25°C	Temperature comfort	RH comfort	Comfort Zone
Room type					
Classroom mean	99%	97%	88%	74%	66%
Sleep room mean	97%	98%	80%	66%	55%
Mean across all rooms	98%	97%	86%	71%	63%
Classroom construction type					
Timber framed construction	98%	99%	91%	71%	66%
Non timber framed construction	99%	94%	85%	78%	66%
Season					
Spring					
Classroom mean	99%	99%	93%	81%	75%
Sleep room mean	98%	100%	84%	73%	62%
Mean across all rooms	99%	99%	90%	79%	71%
Summer					
Classroom mean	100%	94%	85%	71%	57%
Sleep room mean	100%	94%	85%	77%	64%
Mean across all rooms	100%	94%	85%	73%	59%
Autumn					
Classroom mean	99%	98%	89%	61%	54%
Sleep room mean	99%	98%	83%	55%	47%
Mean across all rooms	99%	98%	87%	59%	52%
Winter					
Classroom mean	96%	85%	76%	61%	52%
Sleep room mean	90%	100%	70%	57%	49%
Mean across all rooms	94%	90%	74%	60%	51%

The Pearson correlation coefficient where the correlation is significant at 0.001 level (2-tailed) shows that during operating hours there is a negative correlation between the indoor temperature and the indoor RH, r (1768040) = -0.301, p = 0.001. As per Table 5-10 the strongest negative correlation is in Winter in the non-timber constructed buildings with mechanical ventilation, r (191743) = -

0.723, p = 0.001 followed by the timber constructed buildings with natural ventilation, r (191743) = -0.565, p = 0.001. The weakest negative correlation is non-timber constructed buildings with mechanical ventilation during Summer, r (191743) = -0.088, p = 0.000 followed by the timber constructed buildings with natural ventilation, r (191743) = 0.101, p = 0.001.

Table 5-10 The negative correlation between the indoor temperature and indoor relative humidity by construction type and season during the operating hours of 07h00 to 17h30 Monday to Friday.

Correlations

	Pearson correlation		Sig. (2-tailed)	
	Timber construction type	Non-timber construction type	Timber construction type	Non-timber construction type
Spring	-0.265	-0.356	.000	.000
Summer	-0.101	-0.088	.000	.000
Autumn	-0.254	-0.318	.000	.000
Winter	-0.565	-0.723	.000	.000

These correlations can be seen in the Winter and Summer psychrometric charts below for Centre two's under two-year-old's classroom, Figure 5-16 and Figure 5-17 below. As the indoor temperatures increase the indoor RH decreases with the correlation being:

- stronger in non-timber constructed buildings with mechanical ventilation in Winter and
- weakest in Summer in the same building type.

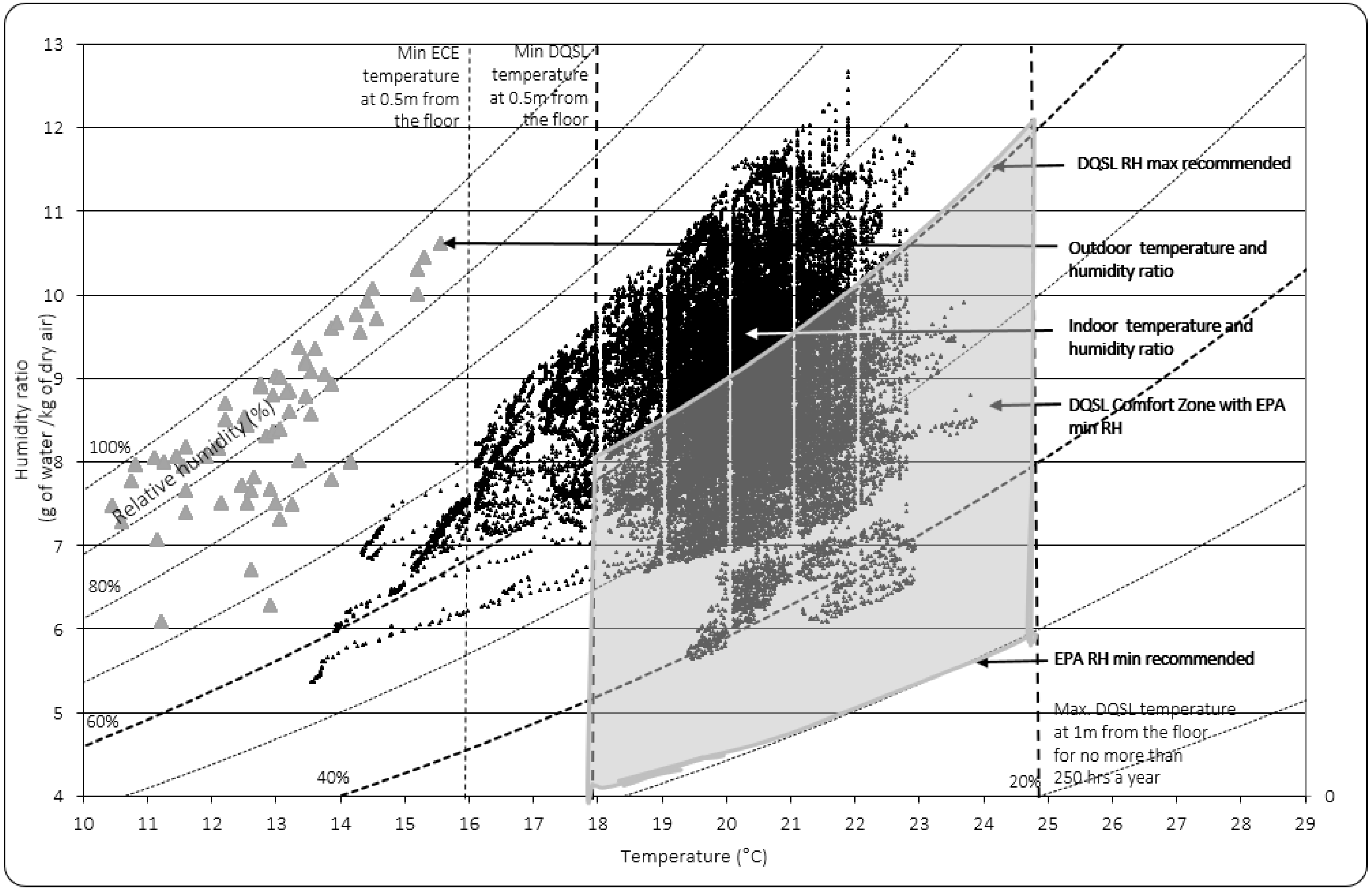


Figure 5-16 The psychrometric chart for Centre two's under two-year-old's classroom in Winter.

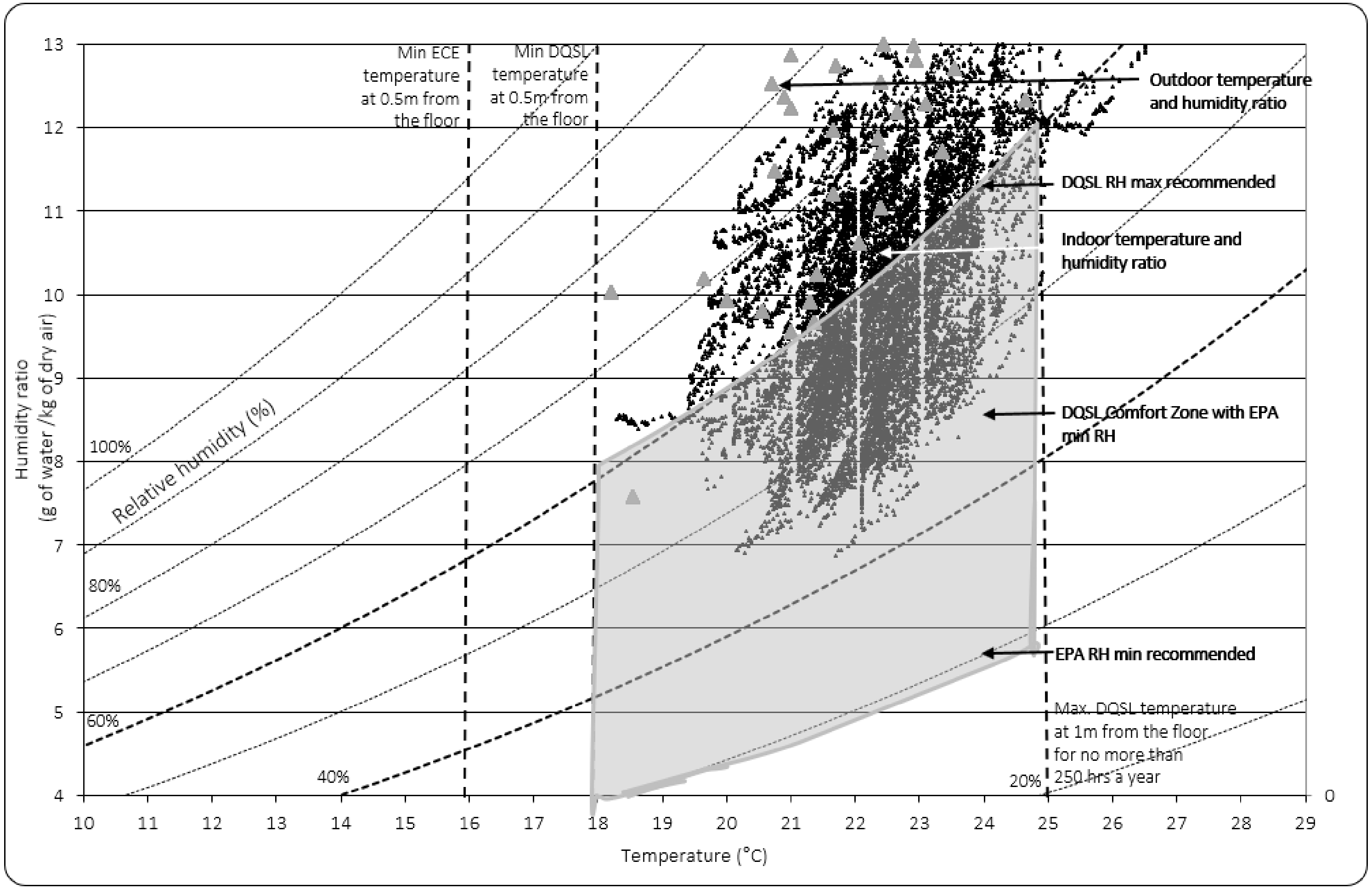


Figure 5-17 The psychrometric chart for Centre two's under two-year-old's classroom in Summer.

As seen in Table 5-11 below, there is a moderately weak positive correlation between the indoor temperature across all rooms and the outdoor mean day temperature, r(1768040) = 0.369, p = 0.001 and a weak negative correlation between the indoor temperature and the outdoor RH, r(1768040) = -0.117, p = 0.001. There is a moderately weak positive correlation between indoor RH and the outdoor temperature r(1768040) = 0.210, p = 0.001 and between the indoor RH across all rooms and outdoor RH, r(1768040) = 0.088, p = 0.001 though this correlation is very weak.

Table 5-11 The correlations between the indoor temperature and relative humidity and the outdoor temperature and relative humidity during the operating hours of 07h00 to 17h30 Monday to Friday.

Correlations

	Pearson Correlation		Sig. (2-tailed)	
	Outdoor mean day time temperature	Outdoor relative humidity	Outdoor mean day time temperature	Outdoor relative humidity
Indoor temperature	.369	-.117	.000	.000
Indoor humidity	.210	.088	.000	.000

The positive correlation between the indoor temperature and the outdoor mean day temperature is relatively stronger in the classrooms of the buildings that are of timber construction and naturally ventilated, r(1768040) = 0.472, p = 0.001 as seen in Table 5-12. The positive correlation in those classrooms that are of non-timber construction with mechanically ventilated is moderately weak in comparison, r=(1768040) = 0.236, p = 0.001, Table 5-13.

Table 5-12 The correlation between the indoor temperature and indoor relative humidity and the outdoor temperature and outdoor relative humidity of the timber constructed classrooms with natural ventilation during the operating hours of 07h00 to 17h30 Monday to Friday.

Correlations

	Pearson Correlation		Sig. (2-tailed)	
	Outdoor mean day time temperature	Outdoor relative humidity	Outdoor mean day time temperature	Outdoor relative humidity
Indoor temperature	.472	-.137	.000	.000
Indoor humidity	.203	.143	.000	.000

Table 5-13 The correlation between the indoor temperature and indoor relative humidity and the outdoor temperature and outdoor relative humidity of the non-timber constructed

classrooms with mechanical ventilation during the operating hours of 07h00 to 17h30 Monday.

Correlations

	Pearson correlation		Sig. (2-tailed)	
	Outdoor mean day time temperature	Outdoor relative humidity	Outdooe mean day time temperature	Outdoor relative humidity
Indoor temperature	.236	-.069	.001	.001
Indoor relative humidity	.279	.053	.001	.001

The correlation between the indoor temperature and the outdoor temperature across all rooms is strongest in Autumn in both construction types, r(425823) = 0.401 p = 0.001 but not significant in Winter, r(425823) = 0.001, p = 0.807. In Autumn and Winter the correlation is almost even between the timber constructed buildings with natural ventilation and non-timber constructed buildings with mechanical ventilation, r(191599) = 0.408, p = 0.001 and r(191599) = 0.428, p = 0.001 and r(191599) = 0.077, p = 0.001 and r(191599) = -0.044, p = 0.001 respectively. In Spring and Summer the correlation is strong in the timber constructed buildings with natural ventilation, r(191599) = 0.342, p = 0.001 and r(191599) = 0.330, p = 0.001 versus the non-timber constructed buildings with mechanical ventilation, r(191599) = 0.149, p = 0.001 and r(191599) = 0.168, p = 0.001. These correlations can be seen in the Autumn and Winter psychrometric charts below for Centre one's over two's classroom, Figure 5-18 and Figure 5-19 below. As the outdoor temperatures increase, the indoor temperature will increase with the correlation being:

- stronger in timber constructed buildings with natural ventilation in Autumn and
- weakest in Winter in the same building type.

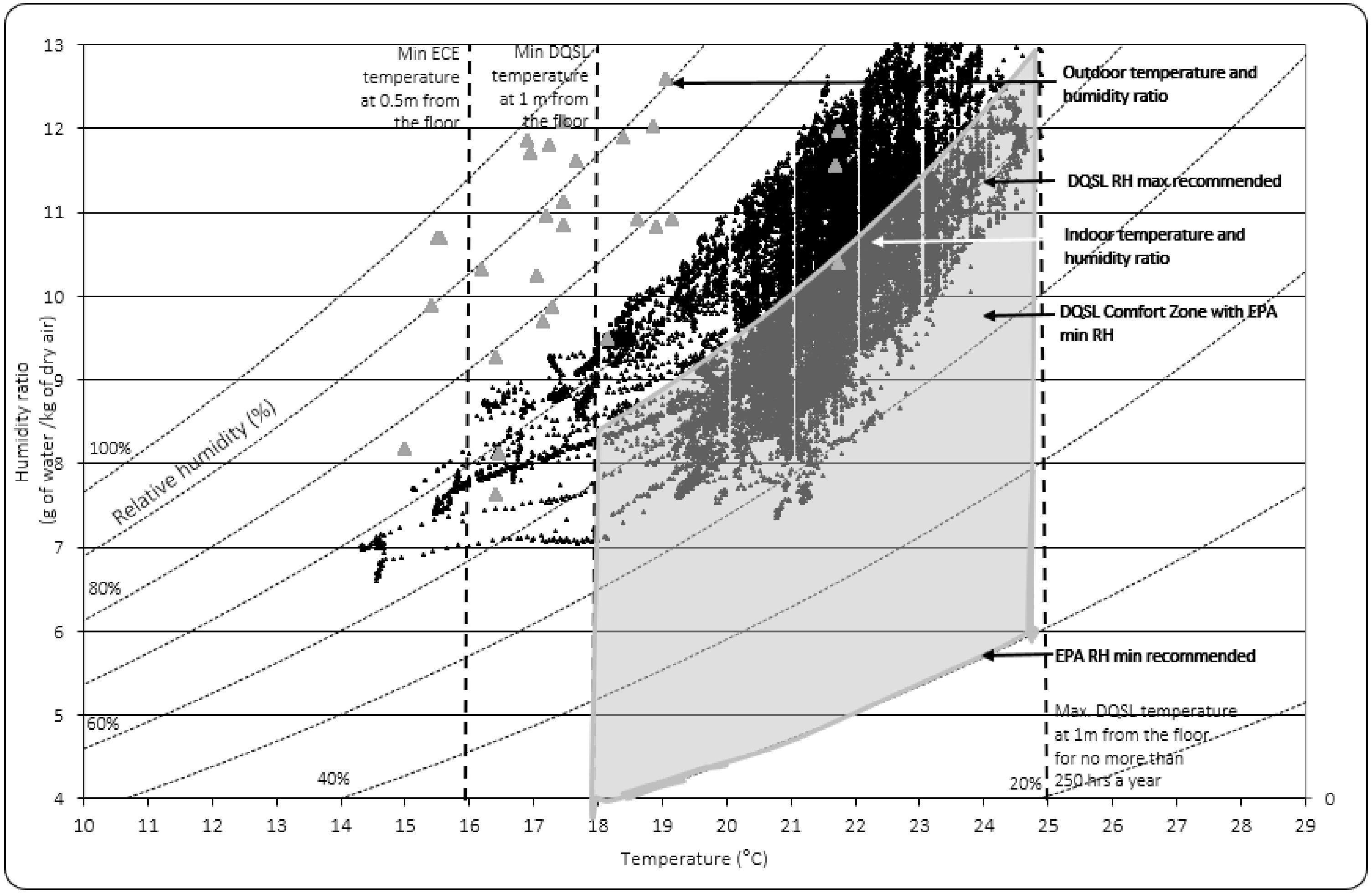


Figure 5-18 The psychrometric chart for Centre one's under two-year-old's classroom in Autumn.

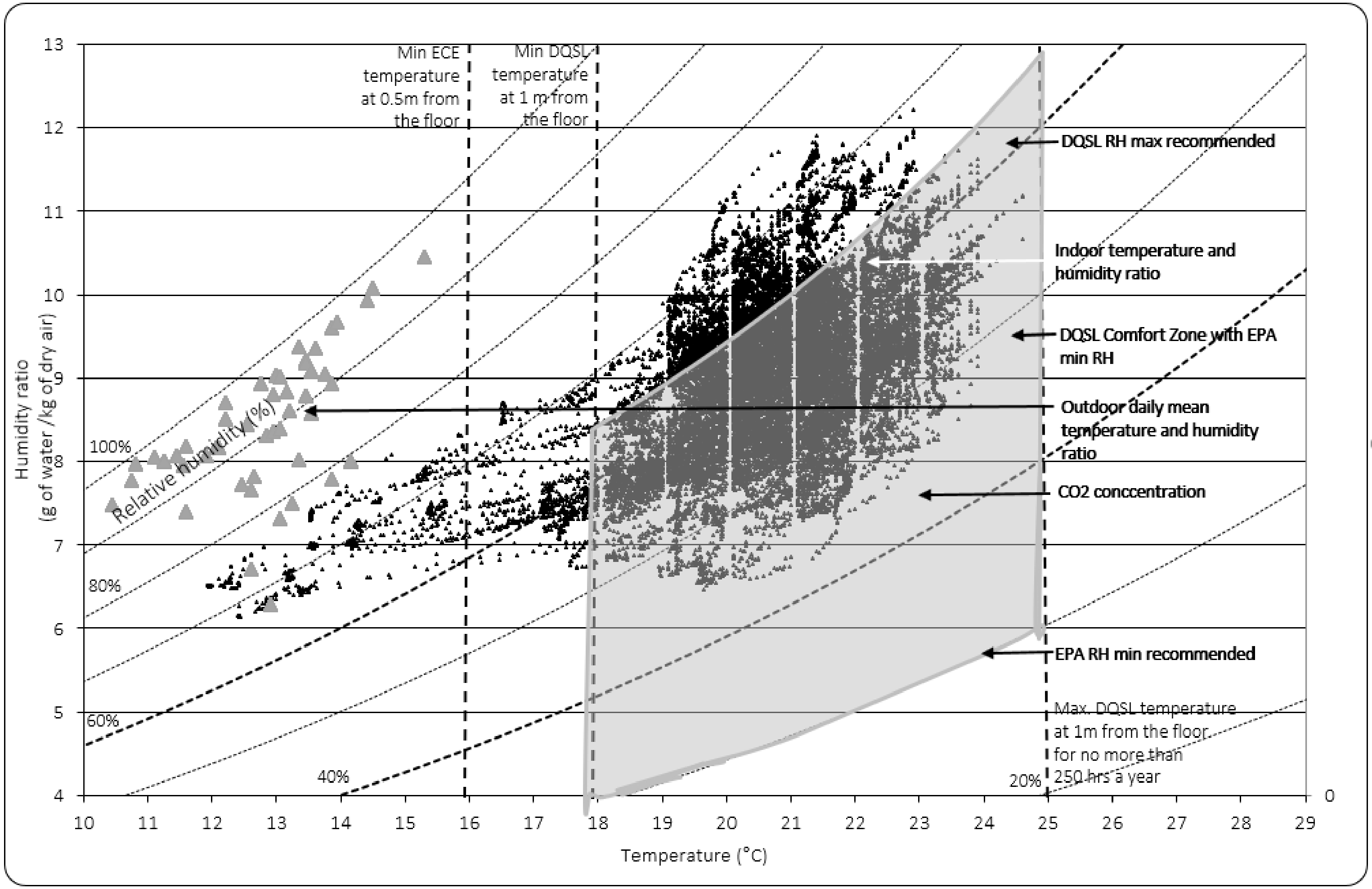


Figure 5-19 The psychrometric chart for Centre one's under two-year-old's classroom in Winter.

Ventilation

As summarised in Table 5-14 below, Centres one and four were naturally ventilated with Centres two and three predominantly mechanically ventilated. The mechanical ventilation in Centres two and three were mixed air recovery systems where the current air is recirculated around the centre via the air ducts with a proportion of fresh air being drawn in and added to the mix. The building consent documentation for these two building contains a producer statement that the ventilation complies with NZS 4303:1990 Ventilation for acceptable indoor air quality (Standards NZ, 1990) and the annual building warrant of fitness includes certificates that verify that the current ventilation system has been maintained and complies with NZS 4303:1990 Ventilation for acceptable indoor air quality (Standards NZ, 1990).

The natural ventilation in the classrooms of Centre one and four was calculated to an average of 14% of openable windows and doors to floor area. As an indication of how deep plan these classrooms are, the average width to depth ratio was calculated at 1:2.1.

During the day across all centres, the doors to the playground predominantly remain open, with the internal doors to the rest of the building predominantly closed for the safety of the children. These internal doors were only opened when someone was entering or exiting that classroom. The windows in one and four are rarely opened with the windows in centre two and three never opened. Any openable windows in the sleep rooms were never opened.

Table 5-14 A summary of the ventilation characteristics of the centres

Building Characteristics		**1**	**2**	**3**	**4**
Ventilation type		Natural	Dominantly-mechanical	Dominantly-mechanical	Natural
Classroom: % of external openable windows and doors to floor area walls	Under twos	13%			20%
	Over twos (Toddlers)	10%			9%
	Over twos (Preschool)	17%			
Width to depth ratio from the playground or predominate natural light source	Under twos	0.7			1.0
	Over twos (Toddlers)	3.6			1.9
	Over twos (Preschool)	3.1			
Sleep room: Operating hours	Under twos		10h30 to 15h00	10h00 to 15h00	10h00 to 15h00
	Over two years old			11h00 to 13h00	

The sleep rooms are used mostly from 10h00 to 15h00. The under two-year-olds start to go down to sleep between 10h00 and 10h30 then will sleep around an hour to an hour and a half. They will then have a second sleep after lunch where they will start to go down again between 13h00 for an hour. The over two-year-olds will have one sleep a day from 11h00 for an hour to an hour and a half.

Centre two's sleep room had one supply air vent and a 50mm gap under the door to the classroom. Half of the gap was blocked by the carpet in the sleep room. In Centre three, the mechanical ventilation in both the sleep rooms had a supply and an extract in the same room. The supply and extract vents were working in the under two-year's sleep room but not in the over two-year's sleep room. Neither sleep room had any additional ventilation mechanism, e.g. door vents or undercuts to the doors. The windows in the sleep rooms of both centres two and three were fixed. Centre four's sleep room's natural ventilation mechanism was through the 50mm gap under the door to the classroom. A third of this gap was blocked by the carpet in the sleep room. The windows in this room were never opened. None of the sleep rooms had any other forms of monitoring mechanism, e.g. CO_2 sensor.

The mean CO_2 concentration across all rooms during operating hours was 706 ppm (SD = 330 ppm). The results of the CO_2 measurements by room type are presented in Table 5-15 below. During operating hours, the classrooms mean CO_2 concentration was 715 ppm (SD = 313 ppm). In the sleep rooms, there was a mean of 684ppm (SD = 368 ppm). The maximum CO_2 concentration in the classrooms and sleep rooms was 3,515 ppm and 2,914 ppm, respectively.

Table 5-15 Measured CO_2 concentrations by centre during the operating hours of 07h00 to 17h30 Monday to Friday.

	Mean	Median	Std. Deviation	Minimum	Maximum
Classroom	CO2 concentration				
Centre one	848	732	377	369	3,515
Centre two	784	669	325	324	2,723
Centre three	511	482	90	357	1,161
Centre four	576	560	98	390	1,190
All Classrooms	715	603	313	324	3,515
Sleep room					
Centre two	681	504	365	385	2,914
Centre three	490	478	60	387	954
Centre four	978	885	440	388	2,608
All Sleep rooms	684	511	368	385	2,914
All rooms	706	583	330	324	3,515

The CO_2 concentration levels in the sleep rooms during the sleep rooms operating hours of 10h00 to 14h00 are summarised in Table 5-16 below. The mean across all the sleep rooms during sleep room operating hours is 977 ppm (SD = 283). Centre three's under two-year-old's sleep room mean had the lowest at 527 ppm, with the highest levels measured in Centre two and three's sleep rooms at 1,378 ppm and 1,230 ppm respectively. The two highest maximums measured were 2,908 ppm at 14h00 in Centre two's under two-year-old's sleep room and 2,608 ppm at 13h00 in Centre four's under two-year-old's sleep room.

Table 5-16 Measured CO_2 concentrations by sleep room by the hour of the day during the sleep rooms operating hours from 10h00 to 15h00 Monday to Friday.

	Hour of the day	Mean	Median	Std. Deviation	Minimum	Maximum
		CO2 concentration				
Centre 2, Under 2s sleep room	10:00	1,042	1,050	307	396	2,640
	11:00	1,275	1,310	382	396	2,479
	12:00	1,563	1,589	507	395	2,806
	13:00	1,629	1,684	537	396	2,844
	14:00	1,379	1,356	494	395	2,908
Mean		1,378	1,398	445	396	2,735
Centre 3, Under 2s sleep room	10:00	496	492	45	390	702
	11:00	545	535	71	390	796
	12:00	572	573	60	388	877
	13:00	525	523	52	389	954
	14:00	496	494	46	389	876
Mean		527	523	55	389	841
Centre 3, Over 2s sleep room	10:00	468	460	57	392	2,117
	11:00	678	499	323	392	1,936
	12:00	1,044	1,106	366	392	2,110
	13:00	994	937	345	391	1,959
	14:00	673	631	179	389	1,638
Mean		772	727	254	391	1,952
Centre 4, Under 2s sleep room	10:00	863	838	262	397	1,929
	11:00	1,123	1,145	376	395	2,168
	12:00	1,415	1,454	429	392	2,592
	13:00	1,445	1,496	413	392	2,608
	14:00	1,304	1,320	402	389	2,599
Mean		1,230	1,251	376	393	2,379
All sleep rooms		977	975	283	392	1,977

During operating hours, the CO_2 concentrations from Monday to Friday are mostly constant across both the classrooms and the sleep rooms except for more outliers on a Thursday as can be seen in Figure 5-20 below.

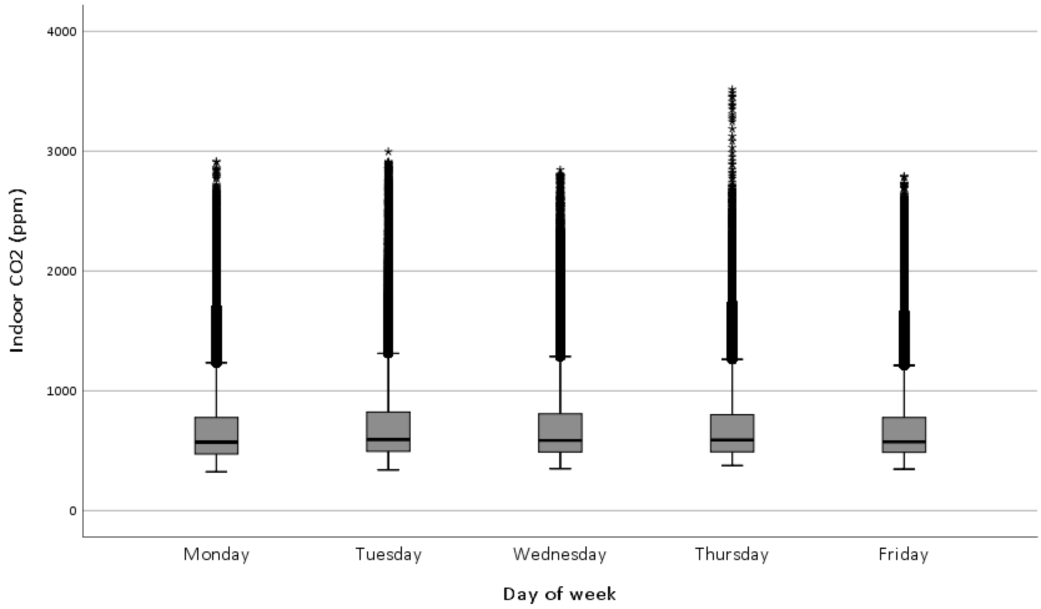


Figure 5-20 A box plot of the CO_2 concentration by the day of the week during operating hours 07h00 to 17h30 Monday to Friday.

The mean daily CO_2 concentration across all centres over a twenty-four-hour period from Monday to Friday was 578 ppm. As can be seen in Figure 5-21, this falls to 428 ppm over the weekend, almost to the level of the outdoor CO_2 concentration level recorded at 410 ppm.

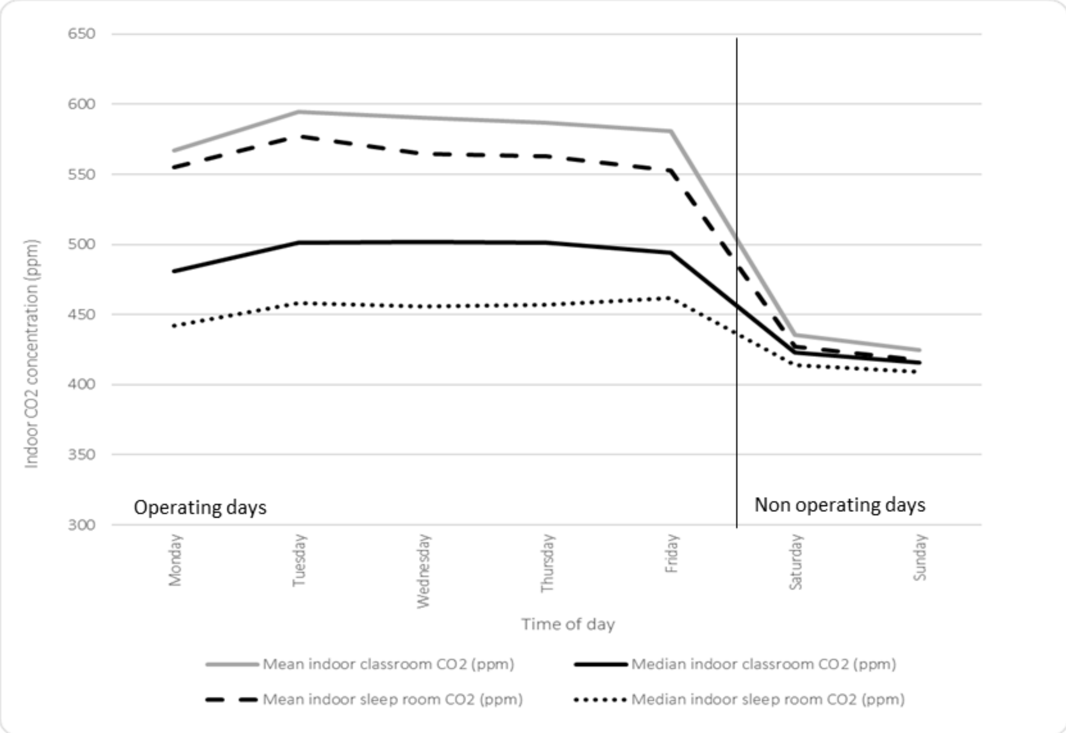


Figure 5-21 A line chart of the mean indoor CO_2 concentration over twenty-four-hours for all classrooms and sleep rooms by the day of the week, Monday to Sunday.

Like the temperature and RH, the CO_2 concentration over a twenty-four-hour period during the week is cyclical in nature, increasing through the operating day and then slowly decreasing during the night when the centres are closed, and the mechanical ventilation is off in those centres with mechanical ventilation. As can be seen in Figure 5-22 below, the CO_2 concentration in the classrooms begins to rise as the teachers and children start to arrive from 7.00 to 7.30 am, then dips when the older children go outside to play late morning, and the younger children go for their morning sleep. It then rises again when the older children come in for lunch, and the younger children wake up. It then begins to fall again as the children go outside in the afternoon and continues to fall as the children are picked up and taken home. The CO_2 concentration in the sleep room begins to climb as the children go for their mid-morning sleep and begins to fall as the children wake up after a one to two-hour sleep.

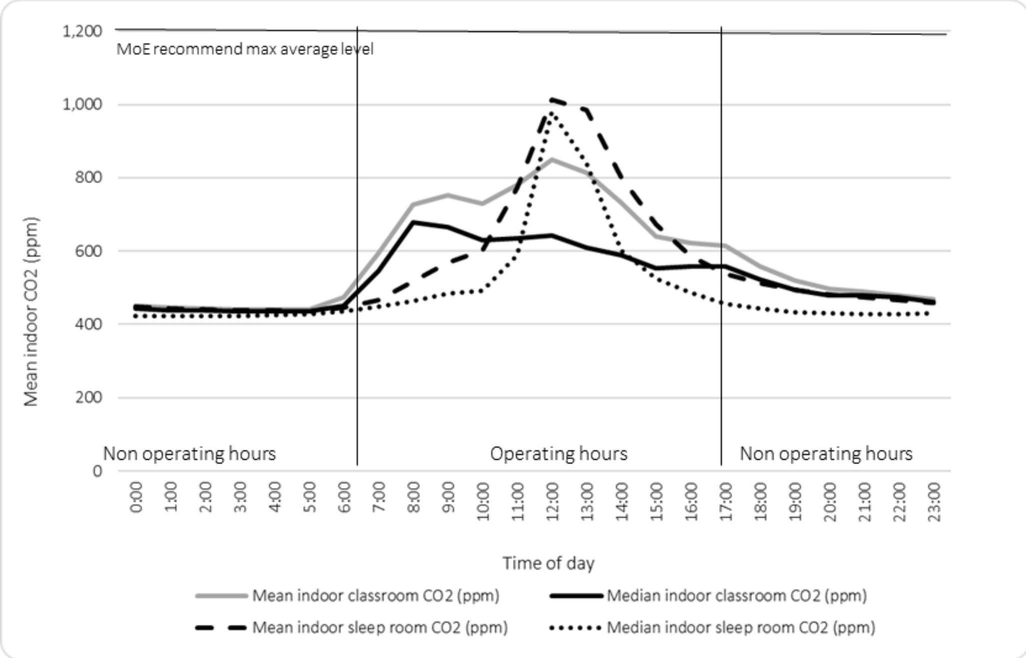


Figure 5-22 A line chart of the mean hourly CO_2 concentration over twenty-four-hours across the classrooms and sleep rooms from Monday to Friday.

Below in Figure 5-23 is a summary of the percentage of time CO2 was below 1500ppm and 1200ppm across all rooms. During operating hours, all room type's CO2 concentration levels remained below 1,200 ppm for 89% of the time and below 1,500 ppm for 95% of the time. The classrooms were below 1,200 ppm for 92% of the time and below 1,500 ppm for 97%. The sleep rooms remained below 1,500 ppm for 82% of the time and below 1,200 ppm for 91% of the time. The naturally ventilated buildings were below 1,200 ppm 91% of the time and below 1,500 ppm 96% of the time and the mechanically ventilated buildings were below 1,200 ppm and 1,500 ppm 94% and 98% of the time. The lowest percentage of time below 1,500 ppm was in winter in the classroom at 86% and below 1,200 ppm was recorded in the sleep rooms during Autumn and Winter at 80% of the time.

When analysing the results by classrooms, five of the nine classrooms and one of the four sleep rooms remained below these two levels, 100% of the time as seen in Figure 5-23. The other four classrooms remained below 1,200 ppm on average 83% of the time with Centre one's over two's classroom remaining below 1,200 ppm 55% of the time. The other three sleep rooms remained below 1,200 ppm on average 72% of the time with Centre 2's under two's sleep rooms remaining below 1,200 ppm 63% of the time.

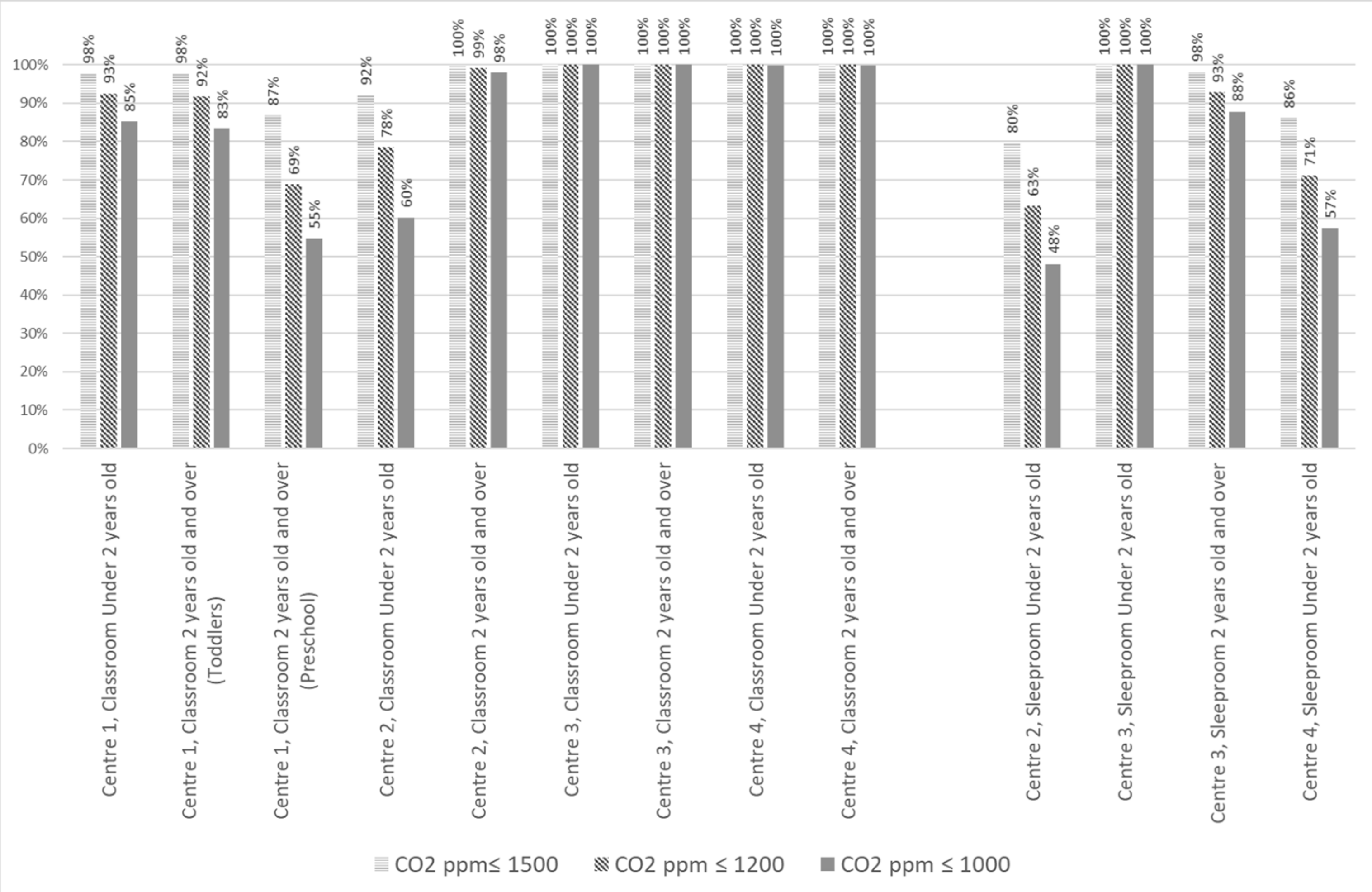


Figure 5-23 The percentage of time CO_2 was below 1500ppm and 1200ppm across all rooms.

The Pearson correlation coefficient where the correlation is significant at 0.001 level (2-tailed) shows that overall during operating hours there is a weak positive correlation between CO_2 concentration and indoor temperature, r(1,768,042) = 0.026, p = 0.001 and to RH, r(1,768,042) = 0.192, p = 0.001. The correlation between CO_2 concentration and RH was stronger, however, when analysed by season in Table 5-17, in Winter there is a relatively strong positive correlation that exists between the CO_2 concentration and temperature in timber constructed buildings with natural ventilation, r (143,349) = 0.444, p = 0.001. Conversely there is a weak negative correlation in non-timber constructed buildings with mechanical ventilation, r (143,349) = -0.027, p = 0.001. In Summer these correlations reverse to a moderately weak negative correlation in the timber constructed buildings with natural ventilation, r (224,517) = -0.357. In the non-timber constructed buildings with mechanical ventilation there is very weak positive correlation r (224,517) = 0.068, p = 0.001.

Table 5-17 The correlations between the indoor CO_2 and temperature by construction type and season during the operating hours of 07h00 to 17h30 Monday to Friday.

Correlations - CO_2 concentration and temperature

	Pearson correlation		Sig. (2-tailed)	
	Timber construction type	Non-timber construction type	Timber construction type	Non-timber construction type
Spring	.049	0.76	.001	.001
Summer	-.357	.068	.001	.001
Autumn	.022	.188	.001	.001
Winter	.444	-.027	.001	.001

There are moderately strong correlations between CO_2 concentration, and RH is in Winter and Spring in both types of buildings, as seen in Table 5-18. In Winter in timber buildings with natural ventilation, r (143,349) = 0.173, p = 0.001 and non-timber buildings with mechanical, r (188,289) = 0.341, p = 0.001 respectively and in Spring, r (310,793) = 0.365, p = 0.001 and r (283,524) = 0.333, p = 0.001 respectively.

Table 5-18 The correlations between the indoor CO_2 and relative humidity by construction type and season during the operating hours of 07h00 to 17h30 Monday to Friday.

Correlations - CO_2 concentration and relative humidity

	Pearson correlation		Sig. (2-tailed)	
	Timber construction type	Non-timber construction type	Timber construction type	Non-timber construction type
Spring	.365	.333	.001	.001
Summer	-.015	-.133	.001	.001
Autumn	.072	.206	.001	.001
Winter	.173	.341	.001	.001

The negative correlation between CO2 concentration, temperature and RH in Summer; and the positive correlation in Winter can be seen in the Psychrometric charts below of Centre one, Figure 5-24 and Figure 5-25 below.

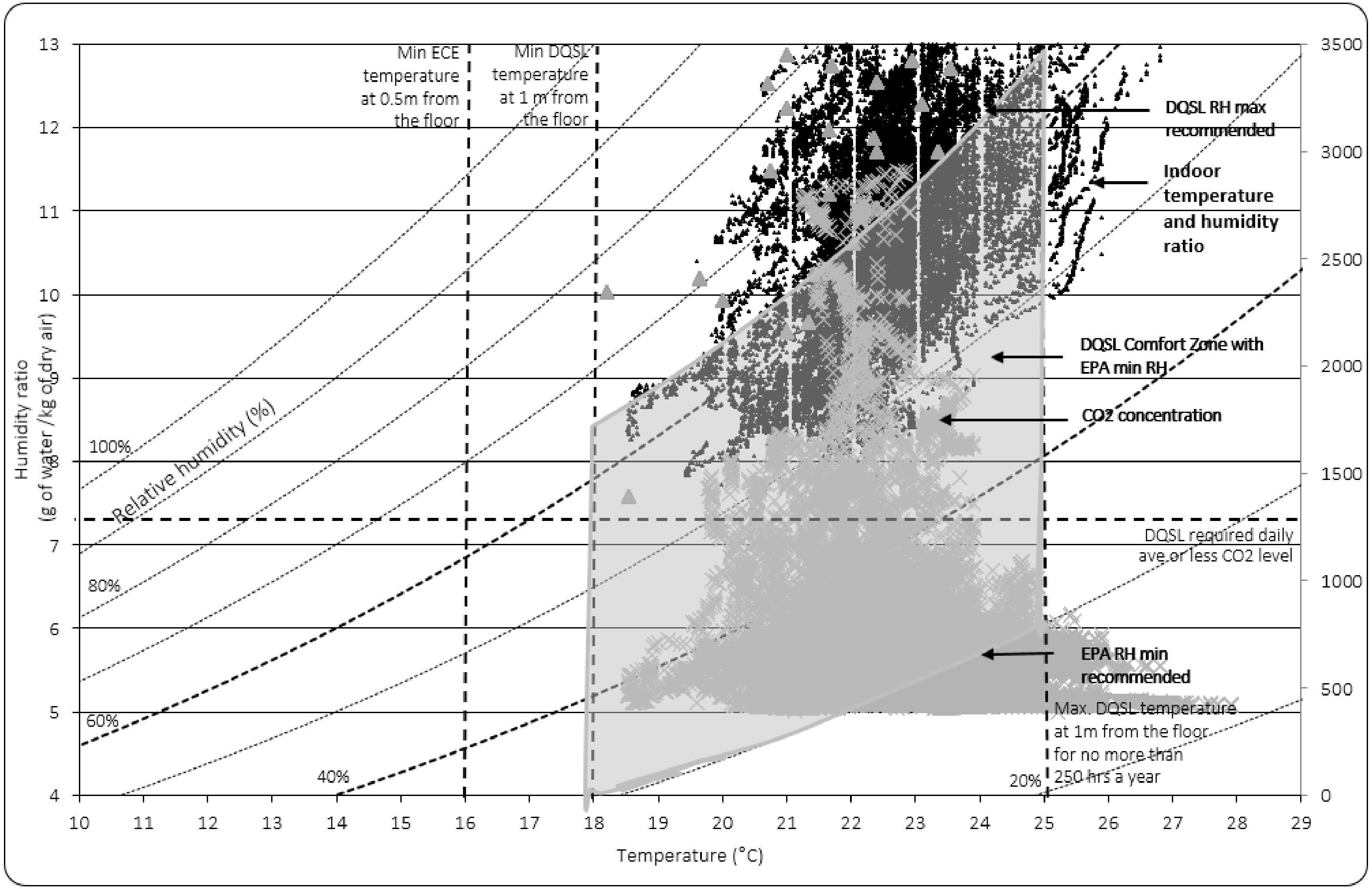


Figure 5-24 A psychrometric chart for Centre one's over the two-years-old classroom in Summer with CO_2 concentration overlaid on the secondary y-axis.

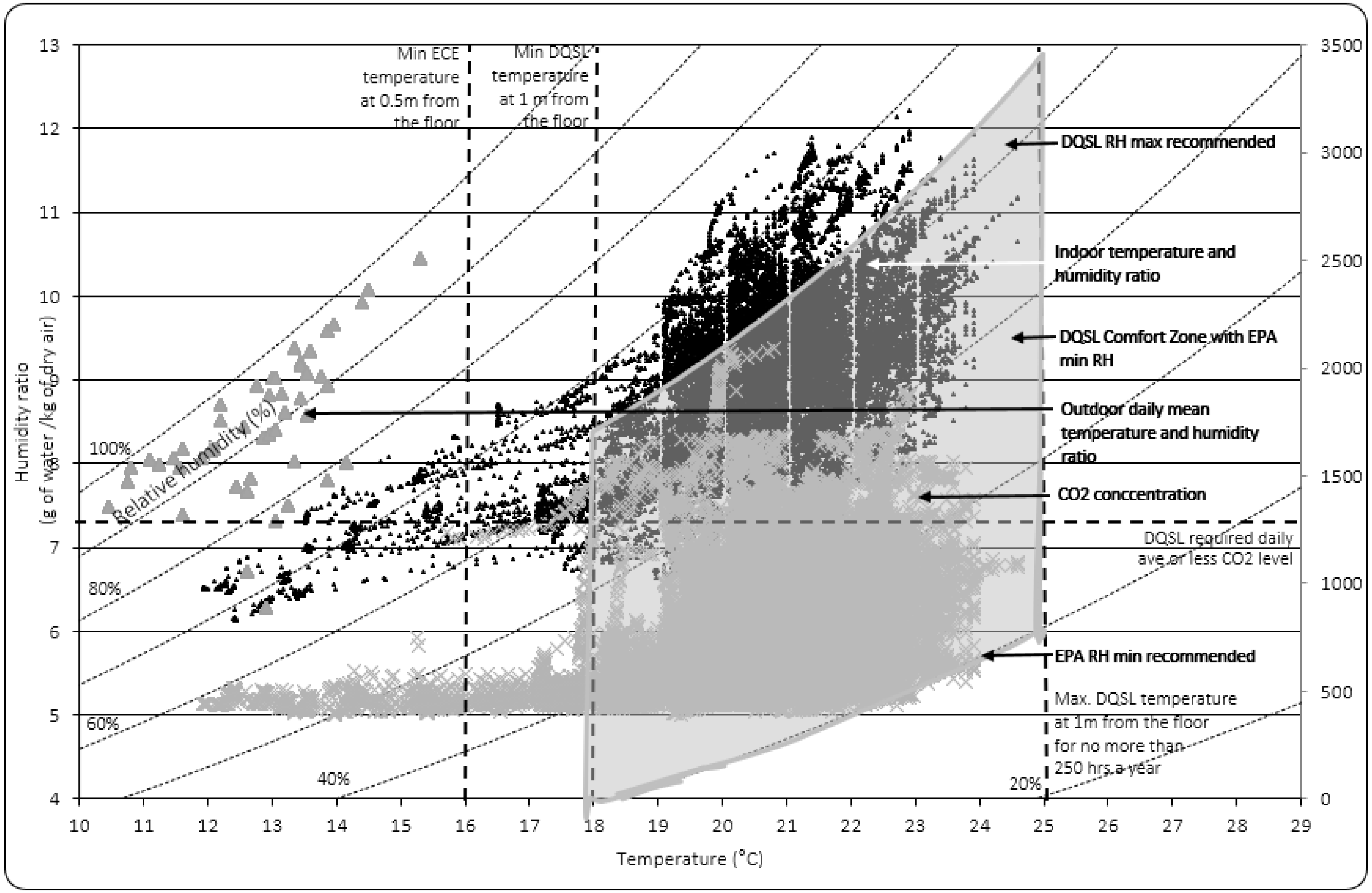


Figure 5-25 A psychrometric chart for Centre one's over two-years-old classroom in Winter with CO_2 concentration overlaid on the secondary y-axis.

CO_2 tracer-gas decay

The CO_2 tracer-gas decay tests were performed in the three rooms being monitored in Centre two. These three rooms were well-defined, enclosed rooms that were predominantly mechanically ventilated. The other centres were, however, not tested as a baseline CO_2 level would have been difficult to achieve. Centre one had half stable doors to the corridors and bathrooms that could not be easily sealed up, in addition to an awkward U-shaped plan. Centre four was an open-plan centre, and Centre three had the largest of all the rooms considered.

The tests were performed in Centre two on 3rd June 2018 over a weekend when the rooms were unoccupied. The tests were completed over the weekend due to the time taken to complete the tests and the rooms needing to be unoccupied during this time as can be seen in Figure 5-26.

Two scenarios were tested in each room. The first scenario was designed to test the minimum level of ventilation within the room, and the second scenario was designed to test the normal operating setting of the mechanical ventilation within the room.

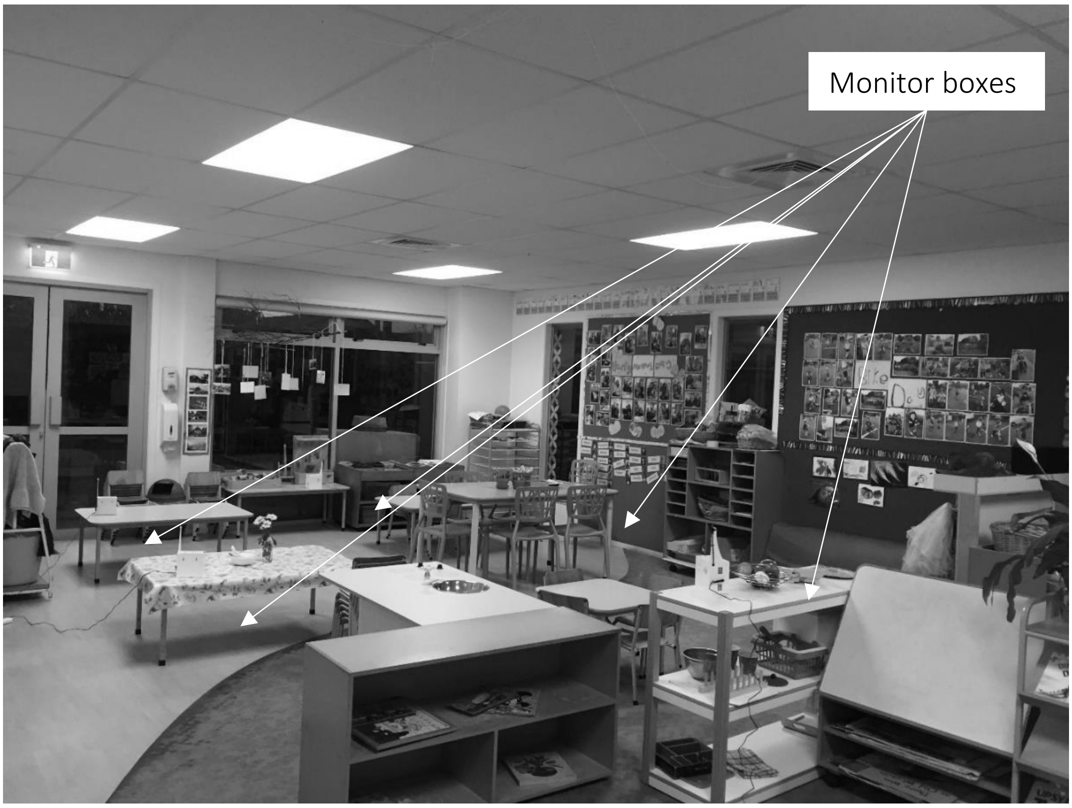


Figure 5-26 CO_2 tracer-gas decay testing in over two's classroom with monitors boxes placed around the room between the height of 0.5m and 1m

The results of the CO_2 tracer-gas decay measurements are shown in Table 5-19 below.

Table 5-19 CO_2 tracer-gas decay results

Air change rate (h^{-1})	Windows and doors closed	
Location	Ventilation off	Ventilation on
Centre 2, Under 2 sleep room	0.713	1.007
Centre 2, Under 2 classroom	0.248	0.441
Centre 2, Over 2 classroom	0.285	0.788
Average	**0.415**	**0.745**

Litre per second per person	Windows and doors closed	
Location	Ventilation off	Ventilation on
Centre 2, Under 2 sleep room	1.426	2.013
Centre 2, Under 2 classroom	0.496	0.881
Centre 2, Over 2 classroom	0.553	1.529
Average	**0.825**	**1.474**

The sleep room for the under two-year-olds had the highest air changes while the ventilation was off at 0.713^{-h} (1.426 l/sec per person) but had the lowest air changes when the ventilation was turned on at 0.441^{-h} (0.881 l/sec per person).

Both classrooms showed a similar air change rate per hour when the ventilation was turned off with the under two-year old's classrooms averaging 0.248^{-h} (0.496 l/sec per person) and the over two-year old's classroom averaging 0.285^{-h} (0.553 l/sec per person). When the ventilation was turned on the under two-year old's room performed at a lower air change rate per hour of 0.441^{-h} (0.881 l/sec per person) versus 0.788^{-h} (1.529 l/sec per person) in the over two-year old's room. Below are examples of the test results graphed over time.

The Auckland Council records for this centre include a producer statement from the installers signing off that the system installed meets the required standards when the building was built. As stated on the producer statement they included NZBC 1993, AS 1668.2: 2002; NZS 4302:1987, NZS 4303:1990 and G4 AS1/1.2 Mechanical ventilation. The system was configured to maintain 22°C and provide fresh air supply at a rate of 10 l/sec/person in the classrooms and sleep rooms.

The system is controlled by thermostats and time clocks. The fresh air is drawn in by the air handling units where it is mixed with re-circulated conditioned air, filtered and returned to the rooms. Forced mechanical extract ventilation was installed in each bathroom and air is drawn from the rooms via a ceiling grill in each room.

There is also documentation confirming annual maintenance of the system as required by the local council as part of the building's annual building warrant of fitness.

Centre cleaning routines and dust observations

All four centres had daily cleaning routines that included vacuuming or mopping the floors and wiping down the kitchen areas and tables. All centres also had regular routines in place to wash their toys as required by the MoE. The mechanical ventilation of Centre's two and three had annual maintenance programs in place. However, none of the extract grills had been recently cleaned, example Figure 5-27 below, even though they had been ticked as being inspected on the maintenance sheets. All heat pumps had an annual maintenance program in place as part of the building warrant of fitness. None of the centres had deep cleaning routines in place to wipe down shelves and windows sills or clean under or behind moveable furniture. This led to layers of dust accumulating on the shelves, dust and mould on the majority of windows, and dust, dirt and sand on the floor under and behind moveable furniture evident in all rooms, particularly in the babies sleep rooms. All bathroom extract vents across all the centres had accumulated dust on the grilles and had not been recently cleaned.

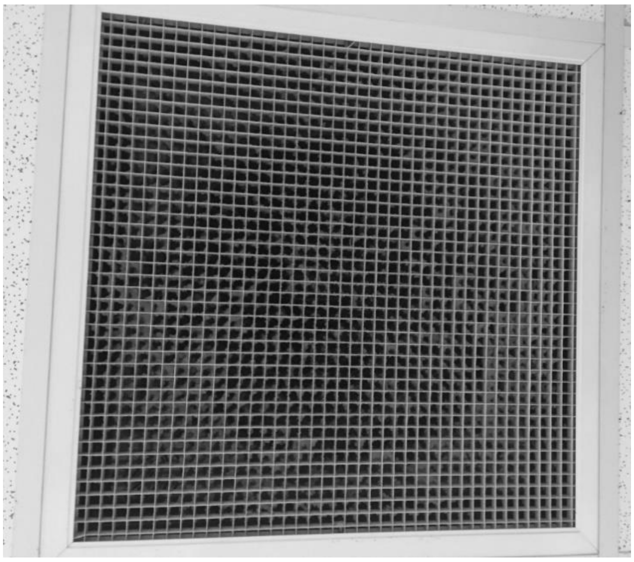


Figure 5-27 Example of accumulated dust on the extract vent of a mechanically ventilated centre.

Centres one and four were located on a secondary collector road with Centres two and three located on low volume access roads as defined by Auckland Transport (Auckland Transport Agency, 2019). The results are summarised in Table 5-20 below.

Table 5-20 A summary of the cleaning and maintenance routines of the centres and the closest road type to that centre.

Building Characteristics	1	2	3	4
Surface cleaning (Kitchens)	Daily	Daily	Daily	Daily
Surface cleaning (Tables)	Weekly	Weekly	Weekly	Weekly
Surface cleaning (Shelves)	No routine	No routine	No routine	No routine
Floor cleaning	Daily	Daily	Daily	Daily
Entry/Exit mats	Main entrance only	Main entrance only	Main entrance only	Main entrance only
Heat pump maintained	Annual	Annual	Annual	Annual
Ventilation maintained	Not	Annual	Annual	Not
Visible dust on extract fans in bathrooms	Yes	Yes	Yes	Yes
Visible dust on extract grates of the ventilation system	Not applicable	Yes	Yes, except for toddlers sleep room	Not applicable
Visible dust on floor	No	No	No	No
Visible dust on shelves	Yes	Yes	Yes	Yes
Visible dust on floor under or behind moveable furniture	Yes	Yes	Yes	No
Road type as defined by New Zealand Transport Agency	Secondary collector	Low volume access road	Low volume access road	Secondary collector

5.5.4. Light

Natural light

A summary of the natural light characteristics is presented in Table 5-21 below. All classrooms had natural light provided through windows or glass doors that also provided views to outside though Centre two's under two-year-old's room consisted of only two narrow vertical windows that looked straight onto a fence and the neighbouring three-storey high wall less than three metres away. Centre one's windows in the over two-year old's room were mostly frosted. The natural light was calculated at an average of 13% of the window to floor area across all classrooms. The sun orientation of the buildings was mixed with Centre one facing West, Centre two facing South-West, Centre three facing North West and Centre four facing East.

Table 5-21 A summary of the internal natural light characteristics of the centres

Building Characteristics		1	2	3	4
% of glazed external windows and doors to floor area	Under twos	12%	7%	22%	17%
	Over twos (Toddlers)	11%		16%	9%
	Over twos (Preschool)	16%	11%		
Width to depth ratio from the playground or predominate natural light source	Under twos	0.7	0.8	0.7	1.0
	Over twos (Toddlers)	3.6		2.5	1.9
	Over twos (Preschool)	3.1	1.7		
% of glass to wall that provides views to outside	Under twos	7%	4%	13%	10%
	Over twos (Toddlers)	5%		11%	6%
	Over twos (Preschool)	9%	8%		
Orientation of the building		West	South & West	North West	East
Are there views to outside restricted (e.g. frosted, covered or blocked outside)	Under twos	Yes	Yes	No	No
	Over twos (Toddlers)	Yes		No	Yes
	Over twos (Preschool)	Yes	No		

As an indication as to how deep the plan of the classrooms are, the average width to depth ratio was calculated at 1m across the playground to 1.8m deep into the classroom.

The views to outside were calculated at an average 8% of glazing to wall area with 50% of the views restricted by the glass being frosted or covered with children's artwork or by a close neighbouring fence and building, an example in Figure 5-28. All sleep rooms had no views to outside with any windows either covered by blinds, paper stuck across them or very small square windows just short of the ceiling.

The only two narrow windows in the classroom

The view from left hand window, a fence and a two-storey solid wall.

Figure 5-28 An example of a building code approved view to outside.

G7 Natural light requires 30 lux at floor level for 75% of the standard year (MBIE, 2014a). All four centres have been tested against this code compliance requirement using the Velux daylighting software tool, and the results are presented below in

Figure 5-29 to Figure 5-32. Centre one achieved this standard across 75% of the three classrooms' floor area monitored in this study. Centre two achieved it across 95% of the two classrooms' floor area for the required time with Centres three and four achieving it across 60% and 90% of their two classrooms' floor area for the required time. None of the centres achieved a daylight factor across the room of greater or equal to 2%

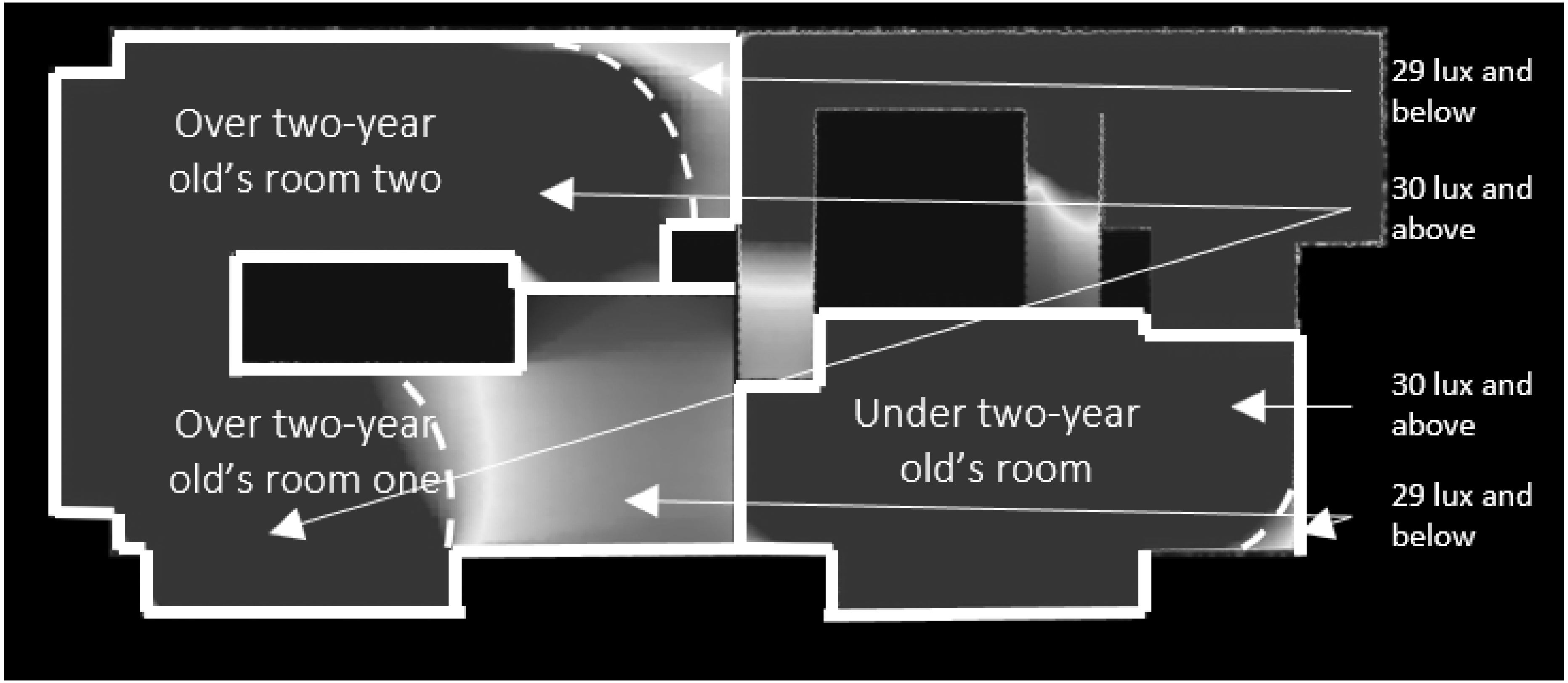


Figure 5-29 Centre one achieved G7 Natural light standard across 75% of the three classrooms' floor area monitored in this study.

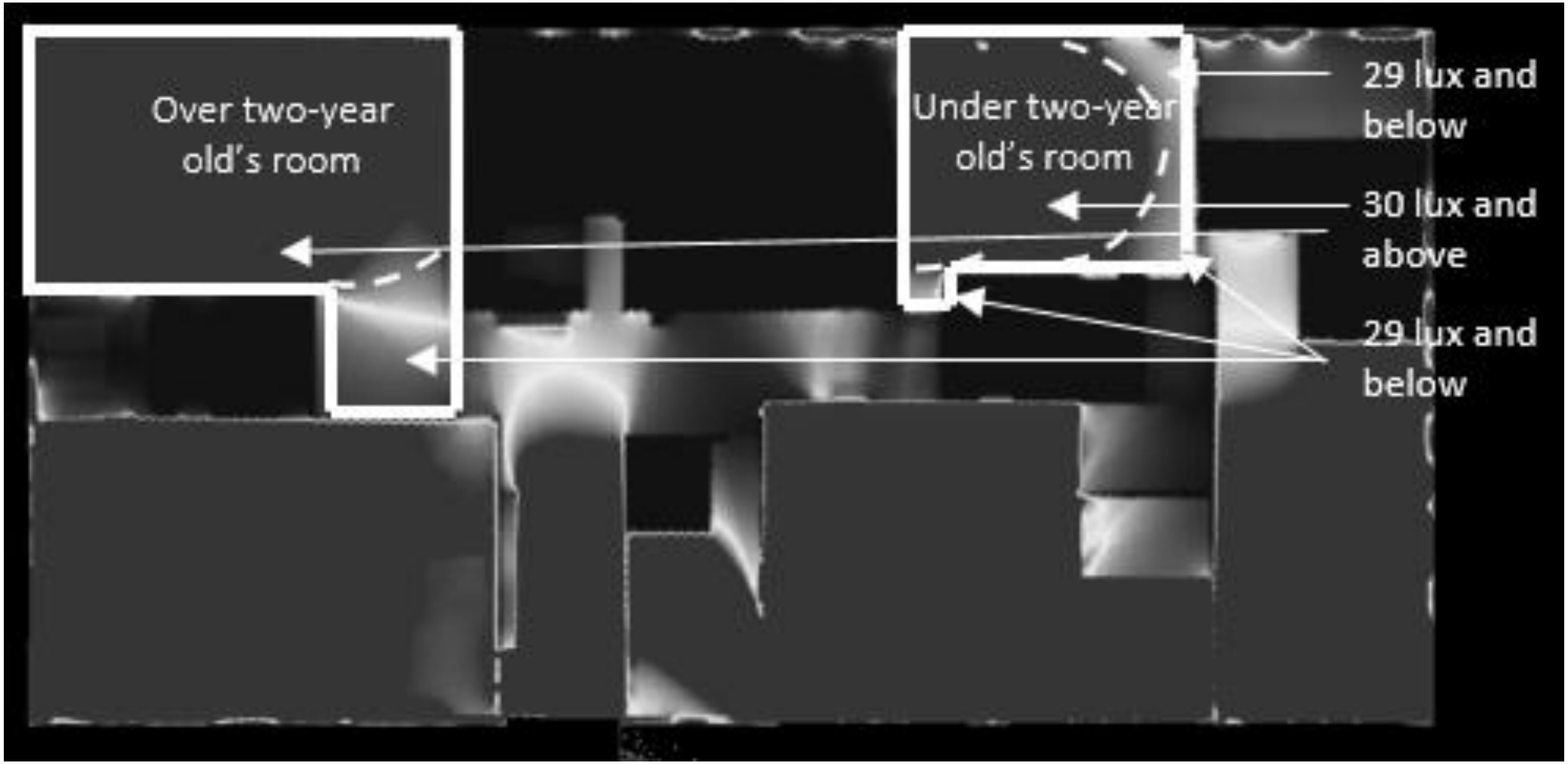


Figure 5-30 Centre two achieved G7 Natural light standard across 95% of the three classrooms' floor area monitored in this study.

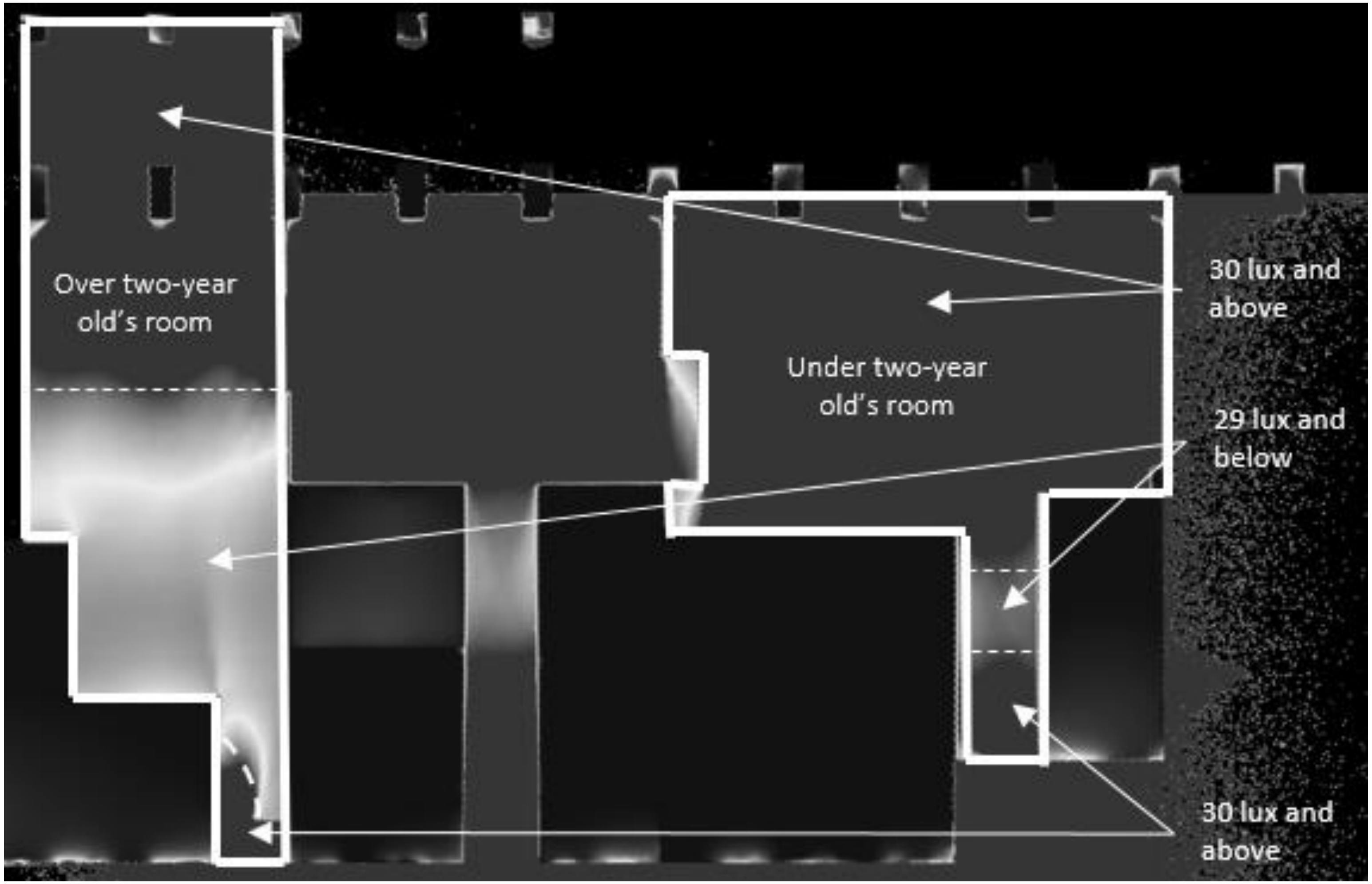


Figure 5-31 Centre three achieved G7 Natural light standard across 60% of the three classrooms' floor area monitored in this study.

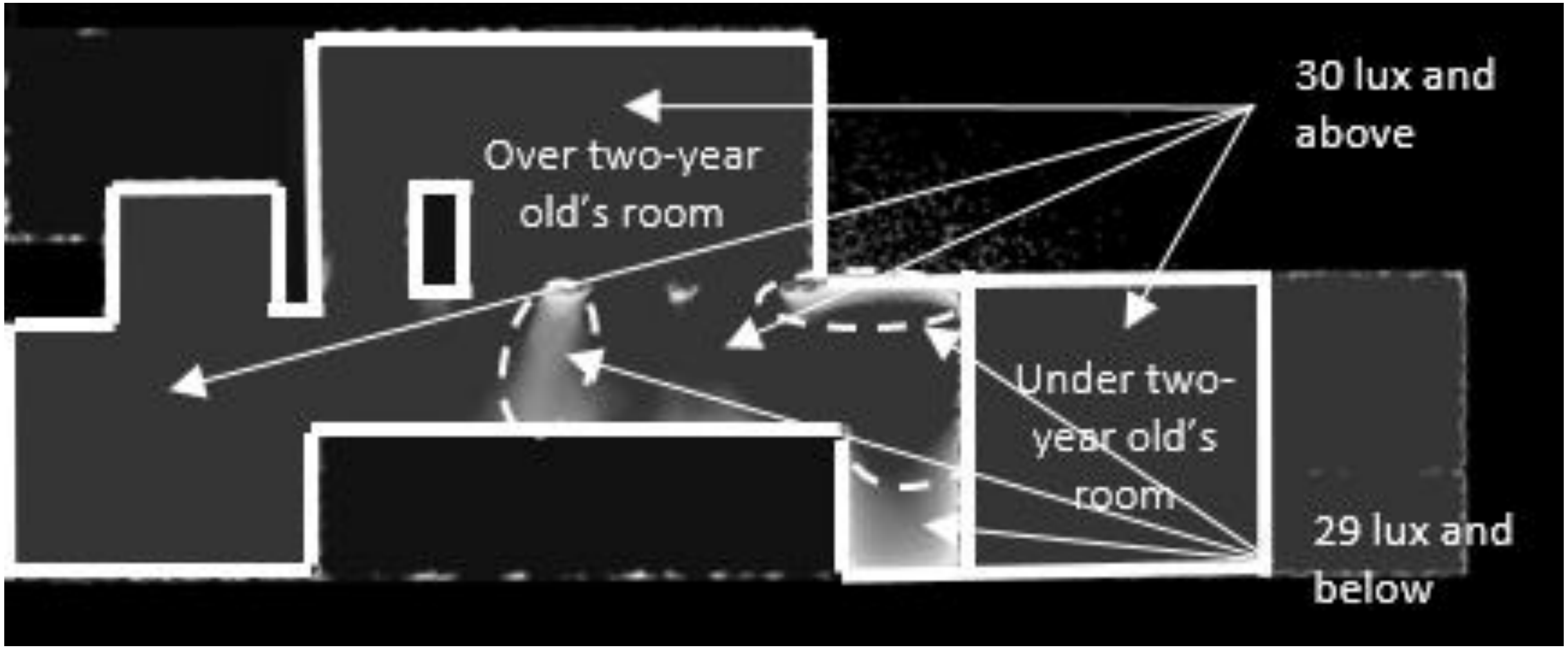


Figure 5-32 Centre four achieved G7 Natural light standard across 90% of the three classrooms' floor area monitored in this study.

Artificial light

Centres one and four had LED downlights with Centre one also having two hanging pendants. No visible flicker was witnessed by the researcher. The video recordings of the artificial lights in Centre one indicated that there might be non-visible flicker. Centres two and three had fluorescent lights that also recorded what may be non-visible flicker. In Centre three's under two-year old's room, three of the fluorescent lights were not working, and another three only had one of the three tubes working. The results are summarised in Table 5-22 below.

Table 5-22 A summary of the internal artificial light characteristics of the centres.

Building Characteristics	1	2	3	4
Type of lights in room	Pendant and LED tube lighting	Fluorescent tube trough lights	Fluorescent tube trough lights	LED downlights
Possible visible flicker witnessed by the researcher	None	None	None	None
Possible non-flicker witnessed through a video recording of the lights	Yes	Yes	Yes	Yes

Interior and workplace lighting

The artificial lighting levels were measured at floor level to assess the centre's lighting against G8 Artificial light. It was also measured at 0.5m and 0.8m AFFL to assess the centre against the AS/NZ 1680 series and MoE DQLS Spaces: Lighting.

The illuminance levels measured across three of the four centres was a mean of 216 lux at floor level, a mean of 249 lux at 0.5m AFFL and a mean of 269 lux at 0.8m AFFL as laid out in Table 5-23 below. Measurements were not taken from Centre 1 due to difficulties in gaining access to the centre after dark.

Table 5-23 The mean lux levels by classroom by height measured

Centre	Age Group	Mean lux levels: Floor height	Mean lux levels: 0.5m AFFL	Mean lux levels: 0.8m AFFL
1	Under 2 years old	Not measured		
1	2 years old and over			
1	2 years old and over			
2	Under 2 years old	316	371	391
2	2 years old and over	287	339	396
3	Under 2 years old	198	222	238
3	2 years old and over	227	258	272
4	Under 2 years old	156	182	186
4	2 years old and over	111	121	130
Mean lux		216	249	269

These measurements were taken in accordance with the methodology laid out in Section 5.2.2, as seen in Figure 5-33 below.

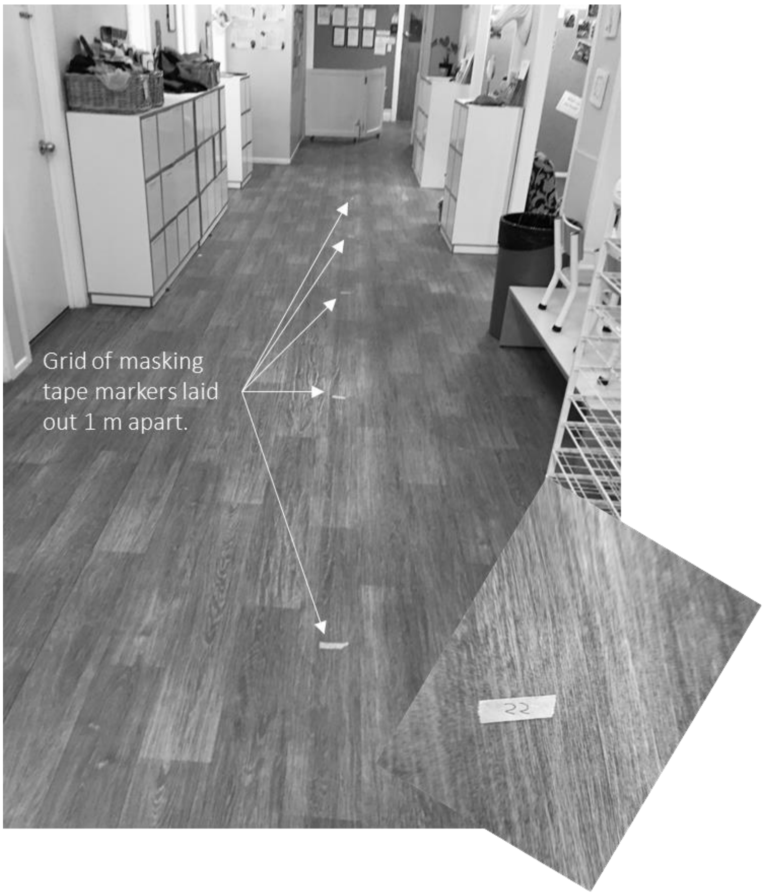


Figure 5-33 The masking tape grid laid out in one of the centres at 1m intervals and numbered prior to the measurements being taken.

All the measured points on the grid met or exceeded 20 lux at floor level. Presented in Table 5-24 below are the results in terms of the percentage of time they met or exceed 240 lux, 300 lux or 320 lux at the three heights measured.

Overall the results were mixed with the lowest results measured in Centre 4 across all rooms and heights. The highest results were measured in Centre two with stronger results at 240 lux then falling away to lower levels the closer to the floor the measurements were taken.

Table 5-24 The percentage of time the measured points on the grid met or exceed 240 lux, 300 lux and 320 lux at floor level and 0.5m and 0.8m AFFL in the classrooms.

		240 lux			300 lux			320 lux			
Centre	**Age Group**	**Floor height**	**0.5m AFFL**	**0.8m AFFL**	**Floor height**	**0.5m AFFL**	**0.8m AFFL**	**Floor height**	**0.5m AFFL**	**0.8m AFFL**	**No. of points measured in the room**
1	Under 2 years old	Not measured			Not measured			Not measured			
1	2 years old and over										
2	Under 2 years old	92%	100%	100%	71%	96%	92%	38%	83%	79%	24
2	2 years old and over	82%	95%	100%	55%	91%	91%	27%	73%	82%	22
3	Under 2 years old	25%	36%	42%	8%	22%	22%	3%	17%	19%	36
3	2 years old and over	46%	54%	59%	22%	43%	46%	16%	24%	41%	37
4	Under 2 years old	0%	0%	0%	0%	0%	0%	0%	0%	0%	8
4	2 years old and over	0%	4%	7%	0%	0%	4%	0%	0%	0%	27
Mean % of times the lux level met or exceeded		**41%**	**48%**	**51%**	**26%**	**42%**	**42%**	**14%**	**33%**	**37%**	

5.5.5. Sound

All classrooms but one had acoustic pinboard material across the walls. The average coverage of the walls in acoustic material was 17%. Centre one’s flooring was timber with all the other centres having an average of 67% carpeted with the rest covered in a vinyl flooring. All the sleep room’s had carpet on the floor. Centre two and three had acoustic ceiling tiles in all the rooms and Centres one, and four had plasterboard ceilings. Three of the four centres also had high wall heat pumps installed in the classrooms and in the sleep rooms that generated a level of constant background noise. A summary of the internal acoustic characteristics is presented in Table 5-25 below.

Table 5-25 A summary of the internal acoustic characteristics of the centres

Building Characteristics		1	2	3	4
Floor surface		Smooth	Mixed	Mixed	Mixed
Wall finish		Painted plasterboard with a panel of acoustic board on most walls	Painted plasterboard with some acoustic board	Painted plasterboard with some acoustic board	Painted plasterboard with a panel of acoustic board on most walls
Type of ceiling		Painted plasterboard	Acoustic ceiling tiles	Acoustic ceiling tiles	Painted plasterboard
Curtain type in the classrooms		None	None	None	None
Curtain type in the sleep rooms			None	None	Blinds
Classroom: Total floor covering in carpet (m^2)	Under twos	-	20.0	71.6	32.7
	Over twos (Toddlers)	-		79.8	43.7
	Over twos (Preschool)	-	45.3		
Classroom: % of floor finish carpeted	Under twos	0%	50%	79%	100%
	Over twos (Toddlers)	0%		78%	37%
	Over twos (Preschool)	0%	60%		
Total wall area including all windows and doors (m2)	Under twos	65.4	67.4	151.6	52.8
	Over twos (Toddlers)	86.7		149.4	164.4
	Over twos (Preschool)	80.6	102.9		
Classroom: Total wall covering in acoustic material (m^2)	Under twos	7.7	4.8	-	8.0
	Over twos (Toddlers)	13.8		32.5	39.7
	Over twos (Preschool)	3.5	59.2		
Classroom: % of wall covering is acoustic in natural	Under twos	12%	7%	0%	15%
	Over twos (Toddlers)	16%		22%	24%
	Over twos (Preschool)	4%	58%		
Sleep room: % of floor finish carpeted	Under twos		100%	100%	100%
	Over two years old			100%	
Sources of any constant internal mechanical background noise observed		Heat pumps	None	Heat pumps	Heat pumps and bathroom extraction fan
Observation of the Lombard and/or café effect		Yes	No	No	Yes

The results from the RT60 Acoustic Reverb Calculator are presented in Table 5-26 and Figure 5-34 below. Centres two and three had the lowest result across all frequencies calculated with Centres one and four having the highest.

Table 5-26 The average reverberation results in seconds (s) of the probable, worst and best case calculated by centre.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
NZS2107:2016 recommended limit			0.50	0.50		
Centre one	0.46	1.15	1.21	1.41	1.25	1.16
Centre two	0.22	0.21	0.22	0.18	0.22	0.17
Centre three	0.41	0.42	0.42	0.33	0.30	0.29
Centre four	0.58	1.29	1.26	0.95	0.68	0.62
Average	0.42	0.77	0.78	0.72	0.61	0.56

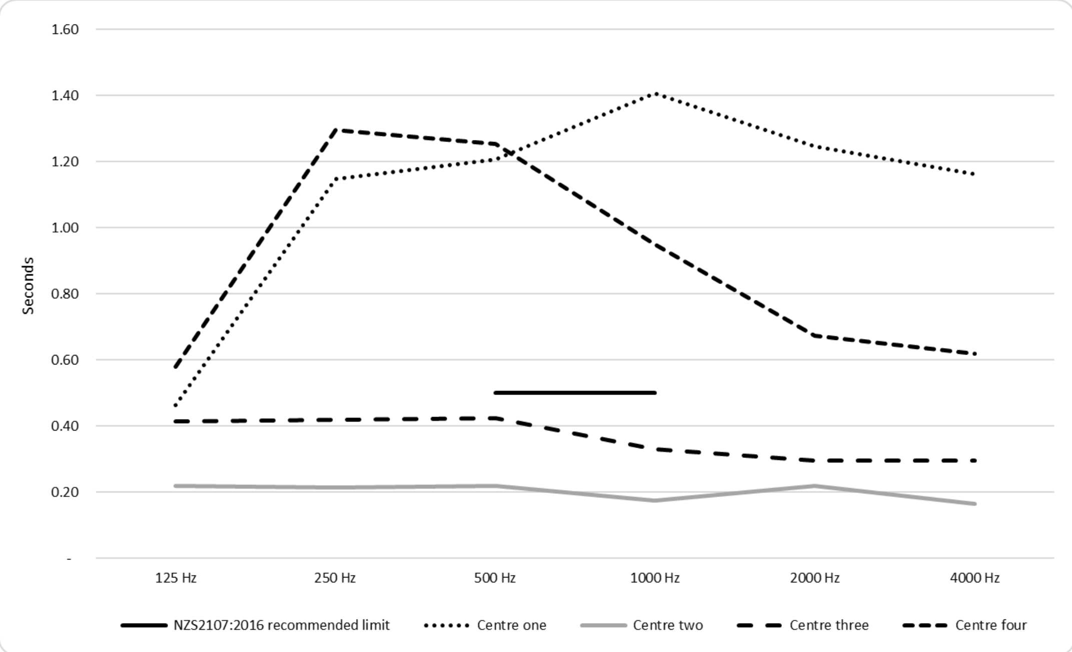


Figure 5-34 A line graph of the reverberation results showing the average of the probable, worst and best case calculated for each centre.

Sources of constant internal mechanical background noise observed included heat pumps in Centres one, three and four and a bathroom extraction fan in Centre four was particularly noticeable. Once the heat pumps and extraction fans were turned off, there was a noticeable drop in how loud occupants were talking.

5.6.Discussion

The third research question measured the IEQ of four ECE centres in Auckland, NZ. These measurements included IAQ, light and sound. Measuring IEQ as a whole is rarely done. This study is a critical step in understanding if the building codes, standards and guidelines continue to be met after the construction of a building is complete and that under five-year-old children's health within an ECE centre is being supported.

Assessment against NZBC regulations, relevant standards and guidelines

Of the IEQ elements related to NZBC, standards and guidelines that were relevant to this study, an average of 60% were met in the classrooms, and 67% were met in the sleep rooms. The results of this assessment are presented in

Table 5-27 and Table 5-28 below and discussed in detail in this section.

The six legislative requirements relevant to the classrooms include:

- Education (Early childhood services) Regulations 2008, classroom space standards per child (NZ Parliament, 2008),
- G4 Ventilation (MBIE, 2016b),
- G5 Indoor environment (Department of Building and Housing, 2011),
- G7.2 Natural light, Functional requirement,
- G7.3.1 Natural light, Performance (MBIE, 2014a) and
- G8 Artificial light (MBIE, 2014b).

Of these six legislative requirements relevant to the classrooms, two were met by all the classrooms. These were the Education (Early childhood services) Regulations 2008 Space standards and G8 Artificial lighting. It must be noted that while all centres met G8 Artificial lighting requirements, this standard is intended for the safe movement within a building and does not consider the tasks or activities within the building, which is not legislated for.

G5 Indoor environment was met by eight of the nine rooms. G4.2 Ventilation was met by all the centres naturally ventilated through the acceptable solution as defined under G4/AS1.2.2 Natural ventilation. Of the mechanically ventilated centres only two of the four classrooms were tested, and these classrooms did not meet the requirements as defined under the acceptable solution G4/AS1 1.5.1 a). G7.2 Natural light, Functional requirement was met by four of the nine classrooms and G7.3.1 Natural light, Performance was met by two. Seven of the nine classrooms, however, met G7/AS1 a) Natural light, the acceptable solution.

Two of these legislative requirements are relevant to the sleep rooms with G5 Indoor environment being met by three of the four sleep rooms and G4 Ventilation being met by only one of the sleep rooms.

MoE governs all education in NZ from early learning to tertiary education. Therefore, when a NZ ECE IEQ regulation, standard or guideline relevant to this study is not available or is non-specific, the equivalent regulation, standard or guideline for NZ schools has also been considered within this assessment.

Of the NZ standards and MoE ECE and school standards and guidelines considered relevant to this study, an average of 40% were met by the classrooms, and 57% were met by the sleep rooms. These include:

- Thermal comfort,
- CO_2 concentration levels,
- Dust,
- Natural light,
- Artificial lighting,
- Interior and workplace lighting and
- Acoustics.

Research has shown a positive correlation between IEQ and educational achievement in terms of kindergarten readiness scores (Satterlee et al., 2015) and a negative correlation between ventilation rates and the number of sick days children take (Kolarik et al., 2016). Outcomes of other similar studies have also introduced Post Occupancy Evaluations (Salleh, Salim, & Kamaruzzaman, 2016) and large scale mandatory IAQ or IEQ monitoring programs (Michelot et al., 2013).

The MoE requires all NZ schools to have a CO_2 monitor displayed in all learning areas (MoE, 2017a). Following in the footsteps of these studies, this study concludes that the MoE's school IAQ monitoring requirements could be widened to include ECE centres and include an IEQ assessment in the centres ERO reports.

The results above and other observations are now discussed within the rest of the section below.

Table 5-27 A summary table assessing the classrooms within this study against NZBC, standards and guidelines relevant to this study.

		Classroom								
Building characteristics		1	2	3	4	5	6	7	8	9
Education (Early childhood services) Regulations 2008 - classroom space standards	Legislative requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Licensing criteria for centre-based education and care services 2008 (updated May 2016) - Amenities provided	Ministry of Education ECE guideline	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Thermal comfort										
G5.3.1 - Indoor environment - ≥ 16°C 0.75 m from floor level and The licensing criteria for centre-based education and care services 2008 (updated May 2016) - HS24 ≥ 16°C at 0.5 m from floor level and PF12 ≥ 16°C	Legislative requirement & Ministry of Education ECE guideline	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Ministry of Education DQLS: Thermal comfort ≥ 18°C and ≤ 25°C 1 m from floor level	Ministry of Education school requirement	No	No	No	No	No	No	No	No	No
Ministry of Education DQLS: Relative humidity comfort ≤ 65% and EPA ≥ 30%	Ministry of Education school guideline	No	No	No	No	No	No	No	No	No
Ventilation										
G4.2 Ventilation - Adequate ventilation is provided for the maximum occupancy and intended use. The licensing criteria for centre-based education and care services 2008 (updated May 2016) PF12: Ventilation (natural or mechanical) that allows fresh air to circulate (particularly in sanitary and sleep areas)	Legislative requirement & Ministry of Education ECE guideline					Refer to G4/AS1 1.2.2				
G4/AS1 1.2.2 Natural ventilation, Acceptable solution - Openable windows are no less than 5% of floor area	Building Code acceptable solution	Yes	Yes	Yes					Yes	Yes
G4/AS1 1.5.1 a) Must provide outdoor air to occupied spaces at flow rates in NZS 4303 Table 2, Education, Classrooms 8 L/s/person and Ministry of Education DQLS: IAQ and thermal comfort - 4 ACH/8L/s/person	Building Code acceptable solution Ministry of Education school requirement				No	No	Not tested therefore refer to DQLS: IAQ			
Ministry of Education DQLS: IAQ and thermal comfort - requires an average of ≤ 1,200 ppm during operating hours	Ministry of Education school requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ministry of Education DQLS: IAQ and thermal comfort - The average of 1,500 ppm must not be exceeded during operating hours	Ministry of Education school requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ministry of Education DQLS: IAQ and thermal comfort, the maximum peak of 3,000 ppm must not be exceeded.	Ministry of Education school requirement	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Particulate Matter										
Ministry of Education DQLS: Entry/exit mats from main entrance	Ministry of Education school guideline	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ministry of Education DQLS: Entry/exit mats from playgrounds	Ministry of Education school guideline	No	No	No	No	No	No	No	No	No

		Classroom								
Natural light		1	2	3	4	5	6	7	8	9
G7.2 Natural light, Functional requirement - visual awareness of outside environment	Legislative requirement	No	No	No	No	Yes	Yes	Yes	Yes	No
G7.3.1 Natural light, Performance - No less than 30 lux at floor level for 75% of the standard year	Legislative requirement	No	No	No	No	No	Yes	No	Yes	No
G7/AS1 1.0.1 a) Natural light, Acceptable solution - Windows are no less than 10% of floor area	Building Code acceptable solution	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Ministry of Education DQLS: Lighting - Daylight factor of ≥ 2	Ministry of Education school guideline	No	No	No	No	No	No	No	No	No
Artificial light										
G8.3 Artificial light - no less than 20 lux at floor level	Legislative requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interior and workplace light										
NZ1680.2.3:2008 - Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series Appendix D - 320 lux at 0.8m above floor level for reading rooms; Ministry of Education DQLS Spaces: Lighting - between 300 to 500 lux in classrooms and The Licensing criteria for centre-based education and care services 2008 (updated May 2016) - PF12 "Parts of the building or buildings used by children have: lighting (natural or artificial) that is appropriate to the activities offered or purpose of each room"	Standard recommendation & Ministry of Education school and ECE guideline				Yes	Yes	No	No	No	No
NZS 1680.1:2006 Interior and workplace lighting part 1: General principles and recommendations - Flicker free lamps	Standard recommendation	Possible non-visible flicker may have been recorded. Further investigation would be required to determine if this was the case								
Sound										
NZS2107:2016 Acoustics - Recommended sound levels and reverberation times for building interiors @ the average probable level of 500Hz and 1000Hz and The Licensing criteria for centre-based education and care services 2008 (updated May 2016) HS24 - All practicable steps are taken to ensure that noise levels do not unduly interfere with normal speech and/or communication, or cause any child attending distress or harm.	Standard recommendation & Ministry of Education ECE guideline	No	No	No	Yes	Yes	Yes	Yes	No	No
Number of times a legislative requirement, standard or guideline was met		10	10	9	10	12	12	10	12	9
Percentage of legislative requirement, standard or guideline was met		*59%*	*59%*	*53%*	*56%*	*67%*	*71%*	*59%*	*67%*	*50%*
Number of times a standard or guideline was met		7	7	6	7	8	7	7	7	6
% a standard or guideline was met		*41%*	*41%*	*35%*	*39%*	*44%*	*41%*	*41%*	*39%*	*33%*

Table 5-28 A summary table assessing the sleep rooms within this study against NZBC, Standards and guidelines relevant to this study.

		Sleep room			
Building characteristics		1	2	3	4
Education (Early childhood services) Regulations 2008 - classroom space standards	Legislative requirement				
Licensing criteria for centre-based education and care services 2008 (updated May 2016) - Amenities provided	Ministry of Education ECE guideline	Yes	Yes	Yes	Yes
Thermal comfort					
G5.3.1 - Indoor environment - ≥ 16°C 0.75 m from floor level and The licensing criteria for centre-based education and care services 2008 (updated May 2016) - HS24 ≥ 16°C at 0.5 m from floor level and PF12 ≥ 16°C	Legislative requirement & Ministry of Education ECE guideline	Yes	Yes	No	Yes
Ministry of Education DQLS: Thermal comfort ≥ 18°C and ≤ 25°C 1 m from floor level	Ministry of Education school requirement	No	No	No	No
Ministry of Education DQLS: Relative humidity comfort ≤ 65% and EPA ≥ 30%	Ministry of Education school guideline	No	No	No	No
Ventilation					
G4.2 Ventilation - Adequate ventilation is provided for the maximum occupancy and intended use. The licensing criteria for centre-based education and care services 2008 (updated May 2016) PF12: Ventilation (natural or mechanical) that allows fresh air to circulate (particularly in sanitary and sleep areas)	Legislative requirement & Ministry of Education ECE guideline	Refer to G4/AS1 1.2.2			
G4/AS1 1.2.2 Natural ventilation, Acceptable solution - Openable windows are no less than 5% of floor area	Building Code acceptable solution				Yes
G4/AS1 1.5.1 a) Must provide outdoor air to occupied spaces at flow rates in NZS 4303 Table 2, Education, Classrooms 8 L/s/person and Ministry of Education DQLS: IAQ and thermal comfort - 4 ACH/8L/s/person	Building Code acceptable solution Ministry of Education school requirement	No	Not tested therefore refer to DQLS: IAQ		
Ministry of Education DQLS: IAQ and thermal comfort - requires **an average of** ≤ 1,200 ppm during operating hours	Ministry of Education school requirement	Yes	Yes	Yes	Yes
Ministry of Education DQLS: IAQ and thermal comfort - The average of **1,5**00 ppm must not be exceeded during operating hours	Ministry of Education school requirement	Yes	Yes	Yes	Yes
Ministry of Education DQLS: IAQ and thermal comfort, the maximum peak of 3,000 ppm must not be exceeded.	Ministry of Education school requirement	Yes	Yes	Yes	Yes
Number of times a legislative requirement, standard or guideline was met		5	5	4	6
Percentage of legislative requirement, standard or guideline was met		*63%*	*71%*	*57%*	*75%*
Number of times a standard or guideline was met		4	4	4	5
% a standard or guideline was met		*50%*	*57%*	*57%*	*63%*

The current regulatory framework

The IEQ elements considered in this study are poorly represented within the current ECE and building regulatory frameworks. Overall the NZBC, standards and guidelines that govern IEQ in NZ ECEs are limited and nonspecific as can be seen in

Table 5-27 and Table 5-28 above and presented in the Literature review. For example, the natural light and artificial lighting building codes, standards and guidelines are outdated and complicated. In addition to this, the interior and workplace lighting standards do not provide ECE guidelines.

These gaps need to be addressed, and this could be achieved by either clarifying the specific requirements for ECE IEQ standards or including ECE within the school IEQ standards. ECE IEQ considerations that could be specifically addressed include:

- Defining an ECE comfort zone, not just a minimum temperature as the legislation currently stands (Department of Building and Housing, 2011);
- Ventilation that can be easily monitored within a centre, e.g. CO_2 concentrations particularly in the sleep rooms;
- Natural light, artificial lighting and views to outside requirements specific to ECE centres. These requirements could all interrelate to avoid the current contradictions and be set to an under five-year old’s working plane height.
- Reverberation times and a speech transmission index specific to ECE and
- Guidelines for cleaning and maintenance to minimise dust and other PM accumulation within the classrooms and sleep rooms.

In addition to this, MoE and the Ministry of Health are only involved in reviewing and approving an ECE centre once it is built. This can often be too late in the process and expensive to remedy if in conflict with what was approved when the building was granted building consent by the relevant local council.

Space standards

As per Education (Early childhood services) Regulations 2008, all classroom space standards met with the average at 3 m^2 exceeding the minimum requirement of 2.5m^2 plus 10% MoE furniture allowance (NZ Parliament, 2008). The sleep rooms average was 1.8 m^2. The average volume per cubic meter was 8.5 m^3 and 4.9 m^3, respectively. In the sleep rooms, there was a mix of stacked, single-level and portable day beds for those children under two-years-old with all children over 2 sleeping on portable day beds. There is limited research into space standards within ECE classrooms, and sleep rooms and space standards have been cited within many research papers as an area of concern in regards to IEQ (de Waard & Zeiler, 2014; McLaren, 2008).

Thermal comfort

G5 Indoor environment requires a room to maintain a temperature of greater or equal to 16°C at 0.75m above floor level. Similarly, within the Licensing criteria for centre-based education and care services 2008 (updated May 2016) guidance is provided under PS12 that parts of the building used by children should maintain a temperature no lower than 16°C (with no floor height specified) and under HS24 rooms used by children are to be kept at a comfortable temperature no lower than 16°C at 0.5m above floor level.

During operating hours, the temperatures monitored in three of the centres were greater or equal to 16°C on average 99% of the time; therefore, meeting code. It was only the temperatures in Centre three's over two-year-old's classroom and sleep room where the temperatures were greater or equal to 16°C on average 97% of the time.

As this code and guidance define a minimum level temperature, the thermal comfort levels were also assessed against the MoE DQLS: Indoor air quality and thermal comfort (MoE, 2017a). The thermal comfort range defined in this document is greater or equal to 18°C and less or equal to 25°C.

Regarding the humidity comfort, there is no ECE humidity comfort building code, standard or guideline. The RH measurements recorded within this study were therefore also assessed against the upper RH limit of 65% as defined in the MoE DQLS: Indoor air quality and thermal comfort. As a lower limit is not defined in NZ standards or guidelines nor in ASHRAE, the lower RH limit used to define RH comfort within this study was 30% as recommended by the United States Environmental Protection Agency (United States Environmental Protection Agency, 2017b).

The mean temperature across all room types during operating hours was a comfortable 21.1°C (SD = 2.3°C). The RH was at the high end of RH comfort, with a mean of 60.9% (SD = 8.2%). During operating hours across the rooms, they remain within the thermal comfort 86% of the time and the RH comfort 71%. When looking at the comfort zone (i.e. when both the temperature and the RH are within the parameters above), the rooms remain within this zone, only 63% of the time. This picture can be seen constantly across centres, room type and season, with the sleep rooms in Autumn being the lowest of all at 83% of the time within thermal comfort, 55% of the time within RH comfort and only 47% of the time within the comfort zone.

In Winter during operating hours there is a stronger negative correlation between temperature and RH in the non-timber constructed mechanically ventilated buildings $r(191743) = -0.723$, $p = 0.001$ followed by the timber constructed naturally ventilated buildings, $r(191743) = 0.565$, $p = 0.001$. This correlation then becomes weak in summer, particularly in the non-timber constructed buildings with mechanical ventilation. There is a relatively strong positive correlation between the outdoor temperature and the indoor temperature in the timber constructed naturally ventilated buildings, $r(1768040) = 0.472$, $p = 0.001$ and a moderately weak correlation in the non-timber constructed buildings with mechanical ventilation, $r(1768040) = 0.236$, $P = 0.001$. These correlations are stronger in Autumn and Spring but very weak in Summer and Winter. The stronger indoor temperature and RH correlations in Winter and Summer would indicate that the buildings' doors and windows are kept closed more frequently to moderate the indoor environment than in Autumn and Spring when indoor correlations are weaker, but the indoor to outdoor correlations are stronger. The timber constructed buildings with natural ventilation would appear to be more prone to air leakage than the non-timber constructed buildings with mechanical ventilation with weaker indoor correlations and strong indoor to outdoor correlations.

Several of the buildings and therefore classrooms and sleep rooms were not well orientated to the sun or for views to outside to take advantage of or manage solar gain and views to outside. In NZ, a North to North West orientation is preferable with only one building facing North West. Overall, those facing the opposite way had lower outlier temperatures than those that did not. For example, the under two-year-old's classroom faces South, and while it remained in thermal comfort, 91% of the time, it experienced temperatures as low as 13°C during operating hours. Similarly, those rooms that faced north with no eaves/overhang saw higher outlier temperatures than those that did not. For example, the sleep room in Centre four faces North and East. While it remained in thermal comfort 81% of the time during operating hours, it experienced temperatures above 30°C during summer and in the high 20°Cs during Autumn.

The temperature and RH from Monday to Friday in both the classrooms and sleep rooms were constant, with only outliers outside thermal comfort. However, the 75th percentile of RH was an RH of 66.5%, 1.5% above RH comfort and the 95th percentile of RH was an RH of 73.8%, 8.8% above the RH comfort. Over the weekends, the mechanical ventilation and heating are switched off, and the buildings are unoccupied. As a result, the temperature decreases by at least 1% and the RH increases by at least 3%.

Over a twenty-four-hour period during the week, the temperature and RH are inversely cyclical. The temperature rises through the day then falls at night. RH follows the same cycle though falling during the day and building up at night. While the mean hourly temperature overall remained between 18°C and 21.7°C, the RH exceed 65% for eight of the twelve hours (66%) the centres are closed and with no ventilation in any of the centres, i.e. no air movement.

With an RH above 65%, a contributing factor to the breeding of mould, dust mites and other bacteria, these elevated levels are a concern, particularly in the sleep rooms (ASHRAE, 2016; MoE, 2017a). Research has shown that exposure to mould and dampness is associated with airway inflammation, nasal congestion, coughing, wheezing, throat irritation, hay fever and eczema (Ahn, 2014;Lin et al., 2016) and an RH above 60% improves the survival rate of influenza (Myatt et al., 2010).

With these results, it would suggest that a purge of the building's air could be done before a centre is closed at night and when it is then opened again the next day. There could also be the use of heating or dehumidification mechanisms at night to keep the RH below 65% as a minimum, 60% preferably. This research indicates that this would apply to both natural and mechanically ventilated buildings, particularly in Winter and Summer. Other studies to have similar findings and recommendations were completed in Korea (Hwang et al., 2017) and the USA (Arlian et al., 2001;Myatt et al., 2010; Prussin II et al., 2018). These results also suggest the guidelines to keep RH less than 65% could apply across daytime and night time or that a minimum night time temperature could be introduced.

Ventilation

G4 Ventilation requires that adequate ventilation is provided for the maximum occupancy of a space and it's intended use. Similarly, the licensing criteria for centre-based education and care services 2008 (updated May 2016) provide guidance in PF12: Ventilation (natural or mechanical) that allows fresh air to circulate (particularly in sanitary and sleep areas).

Within G4 Ventilation, there is an acceptable solution for naturally ventilated buildings, and there is also one for mechanically ventilated buildings. G4/AS1 1.2.2 Natural ventilation requires the openable windows of a building to be no less than 5% of floor area.

G4/AS1 1.5.1 a) requires that outdoor air must be provided to occupied spaces at the flow rates in NZS 4303:1990 Table 2. Within this table, ECE rooms are not defined. The nearest description under the 'Education' category are classrooms with a rate of 8 L/s/person. The MoE DQLS: IAQ and thermal comfort recommend 4 ACH/8L/s/person in school classrooms.

The MoE DQLS: IAQ and thermal comfort also require in school classrooms during operating hours an average CO_2 concentration level less or equal to 1,200 ppm, with the average not exceeding 1,500 ppm. The maximum peak of 3,000 ppm must also not be exceeded.

In Centres two and three, which were mechanically ventilated, all rooms remained below the MoE: DQLS: IAQ and thermal comfort CO_2 concentration levels of operating average 1,200 ppm and 1,500 ppm and a maximum of 3,000 ppm. Centre two's sleep room did, however, come close to the maximum of 3,000 ppm at 2,914 ppm.

Overall, Centre three performed well with the MoE: DQLS: IAQ and thermal comfort CO_2 concentration operating an average of 1,200 ppm met for 97.5% of the time. Three of the four rooms met it 100% with only the over two-year-old's sleep room falling to 93%. When looking at CO_2 concentrations during the operating hours of the sleep room at 12h00, the CO_2 concentrations reach a mean of 1,044 ppm, and it has reached a maximum of 2,117 ppm at 10h00. These measurements would indicate the ventilation is not working as well as it should be, especially when compared to the under two-year-old's sleep room CO_2 concentrations levels. The mean in this room is 527 ppm (SD = 55), with a maximum mean concentration of 841 ppm.

Centre two's over two-year-old's classroom performed well and remained below the MoE operating average of 1,200 ppm 99% of the time. While the mean was only 592 ppm (SD = 148 ppm), the maximum CO_2 concentration level was 2,059 ppm. However, the under two-year-old's classroom and sleep room performed poorly. The classroom had a mean of 958 ppm (SD = 343 ppm) and maximum of 2,723 ppm with the sleep room's mean at 1,068 ppm (SD = 498) and a maximum of 2,914 ppm. These two rooms remain below the MoE operating average of 1,200 ppm operating 78% of the time and 63% of the time respectively. During the sleep room's operating hours, the mean was 1,378 ppm (SD = 445), which exceeded the average operating CO_2 concentration of 1,200 ppm by 15%. The maximum CO_2 concentration was 2,735 ppm. There is one supply vent in the room. The 50 mm ventilation gap under the door that facilitates the extraction of the air from the room was half blocked by the carpet. These results indicate that there may be an issue with the mechanical ventilation in these two rooms.

The results from the CO_2 tracer-gas decay tests show that the air changes with the ventilation turned on was lower than the four air change rates per hour as recommended in the NZ Designed quality learning spaces: Indoor air quality and thermal comfort (MoE, 2017a). The air changes per hour converted to litres per second per person also fell below the recommended levels as defined in the NZS 4303:1990 Ventilation (Standards NZ, 1990). This standard recommends 8 litres per second per person; however, the results were 1.474 litres per second per person, 6.526 litres per second per person lower, as presented in Table 5-29 below. These results further support the indication that there is an issue with the mechanical ventilation that requires further investigation.

Table 5-29 CO_2 trace- gas decay results compared to NZS 4303:1990 Ventilation (Standards NZ, 1990).

Air change rate (h^{-1})	Windows and doors closed		Designing quality learning spaces: Indoor air quality and thermal comfort	Ventilation on
Location	Ventilation off	Ventilation on		Above / (Below)
Centre 2, Under 2 sleep room	0.713	1.007	4	(2.993)
Centre 2, Under 2 classroom	0.248	0.441	4	(3.559)
Centre 2, Over 2 classroom	0.285	0.788	4	(3.212)
Average	**0.415**	**0.745**	**4**	**(3.255)**

Litre per second per person	Windows and doors closed		NZS4303:1990 Ventilation for acceptable indoor air quality	
Location	Ventilation off	Ventilation on		
Centre 2, Under 2 sleep room	1.426	2.013	8	(5.987)
Centre 2, Under 2 classroom	0.496	0.881	8	(7.119)
Centre 2, Over 2 classroom	0.553	1.529	8	(6.471)
Average	**0.825**	**1.474**	**8**	**(6.526)**

Centres one and four, which are naturally ventilated, had an average openable window to floor area of 14% against the required 5% as presented in Table 5-14. This included Centre four's sleep room. This is above the requirements under G4/AS1 1.5.1 a) by an average of 9%. All the rooms in these two centres except one classroom remained below the MoE: DQLS: IAQ and thermal comfort CO_2 concentration levels of operating average 1,200 ppm and 1,500 ppm and a maximum of 3,000 ppm. This classroom exceeded the maximum peak of 3,000 ppm during one morning over the monitoring period and reached a maximum level of 3,515 ppm. Centre one's classrooms exceeded the operating average of 1,200 ppm one fifth (15%) of the time. Room one, the older of the over two-year-old's rooms as per Figure 5-23, exceeded this level 31% of the time compared to Room two, the younger of the over two-year-old's rooms, that only exceeded the level 8% of the time. Both of these rooms are almost identical with a deep floor plan; however, Room one had a slightly deeper plan in relation to the playground door at a ratio of 1:3.6 versus 1:3.1 as seen in Figure 5-35. This indicates that the windows running down the length of the room are not being opened. It also indicates that the depth of the room from the playground door is further limiting its natural ventilation, with the ventilation not reaching the back of the room as effectively as it is in the other almost identical room.

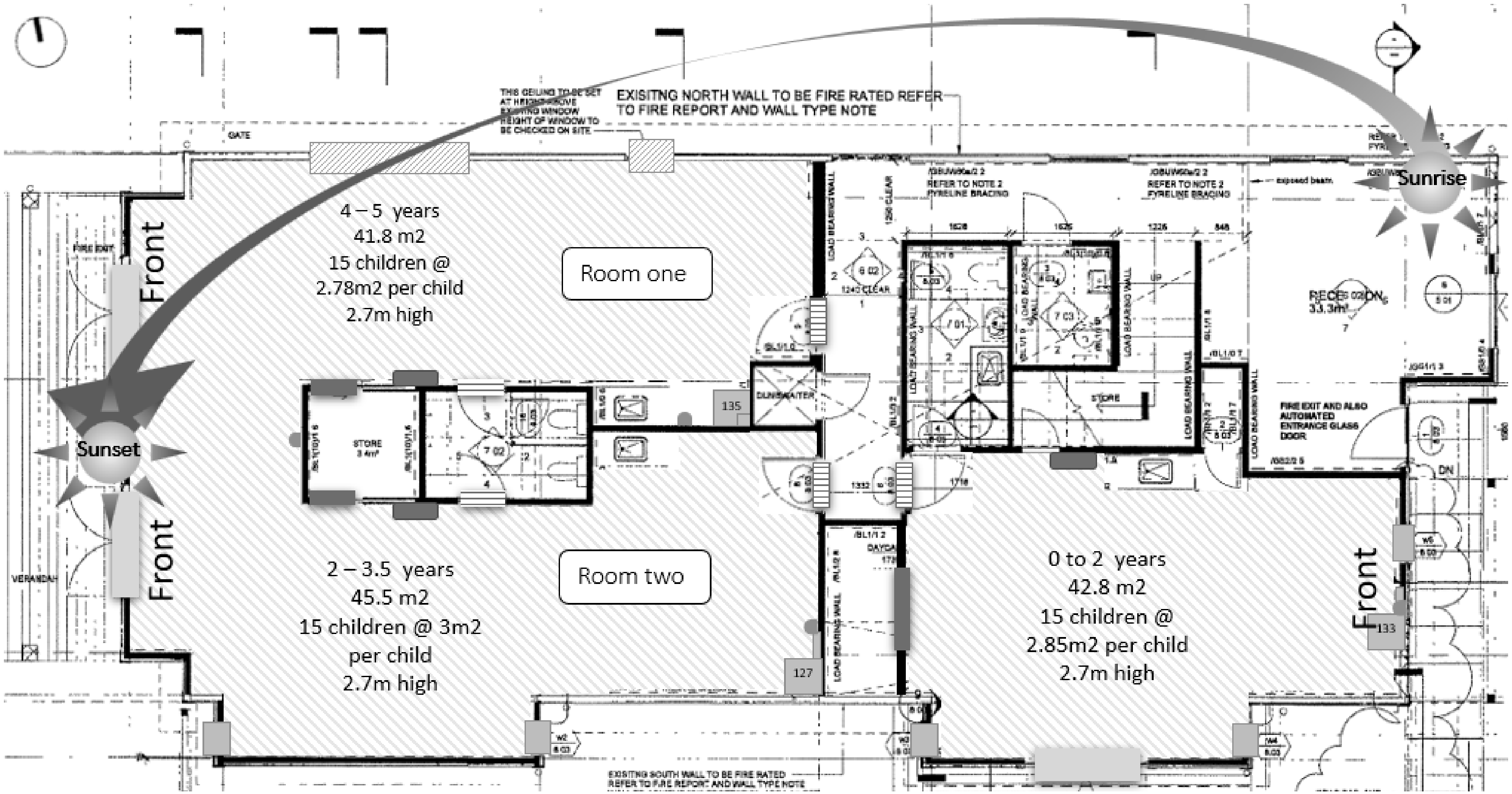


Figure 5-35 Plan of Centre one, including the placement of SKOMOBO monitors. Room one, the older of the over two-year-old's rooms, exceeding the operating average of 1,200 ppm 31% of the time compared to Room two, the younger of the over two-year-old's rooms, that only exceeded the level 8% of the time.

Centre four's classrooms remained below the operating average of 1,200 ppm 100% of the time. However, the sleep room in this centre exceeded this level 29% of the time, as seen in Figure 2-23. When this sleep room's operating times are only considered (between 10h00 and 15h00), the mean CO_2 concentration level was 1,230 ppm (SD = 376 ppm) with a maximum of 2,608 ppm. CO_2 concentration levels did, however, remain below 3,000 ppm, as presented in Table 5-16. There was a 50mm gap under the door between the sleep room and the classroom of which a third was blocked by the carpet. There are windows in this room though it was confirmed they were not opened and there was evidence of undisturbed dust and mould on the windows that supported this. Overnight the CO_2 concentration did drop to levels close to that of outdoor CO_2 concentrations with a minimum CO_2 concentration 389 ppm. This would indicate that the only ventilation in this room is through the building envelope. These results raise a concern if adequate ventilation is being provided in sleep rooms as required under G4 Ventilation.

Other observations include:

- During operating hours, the CO_2 concentration from Monday to Friday are mostly constant across both the classrooms and the sleep rooms as could be seen in Figure 5-20. This is aligned to a similar routine being kept on a daily basis.
- The mean daily CO_2 concentration across all centres over a twenty-four-hour period from Monday to Friday was 578 ppm. As can be seen in Figure 5-22, this falls to 428 ppm over the weekend, almost to the level of the outdoor CO_2 concentration level recorded at 410 ppm. This indicated that both the timber-framed and non-timber framed buildings have air leakage through the building envelope.
- As presented in Table 5-17, during Winter in the timber constructed naturally ventilated buildings there is a relatively strong positive correlation between CO_2 concentration levels and temperature, r (143,349) = 0.444, p = 0.001. This indicates that the doors and windows are more likely to be shut, and the heat pumps are turned on, resulting in poor ventilation. However, in the non-timber

mechanically ventilated buildings there is a weak negative correlation between CO_2 concentration levels and temperature, r (143,349) = -0.027, p = 0.001. This indicates the temperature on the mechanical systems has been increased, therefore increasing the air changes within the rooms. However, this would need to be validated against how the ventilation is configured. This correlation may also be stronger if the ventilation in Centre two is, in fact, not working correctly. In Summer there is a moderately strong negative correlation, r (224,517) = -0.357 in the timber-framed naturally ventilated buildings indicating that when the temperature goes up the doors and windows are being opened, improving the ventilation in the rooms.

IAQ studies in ECE centres have shown similar or worse results (Michelot et al., 2013; Satterlee et al., 2015) including a study in Holland that concluded more attention is required in the assessment of IEQ in centres especially in regards to the sleep rooms (de Waard & Zeiler, 2014). With other studies showing a negative correlation between ventilation rates and the number of sick days children take. For example, a 12% decrease in sick days per hour increase in air change rates measured with the decay method (Kolarik et al., 2016).

This study concludes that the MoE's school CO_2 monitoring requirements need to be widened to include ECE centres (MoE, 2017a). It also concludes that the ventilation standards required in sleep rooms need to be urgently reviewed and updated.

Dust

Dust observations across all the rooms, indicate children are being exposed to PM. These results have been found in other similar studies for example in 40 ECE centres in the USA (Gaspar et al., 2018).

Research has shown in a school and ECE environment PM_{10} can be driven by soil brought in on the under sole of shoes and while $PM_{2.5}$ can be driven by outdoor air pollutants, carpeted floor, soft toys, clothing fibre, shelf area and fan cleaning frequencies (J. Bennett et al., 2018; Gaspar et al., 2018; Trompetter et al., 2018; Zuraimi & Tham, 2008). The presence of dust could be driven by the children tracking dirt and sand in under their shoes which they are disturbing as they play indoors for the morning. In the evening the cleaners are coming into the centres and mostly vacuuming and cleaning kitchen areas. They could possibly not be using HEPA vacuum cleaners, or the machines are poorly maintained. With no direct ventilation on at night and possibly poor cleaning routines, the dust is not being extracted. These results could be exacerbated by the carpet and furnishing being the original carpets and furnishings that are between seven and fifteen years old, the extract vents not being cleaned therefore not working properly and in the mechanically ventilated buildings, the air being partly recirculated. The negative impact of older carpets, toys, poor cleaning routines and poorly maintained extract vents have also been reported in other similar research in NZ (J. Bennett et al., 2018; Trompetter et al., 2018) and in Singapore (Zuraimi & Tham, 2008).

As the results indicate above, more research in this area is needed to understand what is influencing and causing dust and therefore PM. The results also indicate that the ECE centre's cleaning routines are poor, and not all cleaners may be using HEPA vacuum cleaners or they may be using poorly maintained machines. The ventilation and extract maintenance routines are poor or not being completed. As concluded above, improved maintenance routines could be adopted, and IEQ assessments culd be included in ECE centre ERO reports.

Natural light

Only two of the nine classrooms met the Performance requirement of G7 Natural light. This code requires no less than 30 lux at floor level for 75% of the standard year for health and wellbeing. In addition to this, none of the classrooms achieved a daylight factor across the rooms of greater than 2% as set out in the MoE DQLS Spaces. The overall layout of the rooms was generally a deep plan, with an average ratio of 1:1.8. The short side contained the majority of the glazing, and the long side was generally unlit or had a few small windows. One centre had a ratio of 1:3.6 with only two narrow side- on windows within the long wall. A ratio greater than 1:0.8 can make a room difficult to sufficiently daylight if the side walls are not externally facing walls with adequate windows, which is evident in the results above.

All the classrooms but one, however, met G7/AS1 1.0.1 a) Natural light, Acceptable solution where windows are no less than 10% of floor area. The average window to floor area across all centres was 13%. More research is therefore needed in ECE centres to understand if the G7/AS1 1.0.1 a) Natural light, Acceptable solution being applied within ECE centres is meeting the G7.3.1 Natural light, Performance requirement.

The views to outside were calculated at an average across all classrooms of 8% glazing to wall area with an average of 50% of these views restricted in some way, e.g. the windows were covered in children's artwork, or the views of the outside were of the neighbouring fence. As there is no clear definition of views to outside, it is difficult to determine how well any of the centres complied with G7.2 Natural light, Functional requirement. When assessing the views to outside against this code requirement, it was therefore assumed a view to outside meant an unobstructed view of nature at a reasonable distance as suggested by the performance criteria which states, "Habitable spaces shall provide adequate openings for natural light and for visual awareness of the outside environment." (MBIE, 2014a, p. 3)

As the results indicate above, it could be concluded that ECE centres have not been designed to make the best use of natural light. Of the centres in this study, it would appear that all of them were designed to meet the G7/AS1 1.0.1 a) Natural light, Acceptable solution which has not met G7.3.1 Natural light Performance. A study in the Maryland, USA highlighted similar results in terms of how ECE centres were not making good use of natural light (Satterlee et al., 2015) or managing it well (Salleh, Salim, & Kamaruzzaman, 2016).

Artificial light

All the classrooms met G8.3 Artificial light. This code requires an artificial light level of no less than 20 lux at floor level to ensure a person can safely move around the room.

Interior and workplace lighting

Currently there is no specific ECE interior and workplace lighting building code, standard or guideline other than the special consideration for young observers in the NZ Standard AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series Section 3.2 (Standards NZ, 2008a, p. 8) and The Licensing criteria for centre-based education and care services 2008 (updated May 2016) statement in section PF12 (MoE, 2016, p. 14).

The artificial lighting levels measured at 0.5m and 0.8m were therefore assessed against AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3: Specific Educational and Training Facilities Series Appendix D (Standards NZ, 2008a). This standard recommends 320 lux (maintained) at 0.8m AFFL in classrooms used for reading. This standard is aligned with the MoE DQLS Spaces: Lighting guidelines that recommend 300 to 500 lux in classrooms (MoE & BRANZ, 2007).

Two of the six classrooms measured in Centres two to four met AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3 Appendix D with average lux levels across the room of 391 and 396 lux. The two classrooms in Centre three fell on average 20% below the recommended level with the classrooms in Centre four falling on average 50% below.

If it was to be assumed that a more appropriate working plane height for ECE children was 0.5m as set out in section 5.2.2, then again, the same two classrooms would meet the standard, and the remaining classrooms would fall further below the recommended standard. Similarly, if floor level was assumed for under two-year-olds, only one classroom would meet the requirements with the other classrooms falling on average 39% below the standard. If a lower lux level of 240 lux was assumed at 0.8m AFFL, then only one additional classroom would meet the standard. Similarly, if 240 lux AFFL was assumed and the working plane was set at floor level then again only one additional classroom would meet the standard.

AS/NZS 1680.1:2006 Interior and workplace lighting part 1: General principles and recommendations (Standards NZ, 2006) recommended flicker-free lamps. Non-visible flicker was possibly recorded across all four centres. Further investigation would need to be done to determine if this non-visible flicker was recorded using an oscilloscope.

Very little research has been done on lighting within ECE centres and the effect it has on children. Given these results, together with our understanding of the importance of light to developing eyes (Tufford et al., 2018) and how underdeveloped the eyes are in younger children (Point, 2018; Tomita et al., 1989) urgent research is needed and improved lighting standards should be introduced.

Sound

Currently, there is no specific ECE acoustic building code, standard or guideline other than the following statement in The Licensing criteria for centre-based education and care services 2008 (updated May 2016) statement in section HS24 (MoE, 2016):

*"All practicable steps are taken to ensure that noise levels do not unduly interfere with normal speech and/or communication, or cause any child attending distress or harm." (*MoE, 2016, p. 24*)*

The reverberation calculations were therefore assessed against AS/NZS 2107:2016 Acoustics Recommended design sound levels and reverberation times for building interiors (Standards NZ, 2016) for teaching/communication in a classroom. The calculated reverberation measurements were assessed against 0.5 s at 500 Hz and 1,000 Hz as per curve 3 of the reverberation table within the standard.

The classrooms of Centres two and three met the AS/NZS 2107:2016 Acoustics. Overall it was the acoustic ceiling tiles in Centres two and three that had the biggest impact in these centres achieving AS/NZS 2107:2016 Acoustics. Centre four had the highest percentage of acoustic wall covering at 20%, followed by Centre one. However, Centre one had 100% timber floors, and Centre four had a timber floor strip making up 63% of the floor covering running straight through the centre which was fully open plan. Both had plasterboard ceilings. As a result, both centres did not meet the standard according to the calculations. The under two-year old's rooms in Centres two and three had very little to no acoustic wall coverings yet were 50% to 79% carpeted respectively, and 100% of the ceilings were acoustic ceiling tiles. This resulted in both centres meeting the standard across all frequency levels according to the calculations.

The constant internal mechanical background noise observed in the centres was predominantly generated by the heat pumps in Centres one, three and four. In addition to the heat pumps in Centre four, the bathroom extraction fan was particularly noticeable. The Café (MacLean, 1959) and Lombard (J. Whitlock & Dodd, 2008) effects were observed while these units were on, and the centres were at capacity. This was confirmed with a noticeable drop in how loud occupants were talking once all these units were turned off and as children began to go home. These effects are even more critical to manage in an ECE centre with the Lombard Reflex estimated to be stronger in children at a Lombard Coefficient of at least 0.13 dB/dB compared to those of adults at 0.19 dB/dB (Sutherland et al., 2005; J. Whitlock & Dodd, 2008). Constant background noise has also been found to significantly activate the speech-processing network within the brain (Dos Santos Sequeira et al., 2010) and impact a child's ability to distinguish different syllables and consonants (Johnson et al., 1997).

The retrofitting of acoustic materials on ceiling, floors and walls can be easily undertaken. It is worth noting, however, that the testing of acoustics within a room can be costly; therefore, caution should be taken when considering if measures should be taken in order to comply with standards. Similar results and remedies were also found and recommended in studies completed in ECE centres here in NZ (McLaren, 2008) and in Brazil (Tahara Kemp et al., 2013). If an acoustic remedy is carpeting, careful consideration must be given to the impact on other IEQ elements within the room e.g. particulate matter accumulation with research showing that indoor PM levels can be two to five times the outdoor levels and a key contributor is carpet (J. Bennett et al., 2018; Zuraimi & Tham, 2008).

ECE building financing model

One final consideration is how the ECE building assets are financed and the potential implications for those who are unaware. Traditionally, ECE centres were often owned by the operator of the ECE business. However, this model has shifted over the last 30 years to one where a property developer often builds the building and leases it to an ECE operator on 15- to 20-year terms. When the building is complete, and the ECE operator has opened the centre, the property developer may keep the building and become a property investor or sell it to a property investor who is looking for a steady return over the life of the lengthy lease. The property developer and investor’s primary goal is to secure as high a lease as possible for the lowest build cost. The operator is typically looking for a reasonable lease cost for the best quality centre they can get. These contradictory goals can significantly impact the quality of the building and ongoing maintenance. Often one of the first things to be cut back during negotiations between the parties above is the glazing, as it is one of the most expensive materials in the building per metre squared hence the natural lighting is significantly impaired internally.

In this study, three out of the four centre lease their buildings. The most recently renovated building was six and a half years ago with the next most recently renovated building over nine years ago. All carpet and furnishing are the original carpet and furnishings from when the centres were last renovated or opened. Two of the four centres, however, did have their interior walls repainted during the course of the study.

5.7.Limitations

The limitations of this study can be summarised as the following:

- The relatively small ECE centre sample size (n = 4) and the number of rooms (n = 13) limited the statistical power of this study.
- This study assumes no stratification effect (Deng, Feng, & Cao, 2018) occurs within the breathable zone between the head height of the children and the position of the monitor.
- PM results were limited to dust observations due to the technical constraints of the PM sensor within the SKOMOBO monitors.
- It also assumed that the centres rely 100% on artificial lighting to meet interior and workplace lighting standards.
- The NIWA VCSN data provided are daily averages being compared to on average 20-sec interval measurements taken indoors. Also, correlations could not be run across the whole day as the data provided was not on an hourly basis hours. Therefore, the correlations seen may have been weaker or stronger if real-time outdoor data had been captured.
- A 1080-pixel high definition video recorder at 30 frames per second was used to possibly detect the occurrence of non-visible flicker. This is a very rudimentary test, which only indicates that more investigation is required. Further investigation that could be carried to validate if this was flicker is the use of an Oscilloscope.
- The reverberation calculator used assumes the calculations fairly reflect the conditions in the classroom; however, after consultations, there is agreement the results may be optimistic. The inputs are high level, and furniture positions are not accounted for. Nor are all the materials and building finishes within the room included in the calculation. The number of materials available for selection was limited, and only one other surface type could be added to the calculation.

The challenges faced during this study are presented in appendix 8.2.

5.8. Recommendations

To answer the third research question, ‘What is the IEQ in Auckland ECE centres and how does it compare with local regulations, standards and guidelines?’ the IEQ of four ECE centres in Auckland were measured with the results assessed against local regulations, standards and guidelines.

The IEQ measurement included IAQ, light and sound. Measuring IEQ is a critical step in understanding if local building code, standards and guidelines continue to be met once the construction of a building is complete and deciding on mitigating measures that could be taken to support under five-year-old children’s health.

This study included thirteen rooms across four centres. It was an intensive study that analysed IEQ as a whole and measured IAQ over a full year at an average of 20-second intervals. This study is the first of its kind in NZ ECE to do this. Previous studies have predominantly been school focused and based either on IAQ, light or sound.

The recommendations presented in Table 5-30 below focus on the issues highlighted through research question three relevant to the design and the daily operations of an ECE centre and the regulatory framework that support ECE IEQ.

Table 5-30 Study recommendations

Recommendations	Relevant to: Design	Operations	Regulatory
ECE IEQ must be considered as an integrated whole. That is light, ventilation, and thermal comfort must to be considered together with acoustics and PM. Particular points for consideration are the orientation of the building and the placement of windows and doors in terms of solar gain, views to outside, ventilation and natural light; how the ventilation and thermal comfort solutions integrate; the placement of acoustic materials and the use, durability and acoustics of different floor and wall materials.	√	√	√
MoE and the Ministry of Health provide advice and review ECE centre's building consent documentation before a centre is built.	√	√	√
Standards are updated to include ECE IEQ, or MoE guidance is provided in terms of a comfort zone; ventilation (particularly in the sleep rooms); night time RH control; natural light, interior lighting and views to outside appropriate at a younger child's working plane; reverberation times and a sound transmission index, specific standards and cleaning requirements.	√	√	√
Further research in ECE IEQ, in particular, sleep room ventilation and space standards, the implications of centre orientation for appropriate solar gain and views to outside, how RH level is kept below 65% at night time, natural light - does the acceptable solution meet building code. Interior lighting - what maintained lux level and working plane is appropriate for young children; is there flicker present in ECE centres and could flicker be affecting children. Sources and management of dust and what time of day is it propagating and sound, especially the implication of constant internal mechanical background noise on hearing.	√	√	√

Recommendations	Relevant to: Design	Operations	Regulatory
Expand the requirement of CO_2 concentration monitoring in schools to ECE centres and integrate IEQ assessments into the centre's ERO reviews.		√	√
Check the quality of daily cleaning routines by external cleaners and implement weekly, monthly and quarterly cleaning routines to include: Shelves, rugs, blankets, under moveable furniture, extract fans and grills, and heat pumps in addition to those items already specified by the MoE. Also, require the cleaners to use HEPA vacuum cleaners.		√	√
Further research into the NZBC, in particular assessing if: • the G7/AS1 Natural light, Acceptable solution is meeting the requirements set out in G7.3.1 Natural light, Performance. • The G4/AS1 Ventilation, Acceptable solution is providing adequate natural ventilation in sleep rooms as required under G4.2 Ventilation.			√
A building manual must be compiled by the architect who then passes it on to the owner of the building. This manual is then added as an appendix to the lease and reviewed and managed as part of the lease agreement with an annual maintenance program agreed to between tenant and building owner.	√	√	
Investigate the mechanical ventilation in Centre two and in the over two-year-old's sleep room in Centre three to understand if it is working correctly.		√	
The teachers are taught as part of their university training the importance of ECE IEQ and the impact it has on health and wellbeing as part of Te Whāriki, the national ECE curriculum.		√	

Recommendations	Relevant to: Design	Operations	Regulatory
The centre manager continually engages with the staff on how the building operates.		√	
To clear the air of the overnight and weekend RH and PM and minimise mould and bacterial growth within a building, purge the classrooms before closing at night or after they have been used and first thing in the morning, especially in the sleep rooms. To either maintain a minimum room temperature overnight or alternatively to dehumidify the rooms overnight. This would need to be balanced against the electrical cost of doing this.		√	
To minimise the sand and other PM being brought in to the building: - Take off shoes before entering the classroom - Have entry/exit mats placed at all entrances especially those from the playground - Place the sandpit as far away from the building as possible		√	

6. Study conclusion

As concluded in the review of literature, there is a research knowledge gap in NZ ECE IEQ, particularly in Auckland NZ. The objective of this thesis was to, therefore, begin to fill this research knowledge gap. It has done this by being the first to investigate NZ ECE IEQ, particularly in Auckland through the following three research questions:

1. What is the NZ education facilities environment, and is there an interest for IEQ research, particularly in ECE?
2. How can ECE centres be safely and sensitively monitored?
3. What is the IEQ in Auckland ECE centres and how does it compare with local regulations, standards and guidelines?

As seen in Figure 6-1 below, to answer these research questions the objective of:

- Research question one was to gather industry feedback regarding the local NZ education facilities environment from ECE to schools and see if there is was an interest for IEQ research, particularly in ECE.
- Research question two was to determine the scope and appropriate materials and methodology to measure the IEQ of an ECE centre safely and sensitively in NZ. The planning for the symposium began in June 2016 with the four case studies starting shortly after that.
- Research question three was to measure the IEQ within four urban ECE centres in Auckland over a year and to assess these results against current NZ building regulations and educational guidelines. Nine classrooms and four sleep rooms were monitored in total.

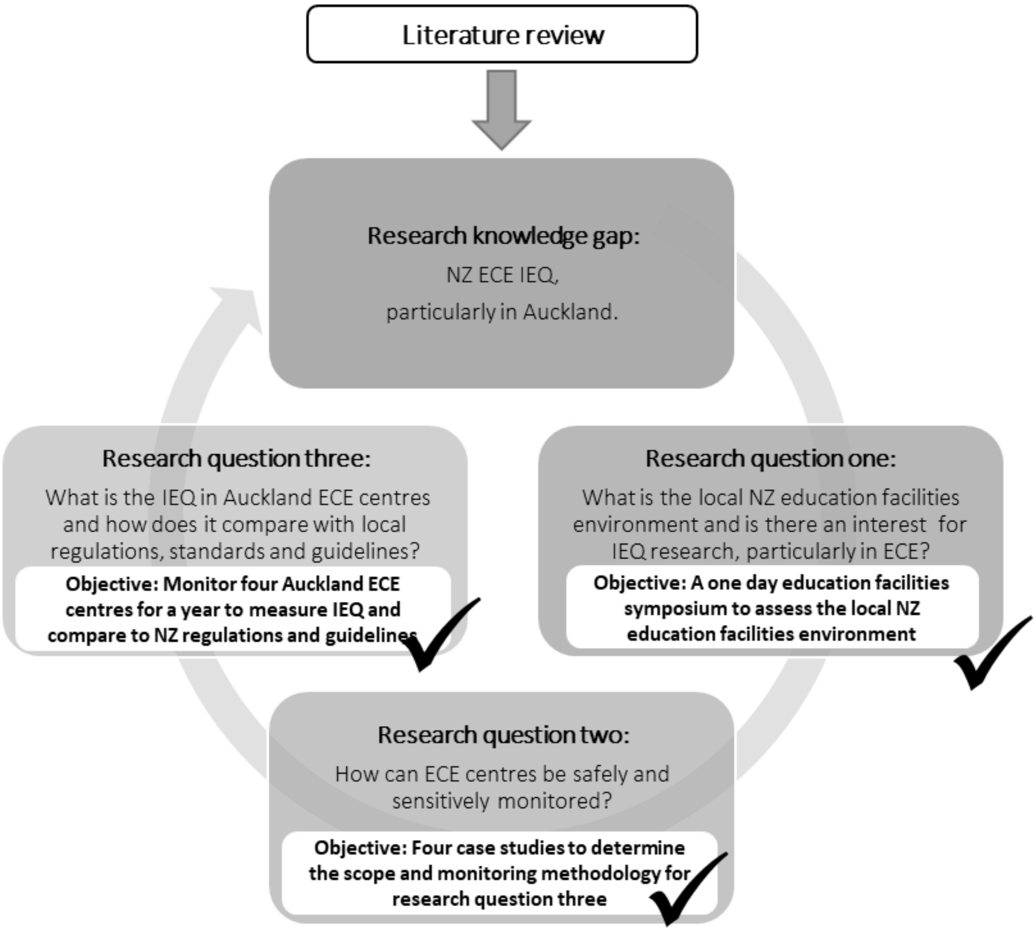


Figure 6-1 The study design to address the research knowledge gap identified in the literature review through three research questions and what was done to answer these research questions. With all three research questions addressed the research knowledge gap identified has begun to be filled.

This study provides a deeper insight into NZ ECE IEQ, particularly in Auckland, NZ. This study highlights the IEQ children under five-years-old are potentially being exposed to and how buildings are performing under the current NZBC, standards and guidelines.

The key results from the research questions to fill the research knowledge gap are:

- Overall there is a lack of indoor environment quality standards for early childhood education, especially when compared to the indoor environment quality standards set for school.
- That while in New Zealand there is an interest in early learning education indoor environment quality there continues to be little done.

- Centres can be safely and sensitively monitored in close consultation with the centre owners and centre managers.
- That monitored results showed that the mean carbon dioxide levels in the classrooms was 715 ppm (SD = 313 ppm) during operating hours, well within ASHRAE and Ministry of Education guidelines for schools. However, three of the four sleep rooms monitored were poorly ventilated and exceeded these guidelines. The results also showed that the mechanical ventilation in one of the centres did not appear to meet the New Zealand mechanical ventilation standard.
- That while the temperature results only fell below the minimum of 16°C, as required by New Zealand building code, for 1% of the time during operating hours, the results showed that they fell outside the thermal comfort range set in schools of between 18°C and 25°C, 14% of the time during operating hours.
- The maximum RH guideline of 65% as set by ASHRAE and recommended in New Zealand schools, was exceed 29% of the time during operating hours and was exceed 66% of the time outside operating hours therefore possibly providing the environment to support mould and bacteria growth.
- The building inspections showed that across most rooms there was evidence where cleaning and maintenance routines should be improved and entrance mats should be placed across all entrances to the building.
- The natural light calculations showed that only two of the nine classrooms met the performance requirement of New Zealand building code G7 Natural light. The results showed that five of the nine classroom had poor views to outside as also required under G7. They showed that none of the classrooms are achieving a daylight factor greater than 2% as set out in the Ministry of Education guidelines for schools. They also showed that while all of the classrooms met New Zealand building code G8.3 Artificial lighting requirements, only two of the six classrooms measured met AS/NZ 1680.2.3:2008 Interior and Workplace Lighting Part 2.3 Appendix D. Flicker-free lamps are recommended in NZS 1680.1:2006 however possible occurrence of non-visible flicker may have been observed in all classrooms.

- The sound calculation results also showed there may be potential reverberation issues in those classrooms with mostly hard floors and hard ceilings.

In conclusion, these results may be applicable to many NZ ECE centres and strongly indicates that:

- Further research is needed to investigate the ventilation requirements in sleep rooms, as well as the natural light, views to outside and interior lighting requirements within classrooms.
- There is a need for clearer indoor environment quality standards that relate to early childhood education centres and that these standards need to consider indoor environment quality as a whole.
- MoE and Ministry of Health provide advice and review the ECE centre's building consent documentation before a centre is built.
- An indoor environment quality assessment should be considered as part of a centre's Education Review Office assessment.
- The importance of indoor environment quality should be considered as part the curriculum for early learning teachers.

This study's findings and recommendations will be applicable to other similar studies. The measurement results and the methods followed in this study may be used as benchmarks for other studies.

Funding

This study had financial and industry consultation support from APL Window Solutions, Autex Industries, Hometech NZ and Winstone Wallboards NZ, particularly for the equipment deployed and used during this study. This research also had time in lieu support from Collingridge and Smith Architects (UK) Ltd.

Conflicts of interest

The author is a minority shareholder and an employee of Collingridge and Smith Architects (UK) Ltd and has experience in designing ECE centres. The author declares no potential conflicts of interest with respect to this research, authorship and/or publication of this thesis. The centres that participated in this study were not designed by the author or by Collingridge and Smith Architects (UK) Ltd.

7. References

Reference

Abramson, M. J., Koplin, J., Hoy, R., & Dharmage, S. C. (2015). Population-wide preventive interventions for reducing the burden of chronic respiratory disease. *International Journal of Tuberculosis and Lung Disease, 19*(9), 1007-1018. doi:10.5588/ijtld.15.0034

Ahn, K. (2014). The role of air pollutants in atopic dermatitis. *The Journal Of Allergy And Clinical Immunology, 134*(5), 993-999. doi:10.1016/j.jaci.2014.09.023

Al horr, Y., Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A., & Elsarrag, E. (2016). Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment, 5*(1), 1-11. doi:10.1016/j.ijsbe.2016.03.006

Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Elsarrag, E., & Mishra, S. (2017). Occupant productivity and indoor environment quality: A case of GSAS. *International Journal of Sustainable Built Environment, 6*(2), 476-490. doi:10.1016/j.ijsbe.2017.11.001

Alexander Turnbull Library. NZ Centennial Exhibition: A model kindergarten building 1937 to 1940.

Almeidaa, R. M. S. F., Barreiraa, E., & Moreira, P. (2017). Assessing the variability of the air change rate through tracer-gas measurements. *Energy Procedia,*, 32, 831-836.

Alvarez-Chavez, C. R., Flores-Bernal, J. L., Esquer-Peralta, J., Munguia-Vega, N. E., Corella-Madueno, M. A., Rascon-Careaga, A., . . . Velazquez-Contreras, L. E. (2016). Detection of allergen sources in the homes of sensitized children. *Environmental Health And Preventive Medicine, 21*(6), 531-538. doi:10.1007/s12199-016-0566-7

Anderson, J., Thundiyil, J., & Stolbach, A. (2012). Clearing the air: A review of the effects of particulate matter air pollution on human health. *Journal of Medical Toxicology, 8*(2), 166.

Anderson, R. (1974). Doris Nicholson Kindergarten Upper Hutt 1974. Retrieved from h6ps://www.archway.archives.govt.nz

Araújo-Martins, J., Carreiro Martins, P., Viegas, J., Aelenei, D., Cano, M. M., Teixeira, J. P., . . . Neuparth, N. (2014). Environment and health in children daycare centres (ENVIRH) - study rationale and protocol. *Revista Portuguesa De Pneumologia, 20*(6), 311-323. doi:10.1016/j.rppneu.2014.02.006

Arlian, L. G., Neal, J. S., Morgan, M. S., Vyszenski-Moher, D. L., Rapp, C. M., & Alexander, A. K. (2001). Reducing relative humidity is a practical way to control dust mites and their allergens in homes in temperate climates. *Journal of Allergy and Clinical Immunology, 107*(1), 99-104. doi:10.1067/mai.2001.112119

Ashdown, I., Bedocs, L., Carroll, W., De Boer, J., Dehoff, P., Donn, M., . . . Zonneveldt, L. (2006). CIE 171:2006 Test cases to assess the accuracy of lighting computer programs.

ASHRAE. (2009). ASHRAE Standard 160-2009, Criteria for Moisture - Control Design Analysis in Buildings In.

ASHRAE. (2016). ASHRAE Standard 62.1-2016, Ventilation for acceptable indoor air quality. In.

ASHRAE. (2017). ASHRAE Standard 55-2017, Thermal environmental conditions for human occupancy (ansi approved). In.

ASTM Standards. (2006). ASTM E741 – 00 (Reapproved 2006): Standard test method for determining air change in a single zone by means of a tracer-gas dilution. In.

Auckland Council. (2017). *Auckland Unitary Plan, chapter a introduction*. Retrieved from http://unitaryplan.aucklandcouncil.govt.nz/Images/Auckland%20Unitary%20Plan%20Operative/Chapter%20A%20Introduction/Chapter%20A%20Introduction.pdf

Auckland Council. (2018). Auckland Council District Plan, Operative Auckland City, Central Area Section 2005. Retrieved from https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/district-and-regional-plans/district-plans/

Auckland Regional Public Health Service. (2018a). Early childhood education centre assessments. Retrieved from http://www.arphs.health.nz/public-health-topics/early-childhood-education-centre-assessments/

Auckland Regional Public Health Service. (2018b). Early childhood education centres pre-licensing information. In.

Auckland Regional Public Health Service. (2018c). *Health safety guidelines for early childhood education centres*. Retrieved from http://www.arphs.health.nz/assets/Uploads/Resources/Healthy-environments/Health-Safety-Guidelines-for-ECEC-20181123-KB.pdf

Auckland Transport Agency. (2019). *One network road classification - functional classification*. Retrieved from https://www.nzta.govt.nz/assets/Road-Efficiency-Group/docs/functional-classification.pdf

Baliatsas, C., van Kamp, I., van Poll, R., & Yzermans, J. (2016). Health effects from low-frequency noise and infrasound in the general population: Is it time to listen? A systematic review of observational studies. *Science of the Total Environment,, 1(557-558)*, 163-169. doi:10.1016/j.scitotenv.2016.03.065

Barnes, J. A., & Allan, D. W. (1966). A statistical model of flicker noise. *Proceedings of the IEEE.* Retrieved 2 54

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The Lancet, 383*(9925), 1325-1332. doi:10.1016/s0140-6736(13)61613-x

Basner, M., Griefahn, B., & Berg, M. (2010). Aircraft noise effects on sleep: mechanisms, mitigation and research needs. *Noise Health, 12*(47), 95-109. doi:10.4103/1463-1741.63210

Bennett, J., Davy, P., Trompetter, B., Wang, Y., Pierse, N., Boulic, M., . . . Howden-Chapman, P. (2018). Sources of indoor air pollution at a New Zealand urban primary school; a case study. *Atmospheric Pollution Research, 10*(2), 435-444. doi:10.1016/j.apr.2018.09.006

Bennett, W. D., Zeman, K. L., & Jarabek, A. M. (2008). Nasal contribution to breathing and fine particle deposition in children versus adults. *Journal of Toxicology and Environmental Health, 71*(3). doi:10.1080/15287390701598200

Beutel, M. E., Jünger, C., Klein, E. M., Wild, P., Lackner, K., Blettner, M., . . . Münzel, T. (2016). Noise annoyance is associated with depression and anxiety in the general population- the contribution of aircraft noise. *PLoS One, 11*(5), e0155357-e0155357. doi:10.1371/journal.pone.0155357

Boulic, M. (2012). *The indoor environmental benefits from replacing unflued gas and portable electric heaters with higher capacity non-indoor polluting heaters : an interventional field study.* (Doctor of Philosophy (PhD.) Doctoral), Massey University. Retrieved from http://hdl.handle.net/10179/4082

Boyce, P. R. (2014). *Human factors in lighting* In

Boyce, P. R., & Barriball, E. (2010). Circadian rhythms and depression. *Australian Family Physician*, 39(35), 307-310.

Branco, P. T. B. S., Alvim-Ferraz, M. C. M., Martins, F. G., & Sousa, S. I. V. (2015). Children's exposure to indoor air in urban nurseries-part I: Carbon dioxide and comfort assessment. *Environmental Research, 140*, 1-9. doi:10.1016/j.envres.2015.03.007

Carreiro-Martins, P., Viegas, J., Papoila, A., Aelenei, D., Caires, I., Araújo-Martins, J., . . . Neuparth, N. (2014). Carbon dioxide concentration in daycare centres is related to wheezing in attending children. *European Journal of Pediatrics, 173*(8), 1041-1049. doi:10.1007/s00431-014-2288-4

Catalina, T., & Lordache, V. (2012). IEQ assessment on schools in the design stage. *Building and Environment, 49*(1), 129-140. doi:10.1016/j.buildenv.2011.09.014

Chappell, P. R., & National Institute of Water and Atmospheric Research. (2014). *The climate and weather of Auckland* (No. 1173-0382). Retrieved from https://www.niwa.co.nz/static/Auckland%20ClimateWEB.pdf

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. *Journal of the Acoustical Society of America*(25), 975-979.

Coates, S. J., Davis, M. D. P., & Andersen, L. K. (2019). Temperature and humidity affect the incidence of hand, foot, and mouth disease: a systematic review of the literature - a report from the International Society of Dermatology Climate Change Committee. *International Journal of Dermatology, 58*(4), 388-399. doi:10.1111/ijd.14188

Coaton, J. R., & Marsden, A. M. (2011). *Lamps and lighting*. In

Commission Internationale de l´Eclairage. (1996). CIE standard overcast sky and clear sky. In.

Comply with.com. (2018). New fire safety and building evacuation regulations. Retrieved from https://www.complywith.com/news-and-events/new-fire-safety-and-building-evacuation-regulations/

Creative Commons, & Unknown Author. (2018). Map of New Zealand. Retrieved from https://creativecommons.org/licenses/by/3.0/

Crossman, A. (2019). Understanding purposive sampling: An overview of the method and its applications. In.

CSG Network. (2019). RT60 acoustic reverb calculator. Retrieved from www.csgnetwork.com/acousticreverbdelaycalc.html

Daisey, J. M., Angell, W. J., & Apte, M. G. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air, 13*(1), 53-64. doi:10.1034/j.1600-0668.2003.00153.x

de Waard, M., & Zeiler, W. (2014). Assessment of the indoor environmental quality in a dutch daycare centre. *ASHRAE Transactions, 120*(2), 1-8.

Deng, H., Feng, Z., & Cao, S. (2018). Influence of air change rates on indoor CO 2 stratification in terms of Richardson number and vorticity. *Building and Environment, 129*, 74-84. doi:10.1016/j.buildenv.2017.12.009

G6 Airborne and impact sound 1st edition amendment 2, (2006).

G5 Interior environment, (2011).

Dong, B., Prakash, V., Fen, F., & O'Neill, Z. (2019). A review of smart building sensing system for better indoor environment control. doi:https://doi.org/10.1016/j.enbuild.2019.06.025

Dos Santos Sequeira, S., Specht, K., Moosmann, M., Westerhausen, R., & Hugdahl, K. (2010). The effects of background noise on dichotic listening to consonant-vowel syllables: An fMRI study. *Laterality (Hove. Print), 15*(6), 577. doi:10.1080/13576500903045082

Education Review Office. (2016). Return times for centre and home-based early childhood service reviews. Retrieved from https://www.ero.govt.nz/how-ero-reviews/ero-reviews-of-early-childhood-services-and-kohanga-reo/return-times-for-early-childhood-service-reviews/

Edwards, N. M., Myer, G. D., Kalkwarf, H. J., Woo, J. G., Khoury, P. R., Hewett, T. E., & Daniels, S. R. (2015). Outdoor Temperature, Precipitation, and Wind Speed Affect Physical Activity Levels in Children: A Longitudinal Cohort Study. *Journal of Physical Activity and Health, 12*(8), 1074-1081. doi:10.1123/jpah.2014-0125

Elliott, B. (1982). *The design manual for preschool buildings*. Retrieved from http://www.kindergartenhistory.org.nz/

Elliott, B. (1982). *Kindergarten building costs, a discussion paper 1982*. Retrieved from http://www.kindergartenhistory.org.nz/

Elliott, B. (1983). *New Zealand Free Kindergarten Union 1983 Annual Meeting, Report on building code*. Retrieved from http://www.kindergartenhistory.org.nz/

Elliott, B. (1985). *Letter to director-general of education re kindergarten building programme*. Retrieved from http://www.kindergartenhistory.org.nz/

Everest, F. A., & Pohlmann, K. C. (2015). *Master handbook of acoustics* In

Eze, I. C., Foraster, M., Schaffner, E., Vienneau, D., Heritier, H., Pieren, R., . . . Probst-Hensch, N. (2018). Transportation noise exposure, noise annoyance and respiratory health in adults: A repeated-measures study. *Environment International, 121*(Part 1), 741-750. doi:10.1016/j.envint.2018.10.006

Faculty of Life Sciences The University of Manchester. (2019). Measuring melanopic illuminance. Retrieved from www.ucasgroup.lab.manchester.ac.uk/research/measuringmelanopicilluminance/

Fire and Emergency NZ. (2017). Evacuation schemes. Retrieved from https://fireandemergency.nz/business-and-landlords/evacuation-schemes/

Fire and Emergency NZ. (2018). Evacuation scheme application reference guide. Retrieved

Fisk, W., Wargocki, P., & Zhang, X. (2019). Do indoor carbon dioxide levels directly affect perceived air quality, health or work performance? *ASHRAE Journal*(61(9)), 70-777.

Frontczak, M., & Wargocki, P. (2011). Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment, 46*(4), 922-937. doi:10.1016/j.buildenv.2010.10.021

Fuentes-Leonarte, V., Ballester, F., & Tenias, J. M. (2009). Sources of indoor air pollution and respiratory health in preschool children. *Journal of Environmental and Public Health, 2009*. doi:10.1155/2009/727516

Gaspar, F. W., Maddalena, R., Williams, J., Castorina, R., Wang, Z. M., Kumagai, K., . . . Bradman, A. (2018). Ultrafine, fine, and black carbon particle concentrations in California child-care facilities. *Indoor Air, 28*(1), 102.

Google Maps. (2018). Map of Auckland.

Goz, D., Studholme, K., Lappi, D. A., Rollag, M. D., Provencio, I., & Morin, L. P. (2008). Targeted destruction of photosensitive retinal ganglion cells with a saporin conjugate alters the effects of light on mouse circadian rhythms. *PLoS One, 3*(9), e3153. doi:10.1371/journal.pone.0003153

Guler, A. D., Ecker, J. L., Lall, G. S., Haq, S., Altimus, C. M., Liao, H. W., . . . Hattar, S. (2008). Melanopsin cells are the principal conduits for rod-cone input to non-image-forming vision. *Nature, 453*(7191), 102-105. doi:10.1038/nature06829

Haas, H. (1972). The influence of a single echo on the audibility of speech. *Journal of the Audio Engineering Society,*(20), 146–159.

Hales, S., Blakely, T., & Woodward, A. (2012). Air pollution and mortality in New Zealand: cohort study. *Journal of Epidemiology and Community Health, 66*(5), 468-473. doi:10.1136/jech.2010.112490

Halonen, J. I., Vahtera, J., Stansfeld, S., Yli-Tuomi, T., Salo, P., Pentti, J., . . . Lanki, T. (2012). Associations between night time traffic noise and sleep: The Finnish public sector study. *Environmental Health Perspectives, 120*(10), 1391-1396. doi:10.1289/ehp.1205026

Halperin, D. (2014). Environmental noise and sleep disturbances: A threat to health? *Sleep Sci, 7*(4), 209-212. doi:10.1016/j.slsci.2014.11.003

Ham, W. T., Mueller, H. A., & Sliney, D. (1976). Retinal sensitivity to damage from short wavelength light. . *Nature*(260(5547)), 153–155.

Hatori, M., Le, H., Vollmers, C., Keding, S. R., Tanaka, N., Buch, T., . . . Panda, S. (2008). Inducible ablation of melanopsin-expressing retinal ganglion cells reveals their central role in non-image forming visual responses. *PLoS One, 3*(6), e2451. doi:10.1371/journal.pone.0002451

Hattar, S., Liao, H. W., Takao, M., Berson, D. M., & Yau, K. W. (2002). Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. *Science, 295*(5557), 1065-1070. doi:10.1126/science.1069609

Henry, J. (1851). On the limit of perceptibility of a direct and reflected sound. *Sound and Science: Digital histories*, 295-296.

Hori, M., Soma, M., & Mizoguchi, T. (2005). Measurement of ventilation rate by concentration-decay method with law-environmental-loading tracer-gas.

Howden-Chapman, P., Pierse, N., Nicholls, S., Gillespie-Bennett, J., Viggers, H., Cunningham, M., . . . Crane, J. (2008). Effects of improved home heating on asthma in community-dwelling children: Randomised controlled trial. *BMJ: British Medical Journal, 337*(7674), 852. doi:10.1136/bmj.a1411

Huang, L., Mo, J., Sundell, J., Fan, Z., & Zhang, Y. (2013). Health risk assessment of inhalation exposure to formaldehyde and benzene in newly remodelled buildings, Beijing. *PLoS One, 8*(11), e79553. doi:10.1371/journal.pone.0079553

Hughes, S., Watson, T. S., Foster, R. G., Peirson, S. N., & Hankins, M. W. (2013). Nonuniform distribution and spectral tuning of photosensitive retinal ganglion cells of the mouse retina. *Current Biology, 23*(17), 1696-1701. doi:10.1016/j.cub.2013.07.010

Hwang, S. H., Seo, S., Yoo, Y., Kim, K. Y., Choung, J. T., & Park, W. M. (2017). Indoor air quality of daycare centres in Seoul, Korea. *Building & Environment, 124*, 186.

International WELL Building Institute. (2019a). WELL Standard - Circadian lighting design In.

International WELL Building Institute. (2019b). WELL Standard - Electric light glare control. In.

International WELL Building Institute. (2019c). WELL Standard - Low-glare workstation design. In.

International WELL Building Institute. (2019d). WELL Standard - Solar glare control In.

Irgens-Hansen, K., Gundersen, H., Sunde, E., Baste, V., Harris, A., Bratveit, M., & Moen, B. E. (2015). Noise exposure and cognitive performance: A study on personnel onboard Royal Norwegian Navy vessels. *Noise Health, 17*(78), 320-327. doi:10.4103/1463-1741.165057

Jambrosic, K., Horvat, M., & Domitrovic, H. (2008). *Reverberation time measuring methods*. Paper presented at the Acoustics 2008, Paris, France. http://webistem.com/acoustics2008/acoustics2008/cd1/data/articles/000306.pdf

Jemmett, C., & The NZ Ministry of Culture and Heritage. (2018, 24/7/2018). Crèches and early childcare. *New Zealand history online.* Retrieved from https://nzhistory.govt.nz/culture/creches-and-early-childcare

Johnson, C. E., Stein, R. L., Broadway, A., & Markwalter, T. S. (1997). "Minimal" High-frequency hearing loss and school-age children: Speech recognition in a classroom. *Language , speech and hearing in schools, 28(1)*, 77-85.

Jung, E. M., Kim, E. M., Kang, M., Goldizen, F., Gore, F., Drisse, M. N. B., & Ha, E. H. (2017). Children's Environmental Health Indicators for Low- and Middle-Income Countries in Asia. *Annals Of Global Health, 83*(3-4), 530-540. doi:10.1016/j.aogh.2017.10.013

Kabir, E., Kim, K. H., Sohn, J. R., Kweon, B. Y., & Shin, J. H. (2012). Indoor air quality assessment in childcare and medical facilities in Korea. *Environmental Monitoring & Assessment, 184*(10), 6395-6409. doi:10.1007/s10661-011-2428-5

Katafygiotou, M. C., & Serghides, D. K. (2014). Bioclimatic chart analysis in three climate zones in Cyprus. *Indoor and Built Environment, 24*(6), 746-760. doi:10.1177/1420326x14526909

Khayata, O. (2014). Fundamentals of HVAC - Space Air Diffusion. Retrieved from https://www.youtube.com/watch?v=zephL3PidMI

Kindergarten History. (2017). Kindergarten history kindergarten buildings grounds. Retrieved from http://www.kindergartenhistory.org.nz/buildings-and-grounds/

Kobav, M. B., & Colarič, M. (2018). Flicker experimental set up and visual perception of flicker.

Kolarik, B., Moller, E., Brauner, E. V., Andersen, Z. J., Ibfelt, T., & Engelund, E. H. (2016). Ventilation in daycare centres and sick leave among nursery children. *Indoor Air, 26*(2), 157-167.

Kostinen, K., Kotzias, D., Kephalopoulos, S., Schlitt, C., Carrer, P., Jantunen, M., . . . Seifert, B. (2008). The INDEX project: executive summary of a European Union project on indoor air pollutants. In.

Labayrade, R., Jensen, H. W., & Jensen, C. (2009). Validation of Velux Daylight Visualizer 2 against CIE 171: 2006 test cases. *Research Gate*.

LeGates, T. A., Altimus, C. M., Wang, H., Lee, H. K., Yang, S., Zhao, H., . . . Hattar, S. (2012). Aberrant light directly impairs mood and learning through melanopsin-expressing neurons. *Nature, 491*(7425), 594-598. doi:10.1038/nature11673

Lighting Research Centre. (2019). Spectral power distribution. Retrieved from https://www.lrc.rpi.edu/education/learning/terminology/spectralpowerdistribution.asp

Lin, Z., Norback, D., Wang, T., Zhang, X., Shi, J., Kan, H., & Zhao, Z. (2016). The first 2-year home environment in relation to the new-onset and remission of asthmatic and allergic symptoms in 4246 preschool children. *Science of the Total Environment, 553*, 204-210. doi:10.1016/j.scitotenv.2016.02.040

Lindegan, B. L. (1982). [Letter NZFKU to M.Wellington opposing proposal to 30 30 rolls].

Liu, C., Fuertes, E., Tiesler, C. M., Birk, M., Babisch, W., Bauer, C. P., . . . Heinrich, J. (2013). The association between road traffic noise exposure and blood pressure among children in Germany: the GINIplus and LISAplus studies. *Noise Health, 15*(64), 165-172. doi:10.4103/1463-1741.112364

Lombard, E. (2003). Le signe de l`élévation de la voix [T. Scelo, Trans.].

Lucas, R. J., Peirson, S. N., Berson, D. M., Brown, T. M., Cooper, H. M., Czeisler, C. A., . . . Brainard, G. C. (2014). Measuring and using light in the melanopsin age. *Trends in Neurosciences, 37*(1), 1-9. doi:10.1016/j.tins.2013.10.004

Luetz, A., Weiss, B., Penzel, T., Fietze, I., Glos, M., Wernecke, K. D., . . . Spies, C. (2016). Feasibility of noise reduction by a modification in ICU environment. *Physiological Measurement, 37*(7), 1041-1055. doi:10.1088/0967-3334/37/7/1041

Lum, S. B., Jenkins, P., & Shimer, D. (2013). Children's activity patterns and inhalation rates: determinants of exposure and dose. Retrieved from https://oehha.ca.gov/public info/public/kids/pdf/Activit1.pdf

Maamari, F., Fontoynont, M., Tsangrassoulis, A., Marty, C., Kopylov, E., & Sytnik, G. (2005). Reliable datasets for lighting programs validation—benchmark results. *Solar Energy, 79*(2), 213-215. doi:10.1016/j.solener.2004.12.003

MacLean, W. R. (1959). On the acoustics of cocktail parties. *Journal of the Acoustical Society of America*(31), 79-80.

Mattsson, M. O., Jung, T., & Proykova, A. (2012). *Scientific committee on emerging and newly identified health risks - Health effects of artificial light*.

Health and Safety in Employment Regulations 1995, (1995).

G7 Natural light, Acceptable solutions and verification methods, (2014a).

G8 Artificial light, Acceptable solutions and verification methods, (2014b).

MBIE. (2014c). *New Zealand building code handbook*.

MBIE. (2015). *Health and safety at work act 2015*.

MBIE. (2016a). Early childhood education centres. Retrieved from https://www.building.govt.nz/building-code-compliance/specific-buildings/early-childhood-education-centres/

G4 Ventilation 3rd edition amendment 4, (2016b).

MBIE. (2016c). New Zealand Regulatory Framework. Retrieved

McLaren, S. J. (2008). Noise in early childhood education centres - the effects on the children and their teachers.

Mendell, M. J. (2007). Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review. *Indoor Air, 17*(4), 259-277.

Michelot, N., Marchand, C., Ramalho, O., Delmas, V., & Carrega, M. (2013). Monitoring indoor air quality in French schools and daycare centres. *HVAC&R Research, 19*(8), 1083-1089. doi:10.1080/10789669.2013.812498

Miller, G. A. (1948). The perception of short bursts of noise. *Journal of the Acoustical Society of America,*(20), 160–170.

Milner, E. S., & Do, M. T. H. (2017). A population representation of absolute light intensity in the mammalian retina. *Cell, 171*(4), 865-876 e816. doi:10.1016/j.cell.2017.09.005

Milosavljevic, N., Cehajic-Kapetanovic, J., Procyk, C. A., & Lucas, R. J. (2016). Chemogenetic activation of melanopsin retinal ganglion cells induces signatures of arousal and/or anxiety in mice. *Current Biology, 26*(17), 2358-2363. doi:10.1016/j.cub.2016.06.057

Ministry for Culture and Heritage. (2015). Plans for home of compassion rèche. Retrieved from https://nzhistory.govt.nz/media/photo/plans-home-compassion-creche

Ministry for Culture and Heritage. (2017). Home of Compassion Crèche. Retrieved from https://mch.govt.nz/pukeahu/park/significant-sites/home-compassion-creche

Ministry for Primary Industries. (2014). *Food Act 2014*. Retrieved from http://www.legislation.govt.nz/act/public/2014/0032/latest/DLM2995811.html

Ministry for Primary Industries. (2019). New Zealand food safety, early childhood educators and kōhanga reo. Retrieved from https://www.mpi.govt.nz/food-safety/food-act-2014/national-programmes/early-childhood-educators-and-kohanga-reo/

Ministry for the Environment. (1991a). *Resource Management Act 1991*.

Resource Management Act 1991, (1991b).

Ministry for the Environment. (2018). About the resource management act 1991. Retrieved from http://www.mfe.govt.nz/rma/about-rma

Health Act, 1956, (1956).

Ministry of Health. (2016). *Annual Update of Key Results 2015/16: New Zealand Health Survey*. Wellington.

Ministry of Internal Affairs. (2017). *Fire and Emergency New Zealand Act 2017*.

Ministry of Primary Industries. (2017). National Programme 2 Guidance v3. In.

MoE. (2014). *Vulnerable children act 2014*. Retrieved from http://education.govt.nz/

MoE. (2016). *Licensing criteria for early learning education and care services 2008 and early learning education curriculum framework as amended May 2016*.

MoE. (2017a). *Designing quality learning spaces: Indoor air quality and thermal comfort*.

MoE. (2017b). *The national picture: What does the ECE census 2017 tell us about ECE services?*

MoE. (2017c). *The national picture: What does the ECE census 2017 tell us about ECE teaching staff?*

MoE. (2017d). *The national picture: What does the ECE census 2017 tell us about enrolments/attendances?*

MoE. (2017e). The regulatory framework of early learning education. Retrieved from https://www.education.govt.nz/early-childhood/licensing-and-regulations/the-regulatory-framework-for-ece/

MoE. (2017f). *Te Whariki early childhood curriculum*.

MoE. (2017g). Understanding the different early learning service types. Retrieved

MoE. (2019). The role of the Ministry of Education in early learning education in New Zealand. Retrieved

MoE, & BRANZ. (2007). *Designing quality learning spaces: Lighting*.

MoE, BRANZ, Acoustic Society of NZ, & Victoria University of Wellington. (2016). *Designing quality learning spaces: Acoustics*.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group (2009). (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement.

Moudon, A. V. (2009). Real noise from the urban environment: how ambient community noise affects health and what can be done about it. *Am J Prev Med, 37*(2), 167-171. doi:10.1016/j.amepre.2009.03.019

Mrosovsky, N., & Hattar, S. (2009). Impaired masking responses to light in melanopsin-knockout mice. *Chronobiology International, 20*(6), 989-999. doi:10.1081/cbi-120026043

Myatt, T. A., Kaufman, M. H., Allen, J. G., MacIntosh, D. L., Fabian, M. P., & McDevitt, J. J. (2010). Modelling the airborne survival of influenza virus in a residential setting: the impacts of home humidification. *Environ Health, 9*, 55. doi:10.1186/1476-069X-9-55

Natalie Marshall. (2015). *Berhampore Kindergarten conservation plan 2015*. Retrieved from http://www.kindergartenhistory.org.nz/media/1027/berhampore-kindergarten-conservation-plan-2015-wrfka.pdf

National Institute of Water and Atmospheric Research. (2016). Virtual Climate Station data and products.

New World Encyclopaedia. (2019). Auckland, New Zealand. Retrieved from http://www.newworldencyclopedia.org/entry/Auckland,_New_Zealand#Geography

Newman, R. S. (2005). The Cocktail Party Effect in Infants Revisited: Listening to One's Name in Noise. *Developmental Psychology, 41*(2), 352-362.

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings, 34*(6), 563-572.

Nowozin, C., Wahnschaffe, A., Rodenbeck, A., de Zeeuw, J., Hadel, S., Kozakov, R., . . . Kunz, D. (2017). Applying melanopic lux to measure biological light effects on melatonin suppression and subjective sleepiness. *Current Alzheimer Research, 14*(10), 1042-1052. doi:10.2174/1567205014666170523094526

NZ Free Kindergarten Union. (1972). *Building report 1972*. Retrieved from http://www.kindergartenhistory.org.nz/

NZ History Online. (2019). Women's national reserve residential nursery in 1950s. Retrieved from https://nzhistory.govt.nz/media/photo/womens-national-reserve-residential-nursery

NZ Kindergartens inc. (2017). Kindergarten history kindergarten notable kindergartens. Retrieved

NZ Parliament. (2008). *Education (Early childhood services) Regulations 2008*.

NZ Parliament. (2018). *Education Act 1989*.

Oberdörster, M., & Tiesler, G. (2008). "Modern Teaching" Needs Modern Conditions – Communication Behaviour of Pupils and Teachers in Highly Absorbent Classrooms. *Building Acoustics, 15*(4), 315-324.

Oliveira, M., Slezakova, K., Delerue-Matos, C., Pereira, M., & Morais, S. (2017). Indoor air quality in preschools (3- to 5-year-old children) in the Northeast of Portugal during spring-summer season: pollutants and comfort parameters. *Journal of Toxicology & Environmental Health: Part A, 80*(13-15), 740-755. doi:10.1080/15287394.2017.1286932

Page, W. (2019). *Paper 218.761 - Design and management of healthy buildings: Noise and vibration*.

Palumaa, T., Gilhooley, M. J., Jagannath, A., Hankins, M. W., Hughes, S., & Peirson, S. N. (2018). Melanopsin photoreceptors physiology and potential. *Current Opinion in Physiology, 5*, 68-74. doi:10.1016/j.cophys.2018.08.001

Park, J., Chung, S., Lee, J., Sung, J. H., Cho, S. W., & Sim, C. S. (2017). Noise sensitivity, rather than noise level, predicts the non-auditory effects of noise in community samples: a population-based survey. *BMC Public Health, 17*(1), 315. doi:10.1186/s12889-017-4244-5

Phipatanakul, W., Koutrakis, P., Coull, B. A., Kang, C., Wolfson, J. M., Ferguson, S. T., . . . Gold, D. R. (2017). The school inner-city asthma intervention study: Design, rationale, methods, and lessons learned. *Contemporary Clinical Trials, 60*, 14-23. doi:10.1016/j.cct.2017.06.008

Pierce, A. D. (2019). *Acoustics, An Introduction to Its Physical Principles and Applications* (3rd ed.). New Yor, NY: Springer International Publishing.

Pilorz, V., Tam, S. K., Hughes, S., Pothecary, C. A., Jagannath, A., Hankins, M. W., . . . Peirson, S. N. (2016). Melanopsin regulates both sleep-promoting and arousal-promoting responses to light. *PLoS Biol, 14*(6), e1002482. doi:10.1371/journal.pbio.1002482

Plagmann, M. (2016). New home, old habits. *Building Research Association of New Zealand, 156,* 47-49.

Point, S. (2018). Blue light hazard: are exposure limit values protective enough for newborn infants? *Radioprotection, 53*(3), 219-224. doi:10.1051/radiopro/2018025

Pollock, K. (2012). Early childhood education and care - New developments, 1970s to 2000s.

Prussin II, A. J., Schwake, D. O., Lin, K., Gallagher, D. L., Buttling, L., & Marr, L. C. (2018). Survival of the enveloped virus Phi6 in droplets as a function of relative humidity, absolute humidity, and temperature. *Applied and Environmental Microbiology, 84*(12).

Ramalho, O., Mandin, C., Riberon, J., & Wyart, G. (2013). Air stuffiness and air exchange rate in french schools and day-care centres. *International Journal of Ventilation, 12*(2), 175-180.

Roberts, C., Tingay, J., & Cirrus Research. (2011). What are A, C & Z Frequency Weightings. Retrieved from https://www.cirrusresearch.co.uk/blog/2011/08/what-are-a-c-z-frequency-weightings/

Salleh, N. M., Salim, N. A. A., & Kamaruzzaman, S. N. B. (2016). Occupant expectations on the main IEQ factors at workspace: The studies of private preschool buildings. *MATEC Web of Conferences, Vol 66, p 00120 (2016), 66*, 00120. doi:10.1051/matecconf/20166600120

Salleh, N. M., Salim, N. A. A., Kamaruzzaman, S. N. B., Mahyuddin, N., & Darus, F. M. (2016). The prevalence of SBS and absenteeism among children in urban refurbished private preschools. *MATEC Web of Conferences, 66*, 00119. doi:10.1051/matecconf/20166600119

Satterlee, D. J., Molavi, J. M., & Williams, M. E. (2015). An evaluation of early education based on physical environmental guidelines. *SAGE Open, Vol 5, Iss 2 (2015)*(2). doi:10.1177/2158244015586810

Scientific Committee on Health, E. a. E. R. (2018). *Opinion on Potential risks to human health of Light Emitting Diodes (LEDs)*. Retrieved from https://ec.europa.eu/health/sites/health/files/scientific_committees/scheer/docs/scheer_o_011.pdf

Semo, M., Gias, C., Ahmado, A., Sugano, E., Allen, A. E., Lawrence, J. M., . . . Vugler, A. A. (2010). Dissecting a role for melanopsin in behavioural light aversion reveals a response independent of conventional photoreception. *PLoS One, 5*(11), e15009. doi:10.1371/journal.pone.0015009

Sheposh, R. (2018). Noise. In: Salem Press.

Sherman, M. H. (1990). Tracer-Gas Techniques For Measuring Ventilation in a Single Zone.

Smolander, J. (2002). Effect of cold exposure on older humans. *International JOurnal of Sports Medician*, 86-92.

Spitschan, M., Jain, S., Brainard, D. H., & Aguirre, G. K. (2014). Opponent melanopsin and S-cone signals in the human pupillary light response. *Proceedings of the National Academy of Sciences of the United States of America, 111*(43), 15568-15572. doi:10.1073/pnas.1400942111

Standards NZ.). Standards New Zealand, About us. Retrieved from https://www.standards.govt.nz/about-us/

Standards NZ. (1984). NZS 6703:1984 Code of practice for interior lighting design. In.

Standards NZ. (1990). NZS 4303:1990 Ventilation for acceptable indoor air quality. In.

Standards NZ. (2001). *NZS 4121:2001 Design for access and mobility - buildings and associated facilities*.

Standards NZ. (2002). AS/NZS 2460:2002 Acoustics - Measurement of the reverberation time in rooms. In.

Standards NZ. (2005). AS/NZS 1269.1:2005 Australian/New Zealand Standard - Occupational noise management Part 1: Measurement and assessment of noise immission and exposure. In.

Standards NZ. (2006). AS/NZS 1680.1:2006 Australian/New Zealand Standard - Interior and workplace lighting Part 1: General principles and recommendations. In.

Standards NZ. (2008a). AS/NZS 1680.2.3:2008 Australian/New Zealand Standard - Interior and workplace lighting Part 2.3: Specific applications - Educational and training facilities. In.

Standards NZ. (2008b). NZS 6802: 2008 Acoustics: Environmental noise. In.

Standards NZ. (2016). AS/NZS 2107:2016 Acoustics - Recommended design sound levels and reverberation times for building interiors. In.

Stats NZ. (2013). *NZ Social Indicators, Suicide*.

Stats NZ. (2017). New Zealand and Auckland's resident population. Retrieved from http://archive.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=13170&tabname

Staveley, J. (2016). *Natural Ventilation; Durability of hardware and Safety of doors and windows; In Early Childhood Centres and Preschools.*

Stewart, D. W., Shamdasani, P. M., & Rook, D. W. (2007). *Focus Groups: Theory and Practice* (3rd ed.): Sage.

Sutherland, L., Lubman, D., & Pearsons, K. (2005). *Acoustical challenges to communication in group work classrooms*. Paper presented at the Meeting of the Acoustical Society of America, San Diego, CA.

Szalma, J. L., & Hancock, P. A. (2011). Supplemental material for noise effects on human performance: A meta-analytic synthesis. *Psychological Bulletin*. doi:10.1037/a0023987.supp

Tahara Kemp, A. A., Delecrode, C. R., Guida, H. L., Ribeiro, A. K., & Vieira Cardoso, A. C. (2013). Sound pressure level in a municipal preschool. *International Archives of Otorhinolaryngology, 17*(2), 196-201. doi:10.7162/S1809-97772013000200013

Tam, S. K., Hasan, S., Hughes, S., Hankins, M. W., Foster, R. G., Bannerman, D. M., & Peirson, S. N. (2016). Modulation of recognition memory performance by light requires both melanopsin and classical photoreceptors. *Proceedings. Biological Sciences, 283*(1845). doi:10.1098/rspb.2016.2275

Taptiklis, P., Phipps, R., & Plagmann, M. (2017). *BRANZ indoor air quality in New Zealand homes and schools*.

Te Ara NZ.). Logan Campbell Kindergarten, Auckland. Retrieved from http://www.teara.govt.nz/en/1966/campbell--sir--john--logan

Telfar Barnard, L., & Zhang, J. (2018). The impact of respiratory disease in New Zealand: 2018 update.

The McGuinness Institute, a. p. o. P. T. (2016). *Working paper 2016/03: History of education in New Zealand*. Retrieved from http://www.mcguinnessinstitute.org/working-papers/

The National Aeronautics and Space Administration. (2007). Summary of the electromagnetic spectrum properties across a range of frequencies and wavelengths. In E. Spectrum3-new.jpg (Ed.).

Thomson Higher Education, U. o. W. (2019). *Chapter 11: Sound Pitch*.

Thorne, R. (2007). Assessing intrusive noise and low amplitude sound. *Institute of Food, Nutrition and Human Health, Degree of Doctor of Philosophy in Health Science*.

Tiesler, G., & Oberdörster, M. (2008). Noise - A stressor? Acoustic ergonomics of schools.

Tomita, Y., Shichida, K., Takeshita, K., & Takashima, S. (1989). Maturation of blink reflex in children. *Brain and Development, 11*(6), 389-393. doi:10.1016/s0387-7604(89)80022-1

Trompetter, W. J., Boulic, M., Ancelet, T., Garcia-Ramirez, J. C., Davy, P. K., Wang, Y., & Phipps, R. (2018). The effect of ventilation on air particulate matter in school classrooms. *Journal of Building Engineering, 18*, 164-171. doi:10.1016/j.jobe.2018.03.009

Tufford, A. R., Onyak, J. R., Sondereker, K. B., Lucas, J. A., Earley, A. M., Mattar, P., . . . Cayouette, M. (2018). Melanopsin retinal ganglion cells regulate cone photoreceptor lamination in the mouse retina. *Cell Rep, 23*(8), 2416-2428. doi:10.1016/j.celrep.2018.04.086

U.S. Department of Commerce. (2019). Trends in atmospheric carbon dioxide.

United States Environmental Protection Agency. (2017a). *Clean air act title IV - noise pollution: Overview of the clean air act and air pollution*. Retrieved from https://www.epa.gov/clean-air-act-overview/clean-air-act-title-iv-noise-pollution

United States Environmental Protection Agency. (2017b). Mould Course Chapter 2, Why and where mould grows. Retrieved from https://www.epa.gov/mold/mold-course-chapter-2

Velux. (2019a). Daylight Visualizer 2. Retrieved from https://www.velux.com/article/2016/daylight-visualizer

Velux. (2019b). User guide - Daylight Visualizer 2. Retrieved from http://viz.velux.com

Viegas, J. C., Nogueira, S., Aelenei, D., Cruz, H., Cano, M., & Neuparth, N. (2015). Numerical evaluation of ventilation performance in children daycare centres. *Building Simulation, 8*(2), 189-209.

Vogels, I., Sekulovski, D., & Perz, M. (2011). Visible artefacts of LEDs. *27th Session of the CIE, Sun City, South Africa, 9-16 July 2011. CIE, 2011.*

von Ehrenstein, O. S., Heck, J. E., Park, A. S., Cockburn, M., Escobedo, L., & Ritz, B. (2016). In utero and early-life exposure to ambient air toxics and childhood brain tumors: A population-based case-control study in California, USA. *Environmental Health Perspectives, 124*(7), 1093-1099. doi:10.1289/ehp.1408582

Wang, Y., Boulic, M., Phipps, R., Chitty, C., Moses, A., Weyers, R., . . . The Healthy School Research Team. (2017). Integrating open-source technologies to build a school indoor air quality monitoring box (SKOMOBO). doi:10.1109/APWConCSE.2017.00046

Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, P. O., Gyntelberg, F., . . . Wouters, P. (2002). Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN). *Indoor Air, 12*(2), 113-128. doi:10.1034/j.1600-0668.2002.01145.x

Wargocki, P., Wyon, D. P., Baik, Y. K., Clausen, G., & Fanger, P. O. (1999). Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads. *Indoor Air, 9*(3), 165-179.

Warthen, D. M., Wiltgen, B. J., & Provencio, I. (2011). Light enhances learned fear. *Proc Natl Acad Sci U S A, 108*(33), 13788-13793. doi:10.1073/pnas.1103214108

Whitlock, J. (2001). An investigation into the sensitivity of intelligibility of "reversed segmented speech" to acoustical conditions.

Whitlock, J., & Dodd, G. (2008). Speech intelligibility in classrooms specific acoustical needs for primary school children.

Wilkins, A., & Lehman, B. (2010). A review of the literature on light flicker: Ergonomics, biological attributes, potential 3 health effects, and methods in which some led lighting may introduce flicker.

Woeldersa, T., Leenheersa, T., Gordijna, M. C. M., Huta, R. A., Beersmaa, D. G. M., & Wamsa, E. J. (2018). Melanopsin- and L-cone–induced pupil constriction is inhibited by S- and M-cones in humans. *Proc Natl Acad Sci U S A, 115*(9), E2147. doi:10.1073/pnas.1801001115

Work Safe. (2019). Health and safety at work. Retrieved from https://www.employment.govt.nz/workplace-policies/health-and-safety-at-work/

World Health Organisation Geneva. (1999). *Guidelines for community noise*. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0009/383922/noise-guidelines-exec-sum-eng.pdf?ua=1

World Health Organisation International Agency for Research on Cancer. (2006). *Exposure to artificial UV radiation and skin cancer* (No. 92 832 2441 8).

WHO guidelines for indoor air quality: selected pollutants. World Health Organization, (2010).

World Health Organisation Regional Office for Europe. (2018). Environmental noise guidelines for the European region.

World Health Organisation Regional Office for Europe. (2019). Data and statistics. Retrieved from http://www.euro.who.int/en/health-topics/environment-and-health/noise/data-and-statistics

World Health Organisation Regional Office for South-East Asia. (2019). Environmental health. Retrieved from http://www.searo.who.int/topics/environmental_health/en/

Zuraimi, M. S., & Tham, K. W. (2008). Indoor air quality and its determinants in tropical childcare centres. *Atmospheric Environment, 42*(9), 2225-2239. doi:10.1016/j.atmosenv.2007.11.041

8. Appendices

8.1. Appendix A: A one-day education facilities symposium

8.1.1. Methodology

The participants were recruited using purposive sampling. Using this method six participating groups were defined to ensure the attendees were a reasonable representation of industry leaders involved either in the day to day administration of education facilities or in the design and build of education facilities. As per Figure 8-1 below, they were:

1. Academia
2. Architects
3. Consultants (e.g. engineers, planners, building surveyors)
4. Early Learning
5. MoE
6. Schools

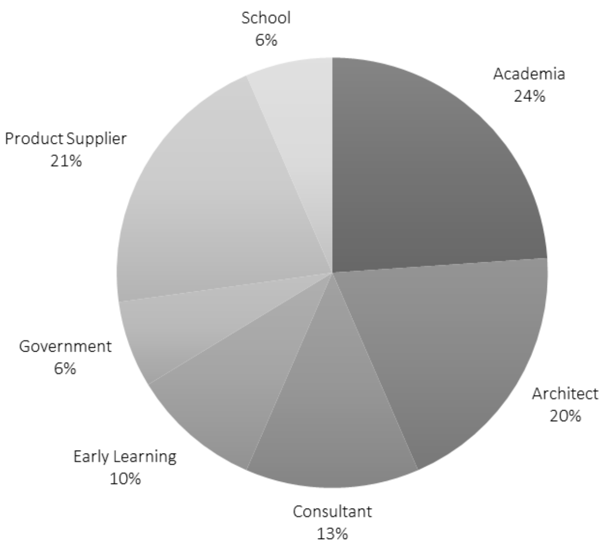


Figure 8-1 The percentage representation of the six participating groups that attended the symposium

The agenda began with a welcome from Professor Robyn Phipps followed by a Mihi from Professor Chris Cunningham, Director of Massey University's Te Pumanawa Hauora Māori Health Research Centre, Figure 8-2. Three keynote speakers were then invited to explore factors influencing children's education and wellbeing. This was designed to set the scene as to why we were all there. The speakers were:

- Craig Cliff, Senior Policy Manager at MoE
- Chris Theobald, Principal of Holy Family School, Porirua East Wellington
- Wendy Nelson, Auckland Educator at Brainwave Trust Aotearoa

Figure 8-2 Opening Mihi at the Education Facilities Symposium from Professor Chris Cunningham, Director of Massey University's Te Pumanawa Hauora Māori Health Research Centre and Massey University staff

This was followed by three roundtable focus group discussions and a panel interview. In the roundtable focus group discussions, open-ended questions were used with supporting questions to give context to the primary questions. These were drafted by the symposium committee and tested with a small group of participants prior to the event. The questions were distributed to the participants prior to the symposium in order to give the participants time to consider the questions. The questions were:

- **What opportunities are there for education facilities?**

  What research do you know of that addresses child development or wellbeing in education facilities? Whom do you know with expertise of child development or wellbeing in education facilities? What organisations advocate for child development or wellbeing *in education facilities? What other opportunities are you aware of regarding education facilities?*

- What is the worst-case scenario?

  What if we do nothing and continue designing education facilities the way we do today? What big risks do you see if nothing changes? What building products, materials or systems are being used that are continually failing? What are the challenges in building or managing an educational facility? What development or wellbeing issues are you seeing in children possibly related to poor education facilities?

- What would education facilities be like if there were an unlimited budget and no regulation?

  What are some great examples of local or overseas schools and childcare facilities? What building products, materials or systems are being used that work well and not so well? What building products, materials or systems have you seen successfully adapted or innovated beyond their original purpose?

- What educational and ECE models are being used?

  What educational and early learning models are most commonly being used (traditional desks and whiteboard, integrated learning, Reggio)? What kind of models do you see in the future, and why? Do you think it's important for educational facilities to reflect the educational and early learning models being used?

- What challenges does a school or ECE centre face?

  What are the day to day non-education facility issues that a school or childcare faces, e.g. sickness, staffing etc.? What are the day to day education facility issues being faced when managing a school or childcare? What are the issues being faced when building or renovating a school or childcare facility?

- What are the top priorities?

  Reflecting on your table's discussions today -What are the top five non-education facilities' priorities for a school or childcare? What are the top five education facilities' issues that need to be addressed if education facilities are to be improved? What are the top five priorities when building a school or childcare? Where do you think more research into education facilities is needed, and why?

The symposium committee designed a seating plan prior to the event. The seating plan divided the participants across ten tables with at least one representative from each participating group present at each table. For details of the seating plan, please see the appendix.

On the day, each table was hosted by a facilitator. The facilitator posed each question, along with the support questions, to the participants who then had five minutes to contemplate their answers. After these five minutes, the facilitator opened the table for discussion and documented their responses on pre-numbered flipchart paper. Additional paper was available if required and numbered accordingly. All facilitators were either Massey University lecturers or Massey research students and included the researcher. All facilitators were briefed prior to the symposium regarding the questions and the process of capture for the participants' responses.

The panel discussion was designed into the agenda to share other industry leaders' views, to allow the participants an opportunity to ask questions and break up the roundtable focus group discussions. The panel included:

- Prof. Robyn Phipps -Panel Facilitator, Professor in Construction at Massey University
- Les Clapcott, Flexible Learning Spaces advisor at MoE
- Phil Smith, Director of Collingridge and Smith Architects (UK)
- Dr Darius Singh, Owner of Chrysalis Early Learning Centre, Avondale
- Byron Bentley, Principal of Macleans College,
- Chris Bradbeer, Associate Principal of Stonefields School and PhD Student

8.1.2. Data management

During the symposium, the facilitators used pre-numbered flipchart paper at each table to capture the participants' feedback and comments. While the participants were considering the questions, the facilitator checked the number on the top of the page to ensure it was the correct table number and question reference. When the allotted time for that question had passed, the pages were collected by the three assigned assistants. If more paper was required, one of the three assistants numbered a page and handed it to the facilitator, who checked it and continued to capture the feedback. At the end of the symposium, the pages were then reconciled against each table and the number of questions to ensure that all pages had been collected and that none were missing.

The feedback and comments were then transcribed into a large Microsoft Word document by table number, then by question, to record the flipcharts. This Word document was printed and resorted by question, then by table number. Subsequently, each question was analysed using the scissor-and-sort qualitative technique (Stewart, Shamdasani, & Rook, 2007). This process was iterative, as can be seen in Figure 8-3. It began with the researcher reading through the material enough times to develop major themes and initial topics within those themes. The material was then colour-coded to classify it against each theme using highlighters and sticky notes. The material in each theme was reviewed and classified into the topics within that theme. This codification was then applied to a copy of the electronic transcript material. Once updated, the material was again resorted and reprinted. Each topic was compared and contrasted to consolidate where they overlapped or split into new topics. The revised electronic transcript was then updated and reprinted. These themes and topics were analysed once more and validated against the revised transcript. Once the validation was complete, the interpretative analysis was developed into a final report.

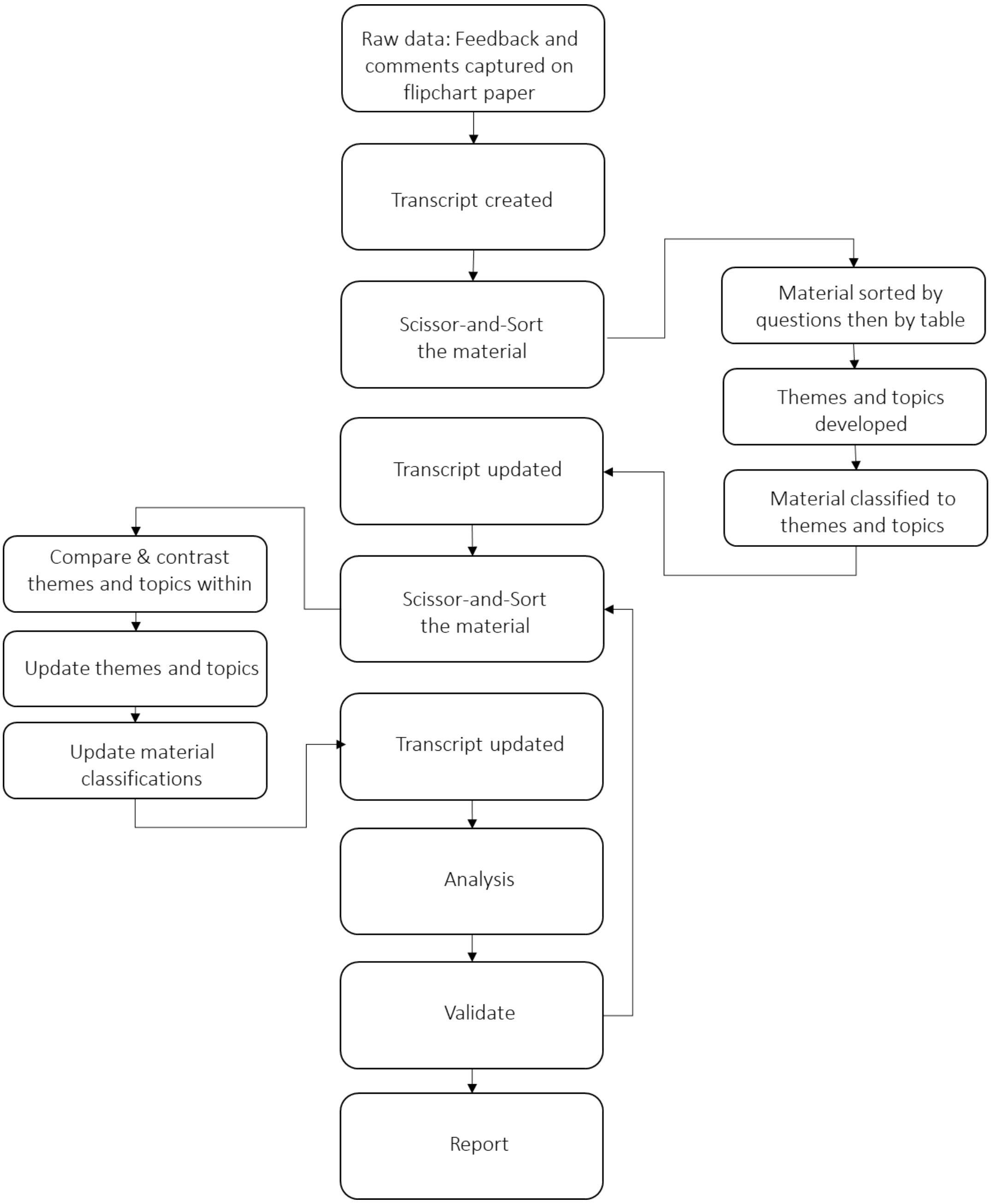


Figure 8-3 A summary of the symposium data management and analysis based on the scissor-and-sort technique (Stewart et al., 2007).

8.1.3. Results

Below are the results, using the scissor-and-sort qualitative technique, of the feedback gathered from each of the questions put to the focus groups during the roundtable discussions (Stewart et al., 2007).

Question one: What are the opportunities in the education facilities sector?

The educational facilities opportunities are quite varied, depending on a person's background and experience of building, using or maintaining educational facilities. However, several themes emerged. Across the participants, some opportunities were seen as proverbially 'quick wins', while others were deemed to require leadership and investment; either way, these opportunities were believed to necessitate further investigation and validation before taking any action.

The strongest themes to emerge included:

- **Get the basics right in building design and construction.**

These basics include, but are not limited to, lighting, acoustics, views to outside, weather tightness, indoor-outdoor flow, IAQ through appropriate ventilation and temperature control through appropriate heating and cooling.

- **Build a clearer understanding of what is meant by a pedagogy.**

This would involve better defining how a pedagogy influences a facility's use, operation, teaching style and education model. Listen to the children, teachers and local community when designing a pedagogy and a facility. Let them contribute to what is, in essence, a community facility. Embrace the changing cultural mix happening across New Zealand on a foundation of Maori and Pakeha. Understand how better briefs could be constructed and facilitated so that nothing is lost in translation.

- **Look for opportunities within classroom design.**

These opportunities exist in early learning centres and schools. They include being more flexible and adaptable to changing learning environments.

- **Learn from experience.**

Look at what has worked well and what has not worked so well in building and maintaining education facilities. Understand the impact of the current financial model that separates investment in an education facility from the maintenance and end of life of that facility.

- Apply understanding of brain and body development into education facilities.

Incorporate the growing knowledge of how brains, bodies and personal learning styles can be incorporated into a school's or early learning centre's pedagogy and, therefore, into facility design. Understand that spaces are being created to support a child's wellbeing and development.

- Make the buildings more sustainable, including considering the impact of climate change.

Review the implications that climate change will have on how future buildings are designed. How can more sustainable buildings be designed and built to balance economics, environment, community and student needs?

- Incorporate architectural and engineering software advancements.

Architectural and engineering software has significantly advanced over the last ten years. Before a building is even built, its indoor environment can be easily and inexpensively modelled to design away any issues.

- Embrace considered technology

Technology is on a huge evolutionary curve. Therefore, consider how it aligns to an early learning centre or a school's pedagogy before embracing it. Further research is also needed to understand technological impacts on basic health and wellbeing—e.g., ergonomics and sleep patterns.

- A directory of experts.

Consider if a directory of experts in the various fields would be useful.

Question two: What is the worst-case scenario?

The worst-case scenario painted a bleak future for education facilities and, therefore, the children and those who work in these environments. The main themes can be summarised as follows.

'The worst-case scenario can often be seen in the schools and education facilities of today.' ***Table 7***

If nothing were to change in the current process, the worst-case scenario would be that the design of education facilities would continue in the absence of a strong pedagogy. Therefore, it would not meet education needs, support local communities or suit the local vernacular—e.g., appropriate sun orientation, prevailing winds, consideration for the local environment, etc.

Boards of Trustee's lack of knowledge and understanding continues to frustrate the process and strain relationships with schools' management, all the while drawing out the decision-making process and costing precious community-raised funds.

The buildings themselves would be built using substandard products and materials, applied in ways not intended and containing chemicals that should not be near children but are permissible under the building code and necessary to meet the per square meter cost constraint.

When the Ministry of Health, the MoE and councils visit a school or early learning centre to grant licenses and the final code of compliance, the decisions made would contradict each other. Guidelines and opinions would be applied as rules leading to inconsistency across facilities.

Once a facility was open, with no consideration given to durability or maintenance in the design process, ongoing maintenance and costs would grow, or, even worse, the maintenance required would be completely overlooked, leading to fast deterioration of the building and a potential health hazard to those using that building—e.g., not scheduling regular filter checks on heat pumps.

As buildings would fail to meet the basic needs of the 21 to 32 people in a room, sickness would be an ongoing issue, leading to longer-term, life illnesses for children and staff. This indoor environment would drive up absenteeism and staff turnover rates as they would struggle within the environment, resulting in poor learning outcomes across the board.

Unfortunately, as mentioned by Table Seven, 'The worst-case scenario can often be seen in the schools and education facilities of today'.

Question three: What would education facilities be like if there were an unlimited budget and no regulation?

The aspiration for education facilities is that they would be environmentally, socially and economically sustainable, designed around a clear pedagogy, supported by an integrated education model that provides children with a constant education and a nurturing learning environment to support their development and wellbeing. These facilities would be designed, built and managed in a collaborative and constant way from start to finish.

These aspirations, however, come with a strong sense of 'be careful what you wish for'.
Table 9

There would be natural human spaces, which would be completely flexible, digitally integrated and supportive of higher teacher to child ratios. They would be connected to the outside environment and form the backbone of communities with a whole-of-life inclusion approach—i.e., cradle to grave. More sustainable and durable products and materials would be used—e.g., products sustainably sourced with low VOCs and maintenance requirements.

Prefabricated buildings would only be used for short periods, and some of the older, more run-down schools and early learning centres would be demolished, instead of continuing to use what are known to be bad and/or unsafe spaces.

These aspirations, however, come with a strong sense of 'be careful what you wish for'. The underlying message is that unlimited budgets and no regulation would not fix what are seen as fundamental failures in the current design, procurement, building and maintenance of education facilities in New Zealand. The old saying of 'money does not buy happiness' seems to ring true, with finances clearly not being able to solve all current issues.

> *'There is a desire to get things right and not at any cost but at the right cost'.* ***Table 1***

As Table 1 mentioned, 'There is a desire to get things right and not at any cost but at the right cost'. The key feeling is that budgets must be appropriately sized. The process should be structured to ensure money is being spent in the right places. Regulations, guidelines and options across the regulating parties. For instance, MoE, Ministry of Health, council and district plans must be consolidated and integrated into one set of rules. Those who should then know these rules must be constantly upskilled. Experts should provide their expertise at the right time in the process. Too often, non-experts—e.g. the Board of Trustees (BoT) and the principal—have to upskill employees early in the process, with experts coming in later and changing key decisions due to inappropriate budget constraints, regulations or guidelines without knowing or understandings decisions made before their arrival.

Question four: What educational and early learning models are used?

As Table 9 stated, 'The early learning models being used essentially come down to a few core models'. The foundational model, as laid down by the MoE, is *Te Whāriki*, with Reggio, Montessori and Steiner applied as a layer on top of *Te Whāriki*.

> *'The early learning models being used essentially come down to a few core models'.* ***Table 9***

Too often, though, *Te Whāriki* and the other models have been implemented almost by checklist, without an understanding of what these models are fundamentally looking to achieve and with little pedagogy to support them.

Within schools, there is a large variety of models mixed with a range of teaching styles. These include (but are not limited to) Innovative Learning Environments, Modern Day Learning Environments, the Activity-Based Model, the Structuralist Model, *Whanau* Based Learning, *Te Ao Maori*, *Kura Kaupapa Maori*, Family Life Education, Blended Learning, Project-Based Learning, Self and Shared Learning, Brainstorming (Problem-Based Learning), Teacher Facilitation Learning and Peer to Peer Learning.

These models and teaching styles appear to be mixed to suit individual teachers' beliefs or subjects, with little reference made to how they relate to a school's pedagogy. There are also examples of Innovative Learning Environments and Collaborative Learning being applied in spaces not designed to support them. There are, however, some great examples of strong pedagogy driving the education model and, therefore, teaching styles—e.g., Stonefields Primary School, Holy Family School Porirua, Hobsonville Primary School, Mellons Bay Primary and Selwyn College.

According to Table 2, 'Early learning centres and schools are excited, though struggling to come to grips with, the ever-evolving technology', what is best to invest in and what is best to use to support children's learning and development.

'Early learning centres and schools are excited, though struggling to come to grips with, the ever-evolving technology.' ***Table 2***

It has been acknowledged that it is unclear what kinds of careers children will face when they leave school, and the question remains as to what is the best way to support them in this. However, it is known that jobs are becoming more project-based, requiring individuals to work in more dynamic and mobile teams that necessitate significant collaboration and coordination.

Children also need a wider, more life-based education. Some schools are partnering with businesses to deliver this—e.g., teaching them about money management, healthy eating and dental care.

Traditional family roles and dynamics have changed significantly over the last 20 years. This leads to the question: 'With more Dads staying at home and blended family's now being the norm, what is the education system's role in these changing dynamics?'

Today, the above models are being challenged by the growing understanding of how the human brain learns and develops. However, the best way to incorporate this new learning into teaching and caring for children has not yet been determined.

Question five: What challenges does a school or early learning centre face?

The challenges education providers face are many and diverse, though intrinsically linked and interdependent. It is, therefore, a fine balancing act, and to manage these challenges often requires material compromise to achieve priorities while impacting staff members' and children's educational outcomes, health and wellbeing. These interdependent challenges can be summarised into the following five topics:

Key interdependent challenges faced by schools and early learning centres

- Social challenges
- Economic challenges
- Daily administrative and pedagogy challenges
- Education facilities challenges
- Design, procurement, building and maintenance process challenges

These challenges, in combination, lead to the question: 'What are the top priorities for education facilities in New Zealand?'

Social challenges

Communities are becoming more culturally diverse. Currently, 40% of Auckland's population originates from outside of New Zealand, and this immigration trend is only growing. This diversity places education providers in a unique position, fostering cultural integration and creating community hubs, with the ongoing challenge of determining how to involve parents and the local community. There are resource and time constraints, and languages, family values and education expectations vary greatly.

There is huge pressure on families to maintain their lifestyles, which is made more difficult by the current economic climate of increased property prices and lagging salaries. This situation pressures education providers to give longer hours and more family support than ever before—e.g., before- and after-school childcare facilities, meals and primary healthcare for children, etc.

Children and education providers often face challenging family and social environments in terms of drugs, alcohol, truancy, bullying, peer pressure, social media, family violence, a lack of nutritional food and inadequate basic parenting skills. These challenges affect student motivation and behaviour which can be disruptive and costly.

Economic challenges

The current economic models across early childhood education do not encourage total life costs and benefit consideration. When designing education facilities or upgrading existing buildings, very little consideration is given to ongoing running costs and maintenance. There is even less consideration given to the building's end of life—e.g., deconstruction/demolition.

From an early childhood education perspective, this behaviour is driven by a change in the business model. Currently, most early childhood education facilities are built by developers, then sold to investors/operators. An early childhood operator leases the building over 15 to 25 years, often taking on part or all of the liability for ongoing maintenance and upgrade costs, with little understanding of or future provision for the costs they will face. This is exacerbated by the current New Zealand property market in Auckland, where most commercial leases do not cover the financing cost and, therefore, drive even cheaper builds and push space standards per child to the maximum.

From a school perspective, the per square metre building cost rate has not kept pace with inflation in building costs over the last ten years. With significant pressure for more schools and additional buildings, build outcomes have been suboptimal, communication chains have been broken, and more pressure has unintentionally been placed on a school's ongoing maintenance budget. As a result of this current funding model, a large proportion of New Zealand schools are facing significant infrastructure issues with no way of resolving them—e.g., leaky buildings with no funding to fix them, old building stock requiring significant upgrades or replacement, installation of heat pumps without provisions for replacement in five years time and long-term use of temporary/relocatable accommodation.

There is also inequality across resources for different schools, across schools and early learning centres and across kindergartens and early learning centres. This is caused by the various funding and operating models in education, though the government is looking to address this through an 18-member advisory group.

In addition to the above, the day-to-day demands on available funding is increasing, with the expectation that schools, and early learning centres provide more resources and educational options at no extra charge and provide staff with ongoing professional development.

Daily administrative and pedagogy challenges

The daily administrative challenges facing early learning centres and schools include:

- The number of students enrolling is increasing as a result of net positive migration and a climbing birth rate. This increase will only continue, with the projected number of children in primary and secondary schools by 2024 being 810,000, up 60,000 from today. Such an increase in students is placing growing pressure on existing schools and resources, and it often leaves teachers with rooms not intended to be permanent teaching spaces.
- Staff turnover is an ongoing challenge in the industry; this includes finding and retaining quality staff. In recent years, this has been exacerbated by higher living costs in cities (such as Auckland), wages in other countries (e.g., Australia), the number of new schools and early learning centres and a higher rate of maternity leave in the education industry (since it is female-dominant).
- Early learning centres and school management are facing a wider range of HR challenges, with personal lives often spilling over into the workplace. They are now expected to provide support where historically this was not the case.
- Ongoing training and communication of a school's or early learning centre's pedagogy to staff, parents and children is necessary so that resources and facilities are used as designed. Using the building as designed is an ongoing challenge and often requires strong, nurturing leadership.

- The governance models that support early learning centres and schools are challenging in terms of ensuring informed decisions are made by a management team and/or board, with the required competency and time commitment. To manage an early learning centre or a school requires commercial and educational competencies. It also requires time, understanding and consultations about matters to make informed decisions. Often, in today's time-poor environment, decisions are made too quickly and/or without the required competencies or consultations.
- Early childhood centres have different requirements than schools, though they are often assessed through ERO by primary or secondary educators, who have little knowledge of early learning centres.
- Schools and early learning centres are, more than ever, having to manage interruptions to business as usual. Whether this is because of an earthquake or closure of a building, it shifts the focus away from what is important to what is urgent.
- There is a concern that children are struggling with transitioning from one education facility to another and then into careers, where there is little alignment between the education facilities' pedagogies and/or teaching models and the final work environment.

The pedagogy challenges faced across the board include:

- The numerous education models and teaching styles are not well understood, and this exacerbates misunderstandings about what 'pedagogy' means, resulting in piecemeal implementation. This is further frustrated by the temptations of technology. Examples are evident in early learning environments where *Te Whāriki* has been implemented and measured via checklists. In schools where there is a significant mix of teaching models and styles, conflict often occurs amongst staff members, who have implemented technology (e.g., Wi-Fi, iPads, Blogs, YouTube) with no consideration of how it feeds into the pedagogy or how it impacts health, staff resources or basic ergonomics.
- There is also a perception that the Future Schools program is unachievable in the current environment and under current standards, with an underlying concern

that schools may not know how to achieve it and that decision-makers do not understand this.

- In recent years, huge discoveries have been made regarding how human development and how the brain works. These discoveries significantly influence the understanding of what makes a great human learning environment, which challenges the design of education facilities and learning.

Education facilities challenges

Challenges concerning educational facilities in early learning centres and schools are evident in the overall quality and durability of a building's design and the materials, furniture, fixtures and finishes used. This challenge results from making decisions from an adult perspective, driven by short-term economic outcomes, instead of from a child development perspective, driven by total lifecycle cost and educational outcomes.

Education facilities challenges exhibit themselves in the following ways:

- Noise issues—from the noise created by children themselves, to the background noise created by heat pumps and computers, to road noise resulting in children not being able to hear the teacher from the back of a room.
- Lighting issues—from too little light, to too much light resulting in glare, to not enough natural light.
- Ventilation issues—from what provides ventilation, to why there is a need for adequate ventilation, to how and when to ventilate rooms.
- Heating, cooling and humidity management issues often outside optimal ranges.
- VOCs found in furniture and finishes that create poor human environments and are often carcinogenic.
- Views to outdoor spaces up against outside distractions—e.g., parents waiting at the end of the day.
- Storage that aligns to the way educators work instead of accumulating wasted resources.
- Ergonomic learning environments for children using various forms of technology.
- The rapid spread of illness from one person to the next.

- Higher maintenance costs of materials, furniture, fixtures and finishes to maintain an ageing building stock, resolve a leaking building or fix failed hardware.
- Privacy issues for children while simultaneously ensuring the safety of children and property through casual observation.
- The lack of safe and efficient drop off and pick up areas.
- The lack of flexibility to cater to different teaching styles, children's learning styles and personality types, in addition to the basics, such as having enough power outlets in this technological age.
- Poor control of premises resulting in vandalism and/or theft.

Design, procurement, building and maintenance process challenges

Fundamentally the overall design, procurement, building and maintenance process has become fragmented, driven by an unclear governance structure with little understanding of how to translate a pedagogy into an education facility. There is limited knowledge or appreciation of the entire process, riddled with conflicting interests, competency issues and contradictory rules, standards and guidelines, often resulting in opinion-based decisions driven by unrealistic timeframes.

As a result of these failings in the school management process, BoTs, early learning centre owners, developers, designers, consultants and material and product owners new to the process should upskill dramatically or learn significant lessons from their mistakes. With upfront costs and time pressure being key drivers later in the process, decisions made earlier are often overturned with little or no consultation as to why they were initially made. These decisions include substitution decisions made from an upfront cost perspective instead of a whole of life, function or well-being perspective.

In schools where everyone would like to be involved in the design process, there is often no clear pedagogy or agreement on outcome guiding the process. These situations generate an unachieved wishlist along with unrealistic expectations that drain an already stretched school management team. This is often exacerbated by a time lag in parents' and teachers' understanding of how education is being delivered now, compared to when they were children.

In early learning centres, a developer is often funding the build for an early learning business. The developer may not have the skills to fully understand what is being built or how it realises the early learning business's pedagogy.

With the process not being properly understood, shortcuts are made, without key stakeholders fully comprehending the implications. Examples include property owners selling land to inappropriate early learning operators or the project manager, planners, consultants, builders and architects taking shortcuts to save money and time.

There is a lack of understanding, through most of the process, about how modern and flexible learning environments are designed and built to meet human needs. This issue even stretches down to the basics of ergonomically designed spaces for iPad use, noise management and views of the outside.

Little consideration is given to the impact that renovations or new builds have on the health and learning of children already enrolled. Often, children are relocated for a year or more to suboptimal accommodation near a building site that emits all kinds of particulates—e.g., wood dust, containing arsenic, chrome and cyanide, used in timber framing and retaining walls.

Question six: What are the top priorities?

Three key topics of concern emerged from the feedback to this question:

- The design of the education facility.
- The design, procurement and build process.
- The maintenance of education facilities.

The strength of these concerns can be seen in Figure 8-4 below.

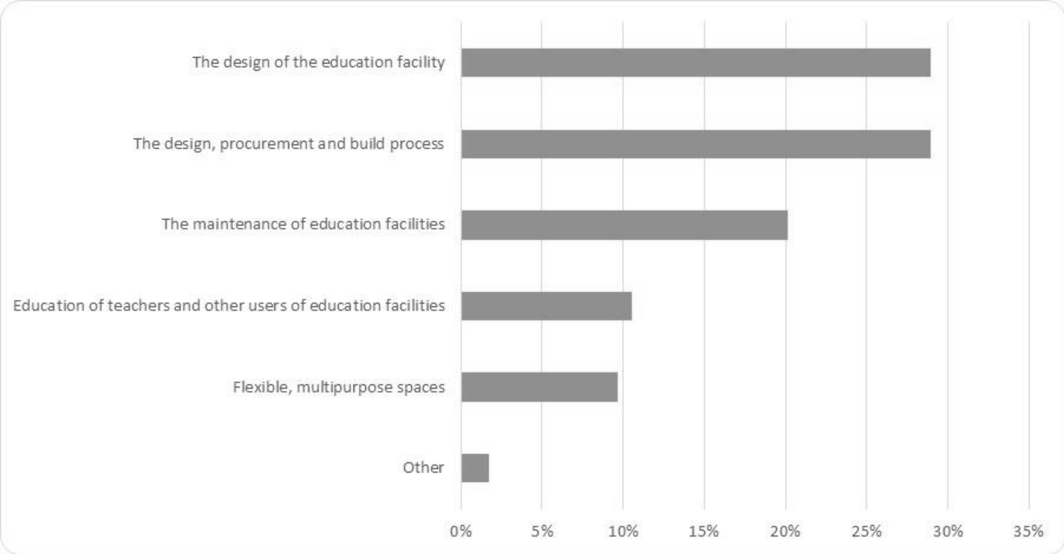


Figure 8-4 The percentage frequency of key concerns raised and captured across all the roundtable discussions

The priorities within each area of concern are summarised below.

The design of the education facility

Priorities included:

- Understanding what a child really needs from education, as what the child will need in ten years' time is unknown.
- Working on everyone's understanding of pedagogy and a design response that encourages collaborative teaching—looking to understand that education facilities can support educational requirements (modern, flexible spaces) while recognising that one style does not fit all.
- Appropriate budgets for project outcomes for future growth and meeting community and cultural needs in purposeful spaces that are adjustable where design is adaptable.
- Incorporating what makes a great human building (SCARF)—connected/belonging/authenticity—and understanding if the basics are being properly achieved.

The design, procurement and build process

Priorities included:

- Designing from a pedagogy instead of by checklist, as there is no substitute for good design; utilising a fabric first approach, which designs a building from the inside out rather than from the outside in.
- Collaborative design across the entire design, procurement, building and maintenance process with people, property, and policies interrelated (i.e., design professionals, end-users, product specialists, the MoE, building professionals and consultants).
- Tools of the trade required to deliver quality outcomes and understanding where people's expertise lies. Currently, too much onus is placed on a school's BoT. The BoT members may not necessarily have the expertise to facilitate the process if the project manager and architect are brought in too late.
- A review of the cost versus benefit over the life of the asset, including understanding from where products come, of what they are made, their maintenance requirements and their end of life costs.
- Collaboration, rather than competition, between schools in New Zealand.

The maintenance of education facilities:

Priorities included:

- Ongoing education of teachers and management in how their education facilities work and, therefore, deliver their pedagogy.
- Correctly implementing the specifications that deliver the intended pedagogy, balancing investment and ongoing maintenance costs and supporting the health and wellbeing of the children and staff.

8.1.4. Discussion

The intention of the Education Facilities Symposium was to gather an understanding of the industry from end to end, to form an education facilities roadmap that positively supports children's education and wellbeing.

The challenges education providers face are many and diverse, though intrinsically linked and interdependent. Education is, therefore, a fine balancing act, and managing these challenges often requires material compromise to achieve priorities, while impacting staff members' and children's educational outcomes, health and wellbeing

After analysing all feedback from the roundtable discussion questions—particularly 'What are the top priorities?'—the following five final topics were consolidated to address participants' priorities.

- ***Bring constancy and certainty to the education facilities' regulatory frameworks***

Bring constancy and certainty to the design, procurement, building and maintenance process by consolidating the numerous laws, rules, recommendations, guidelines and standards that govern education facilities—e.g., the Education Act 1989, the DQLS Guidelines, Regulations for ECE Services and Playgroups 2008, ECE Standards, the Ministry of Health, the Building Code and the Resource Management Act.

- ***Review the education facilities' design, procurement, building and maintenance process***

Review the education facilities' design, procurement, building and maintenance process to understand what is working well and what is not working well. This review should include what is expected at each stage in the process, who the key stakeholders are, what their role is within the process from end-to-end, who is responsible for creating consistency across the process and ensuring nothing is lost in translation; what is the total real cost across the process against the value created; and how the current financing models are driving decisions.

- ***Provide an education facilities framework from end to end***

Evolve the current school's project management model to provide a facilitated framework that supports key education facilities' stakeholders across the process, end-to-end. This facilitated framework would create a common understanding of pedagogy and how it should influence an education facility's design and operation, provide building products education, and ensure that nothing is lost in translation across the process, end-to-end. It is also important to understand how this model may support early learning centres in achieving better outcomes.

- ***Leverage existing processes to assess education facilities' issues***

Leverage existing tools or programmes to assist schools and early learning centres, assessing if there are environmental issues in education facilities—e.g., incorporate into an ERO an education facilities assessment, review the structure of the school's design panel and review the building warranty of fitness process for educational facilities.

- ***Create ongoing opportunities to stay connected***

Create ongoing opportunities for key stakeholders within the education facilities design, procurement, building and maintenance process to stay connected, keep informed and give feedback to the MoE—e.g., the Massey Symposium, teacher continuous professional development, Principal's Conference, the MoE's Communities of Learning program and the MoE's 18-member advisory group to review education funding. These opportunities should encourage vertical as well as horizontal stakeholder collaboration.

8.1.5. Recommendations

Based on the above, the following top five education facilities priorities were defined:

Top Three New Zealand Education Facilities Priorities

- Bring constancy and certainty to the education facilities' regulatory framework.
- Review the education facilities' design, procurement, building and maintenance process.
- Provide an end-to-end education facilities' framework.

The following roadmap is recommended:

New Zealand Education Facilities Proposed Roadmap

1. Validate the outcomes of the symposium with participants.
2. Establish a working party or parties to validate and drive the priorities.
3. Establish a research agenda to support the working party or parties.
4. Keep those who are engaged connected, involved and informed.
5. Hold annual symposiums to monitor the progress of the priorities.

8.1.6. Conclusion

This symposium highlighted how schools dominate ECE centres in the education and building industry. It also highlighted potential inconsistencies and uncertainties in the education facilities' regulatory framework, a possible breakdown in the education facilities' design, procurement, building and maintenance process and the idea that education facilities may not be meeting building codes and other guidelines set out by the MoE. This confirmed that further research into the IEQ of New Zealand education facilities is valid.

8.2. Appendix B: The challenges faced during this study.

Research challenges within ECE - A joint study with Auckland University and Waikato University

The education departments of Auckland University and the University of Waikato are researching the wellbeing of children and teachers within ECE centres. Their research aligned with this thesis study and provided a potential opportunity to broaden the scope of both projects' research. This would depend on a correlation between the occupants' wellbeing and the IEQ being monitored.

A joint ethics paper was prepared and presented to The Health and Disabilities Ethics Board by the researcher, as proposed by Massey University. However, this joint research was descoped back into two independent studies, due to the complex ethical environment put forward by Massey University and the Health and Disability Ethics Committee and the necessity of keeping this study's scope within the parameters of a master's degree.

Symposium data challenges

The sheer volume of feedback from the symposium far exceeded expectations. Processing this volume of data was challenging and time-consuming with a number of techniques trialled before the more traditional technique of the scissor-and-sort qualitative technique (Stewart et al., 2007) was used that suited this volume and type of data.

SKOMOBO data challenges

With over 5.8 million SPSS cases of data, it took a significant amount of time and strict data management to work out how to handle, analyse and then run the analysis in SPSS and Microsoft Excel on so much data.

In addition to this, the data collected from the presence sensors were removed from the data analysis. It was determined that the recording of a presence in the room was not always reliable, as the sensor could not always be placed where they were able to sense movement across the entire room.

Installation challenges

During installation, several challenges had to be overcome. They included:

- Transportation issues with the SKOMOBOs having no protective casing and the fragile nature of the boxes. The SKOMOBOs were manufactured in the Massey University lab and, therefore, were considered fragile, compared to similar commercial products. They also had no protective casing for transportation. Each sensor was wrapped in bubble wrap and boxed to protect the SKOMOBOs during transportation. Upon arrival at each location, it was still found that, during transportation, internal plates could be dislodged, and the small, internal washers, which hold the internal sensors and boards in place, could become loose. To assist in managing this issue, the boxes were very carefully handled during transportation, with a full external and internal inspection completed. The units were also tested before transportation and before installation, and then tested again once installed.
- Ensuring the installation was temporary but correct, safe and secure. During the initial trials, 3M Velcro removal wall hanging strips and cable holders were found to be a safer and more secure temporary installation solution than using hanging hooks and electrical or sticking tape, which damaged the centres' walls. Additional funding was, therefore, obtained to procure these products for this study. However, the SKOMOBOs were designed to be hung by hanging hooks, with extruded teeth on the lower back of the box to ensure the box hung vertically. These teeth, however, prohibited the use of the flatter Velcro strips. To overcome this issue, the teeth were carefully removed via a miniature hacksaw before installation; however, this significantly increased the time it took to install the units.
- The number and location of plug sockets. It was found that, in most rooms, there were very few plug sockets. This resulted in two issues. The first was that those within the room were found to be fully loaded, and the second was that they were often located in areas that were not considered ideal locations for the monitors. These issues required additional funding to procure extension cables and boards for each room and further increased the installation time per room. It also rendered the presences sensors not viable as they could not be placed in aa position that enabled them to monitor the entire room.

The installation height of the SKOMOBOs. The sensors of the units were designed to be far enough away from the main box so that the power and heat generated by the box did not interfere with the sensors. This, however, added a further 50 mm of height, making it challenging to keep the sensors as close to the breathable zone as possible but high enough up the wall to ensure the safety of the children. It was found that the units could be turned on their side, or even upside down, with no impact to their performance.

8.3. Appendix C: Information and consent sheets

8.3.1. Centre Owner information and consent sheet

Centre Owner information and consent sheet

Title of the project: The indoor environment in urban early childhood centres.

Researchers:

- Dr Robyn Phipps, Professor in Construction, Massey University
- Dr Mikael Boulic, Senior Lecturer, Massey University
- Tiffany Smith, Masters Student, Massey University

Dear **[XXX]**,

This is an invitation to participate in an exciting pilot research project. The aim of the pilot project is to learn about the indoor environment within the early childhood centres in a localised area.

The research involves the scientific measurement of the indoor environment in a small group of early childhood centres, by gathering scientific readings of the indoor environment within the centres' rooms. In parallel there are two similar projects being conducted in 100 school classrooms across New Zealand and in 15 early learning rooms across the wider Auckland Region and Northland.

We invite you to consent to us conducting our research at ***[XXX]***.

We seek your approval to scientifically measure the indoor environment in **[XXX]** and to approach the centre manager to request their approval to scientifically measure the indoor environment. Only with your approval and the approval of the centre manager will we proceed with the research.

This project looks to specifically measure the indoor environment of the babies' classroom, the babies' sleep room and one other classroom to be agreed with the centre manager over a twelve-month period. At the conclusion of the twelve-month period the monitors will be removed unless mutually agreed otherwise.

There is no direct cost associated with this project. Funding is being provided by six principle sponsors – Solatube, Autex, APL Window Solutions, GIB, Resene Paints and Collingridge and Smith Architects (UK).

The indoor environment in the context of this pilot project is the physical characteristics of a classroom or sleep room within an early childhood education centre. These characteristics include indoor air quality (carbon dioxide, relative humidity, temperature, particulate/dust levels), the balance of natural daylight vs artificial light, lighting levels, views to outside and sound quality. These physical characteristics will be measured by using a well-placed integrated indoor environmental monitor in each room.

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

To monitor the indoor environment Massey has developed a small, low-cost indoor monitoring instrument specifically for indoor education environments. This non-intrusive, non-emitting instrument sends indoor environment data remotely, therefore, having no impact or interaction with the occupants of the indoor environment being measured. The indoor monitoring instrument, named SKOMOBO (SKOol MOnitor BOx) is the size of an ice cream container and measures temperature, relative humidity, particulate matter, carbon dioxide, sound and the opening and closing of windows and doors.

Figure 1. The indoor monitoring instrument to be installed is no bigger than a small ice cream container.

The small SKOMOBOs will be installed in the classrooms when the centre is closed and unoccupied at a time agreed with the centre manager.

While the monitors are being installed carbon dioxide degradation measurements may be taken to understand the full picture of how the ventilation works in each room. Other information to be gathered while installing the monitoring instruments will be the attributes of the room, e.g. construction of the building and the room fit out (e.g. heating and cooling mechanisms, room sizes, windows sizes and type, furniture placement and materials). Other information to be gathered will be any building property documentation held by the Council.

Inclusion in this project is completely voluntary and completely confidential. Approval may be withdrawn from the study at any time up to the commencement of data analysis.

We will provide an information sheet that can be shared with the teachers, parents and Whānau and if you would like us to explain the research project to the teachers, parents, children and/or Whānau we are more than happy to, though the actual data recorded from the centre will remain confidential and anonymous at all times and there is no direct participation or interaction with any teachers, parents, children or Whānau of the centre in the actual project itself.

Signed consent forms will be scanned and securely stored electronically for a maximum period of five years with the original paper version destroyed once it has been scanned. All data will be securely stored electronically with access to the data being restricted to the researchers and the research assistants.

Findings of the pilot project will be used for presentations and publications. The planned outputs from this project are conference presentations and articles and may form the basis for further national and international research projects.

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

All attempts will be made to protect the centre's identity in publications and conference presentations, and pseudonyms will be used for the centre involved. In publications or presentations, it is possible that the centre may be identifiable.

You may request an oral and/or written summary of findings to be presented to interested parties.

Thank you for considering our request. To agree that we can conduct this pilot project in the above centre, please sign and return the consent form below. If you would like further information about the proposed research project, please contact the researchers:

- Tiffany Smith, tiffany@collingridgeandsmitharchitects.com or
- Professor Robyn Phipps, R.A.Phipps@massey.ac.nz

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

Centre Owner consent to invite centre to participate in the research:

Title of the project: The indoor environment in urban early childhood centres.

Researchers:
- Dr Robyn Phipps, Massey University
- Dr Mikael Boulic, Senior Lecturer, Massey University
- Tiffany Smith, Masters Student, Massey University

I have been given an explanation of this research project and I have had an opportunity to ask questions and to have them answered.

- I consent to this research being conducted in ***[XXX]***.
- I consent to the centre manager being approached to approve the research.
- I understand what the project involves.
- I understand that the findings of the project will be used in presentations and publications, including possible photos of the centre.
- I understand that the centre name will not be used in any reports or presentations – pseudonyms will be used.
- I understand that during presentations that the centre may identified.
- I understand that all data will be held securely.
- I understand that all monitors and associated equipment remains the property of Collingridge and Smith Architects (UK) and/or Massey University and will be removed at the end of the study unless mutually agreed otherwise.
- I understand that at the conclusion of the project I can ask to have an oral or written summary of the findings presented to interested parties and the specific data relating to the centre.

Signed:

Name:

Date:

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

8.3.2. Centre Managers information and consent sheet

Centre Manager information and consent sheet

Title of the project: The indoor environment in urban early childhood centres.

Researchers:

- Dr Robyn Phipps, Professor in Construction, Massey University
- Dr Mikael Boulic, Senior Lecturer, Massey University
- Tiffany Smith, Masters Student, Massey University

Dear Centre Manager,

This is an invitation to participate in an exciting pilot research project. The aim of the pilot project is to learn about the indoor environment within the early childhood centres in a localised area.

The research involves the scientific measurement of the indoor environment in a small group of early childhood centres, by gathering scientific readings of the indoor environment within the centres' rooms. In parallel there are two similar projects being conducted in 100 school classrooms across New Zealand and in 15 early learning rooms across the wider Auckland Region and Northland.

We invite you to consent to us conducting our research at ***[XXX]***.

We seek your approval to scientifically measure the indoor environment in the above centre. We have sought to obtain the approval of **[XXX]**, **[XXX]**, to conduct this pilot project within the above centre and only once both your approvals have been given will we proceed with the project.

This project looks to specifically measure the indoor environment of the babies' classroom, the babies' sleep room and one other classroom to be agreed with you over a twelve-month period. At the conclusion of the twelve-month period the monitors will be removed unless mutually agreed otherwise.

There is no direct cost associated with this project. Funding is being provided by six principle sponsors – Solatube, Autex, APL Window Solutions, GIB, Resene Paints and Collingridge and Smith Architects (UK).

The indoor environment in the context of this pilot project is the physical characteristics of a classroom or sleep room within an early childhood education centre. These characteristics include indoor air quality (carbon dioxide, relative humidity, temperature, particulate/dust levels), the balance of natural daylight vs artificial light, lighting levels, views to outside and sound quality. These physical characteristics will be measured by using a well-placed integrated indoor environmental monitor in each room.

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

To monitor the indoor environment Massey has developed a small, low-cost indoor monitoring instrument specifically for indoor education environments. This non-intrusive, non-emitting instrument sends indoor environment data remotely, therefore, having no impact or interaction with the occupants of the indoor environment being measured. The indoor monitoring instrument, named SKOMOBO (SKOol MOnitor BOx) is the size of an ice cream container and measures temperature, relative humidity, particulate matter, carbon dioxide, sound and the opening and closing of windows and doors.

Figure 1. The indoor monitoring instrument to be installed is no bigger than a small ice cream container.

The small SKOMOBOs will be installed in the classrooms when the centre is closed and unoccupied at a time agreed with you.

While the monitors are being installed carbon dioxide degradation measurements may be taken to understand the full picture of how the ventilation works in each room. Other information to be gathered while installing the monitoring instruments will be the attributes of the room, e.g. construction of the building and the room fit out (e.g. heating and cooling mechanisms, room sizes, windows sizes and type, furniture placement and materials). Other information to be gathered will be any building property documentation held by the Council.

Inclusion in this project is completely voluntary and completely confidential. Approval may be withdrawn from the study at any time up to the commencement of data analysis.

We will provide an information sheet that can be shared with the teachers, parents and Whānau and if you would like us to explain the research project to the teachers, parents, children and/or Whānau we are more than happy to, though the actual data recorded from the centre will remain confidential and anonymous at all times and there is no direct participation or interaction with any teachers, parents, children or Whānau of the centre in the actual project itself.

Signed consent forms will be scanned and securely stored electronically for a maximum period of five years with the original paper version destroyed once it has been scanned. All data will be securely stored electronically with access to the data being restricted to the researchers and the research assistants.

Findings of the pilot project will be used for presentations and publications. The planned outputs from this project are conference presentations and articles and may form the basis for further national and international research projects.

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

All attempts will be made to protect the centre's identity in publications and conference presentations, and pseudonyms will be used for the centre involved. In publications or presentations, it is possible that the centre may be identifiable.

You may request an oral and/or written summary of findings to be presented to interested parties.

Thank you for considering our request. To agree that we can conduct this pilot project in the above centre, please sign and return the consent form below. If you would like further information about the proposed research project, please contact the researchers:

- Tiffany Smith, tiffany@collingridgeandsmitharchitects.com or
- Professor Robyn Phipps, R.A.Phipps@massey.ac.nz

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

Centre Manager consent to invite centre to participate in the research:

Title of the project: The indoor environment in urban early childhood centres.

Researchers:

- Dr Robyn Phipps, Massey University
- Dr Mikael Boulic, Senior Lecturer, Massey University
- Tiffany Smith, Masters Student, Massey University

I have been given an explanation of this research project and I have had an opportunity to ask questions and to have them answered.

- I consent to this research being conducted in *[XXX]*.
- I understand that only with [XXX] and my approval for the research to be conducted within the centre/s will the project to proceed.
- I understand what the project involves.
- I understand that the findings of the project will be used in presentations and publications, including possible photos of the centre.
- I understand that the centre name will not be used in any reports or presentations – pseudonyms will be used.
- I understand that during presentations that the centre may identified.
- I understand that all data will be held securely.
- I understand that all monitors and associated equipment remains the property of Collingridge and Smith Architects (UK) and/or Massey University and will be removed at the end of the study unless mutually agreed otherwise.
- I understand that at the conclusion of the project I can ask to have an oral or written summary of the findings presented to interested parties and the specific data relating to the centre.

Signed:

Name:

Date:

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

8.3.3. General information sheet for staff members and parents

Massey University Research Project Information sheet

Title of the project: The indoor environment in urban early childhood centres.

Researchers:

- Dr Robyn Phipps, Professor in Construction, Massey University
- Dr Mikael Boulic, Senior Lecturer, Massey University
- Tiffany Smith, Masters Student, Massey University

Dear Teachers, Parents and Whānau,

This is an information sheet about an exciting pilot research project being undertaken within **[XXX]**. This project has the full support and approval of **[XXX]** and the Centre Manager **[XXX]** of **[XXX]**.

The aim of the pilot project is to learn about the indoor environment within the early childhood centres in a localised area.

The research involves the scientific measurement of the indoor environment in a small group of early childhood centres, by gathering scientific readings of the indoor environment within the centres' rooms. In parallel there are two similar projects being conducted in 100 school classrooms across New Zealand and in 15 early learning rooms across the wider Auckland Region and Northland.

This project looks to specifically measure the indoor environment of the babies' classroom, the babies' sleep room and one other classroom to be agreed with the centre manager over a twelve-month period.

The indoor environment in the context of this pilot project is the physical characteristics of a classroom or sleep room within an early childhood education centre. These characteristics include indoor air quality (carbon dioxide, relative humidity, temperature, particulate/dust levels), the balance of natural daylight vs artificial light, lighting levels, views to outside and sound quality. These physical characteristics will be measured by using a well-placed integrated indoor environmental monitor in each room.

To monitor the indoor environment Massey University has developed a small, low-cost indoor monitoring instrument specifically for indoor education environments. This non-intrusive, non-emitting instrument sends indoor environment data remotely, therefore, having no impact or interaction with anyone in any of the rooms being measured.

The indoor monitoring instrument, named SKOMOBO (SKOol MOnitor BOx) is the size of an ice cream container and measures temperature, relative humidity, particulate matter, carbon dioxide, sound and the opening and closing of windows and doors.

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

The small SKOMOBOs will be installed in the classrooms when the centre is closed and unoccupied at a time agreed with the centre manager.

While the monitors are being installed carbon dioxide degradation measurements may be taken to understand the full picture of how the ventilation works in each room. Other information to be gathered while installing the monitoring instruments will be the attributes of the room, e.g. construction of the building and the room fit out (e.g. heating and cooling mechanisms, room sizes, windows sizes and type, furniture placement and materials). Other information to be gathered will be any building property documentation held by the Council and the Architects.

Figure 1. The indoor monitoring instrument to be installed is no bigger than a small ice cream container.

There is no direct participation or interaction with the teachers, parents or children of the centre in the actual study itself. Inclusion in this project is completely confidential including the data. The other centres involved in the pilot project will also remain anonymous. All data will be securely stored electronically with access to the data being restricted to the researchers and the research assistants.

Findings of the pilot project will be used for presentations and publications. The planned outputs from this project are conference presentations and articles and may form the basis for further national and international research projects.

All attempts will be made to protect the centre's identity in publications and conference presentations, and pseudonyms will be used for the centre involved. In publications or presentations, it is possible that the centre may be identifiable.

You may request an oral and/or written summary of findings to be presented to interested parties.

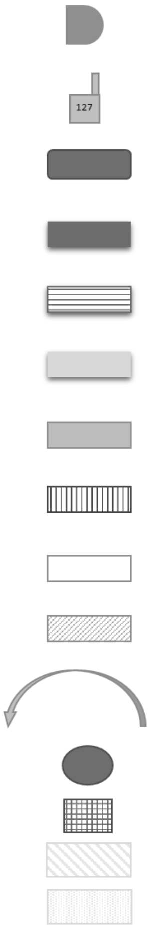
Thank you for your interest in our project. If you would like further information about the research project, please contact the researchers:

- Tiffany Smith, tiffany@collingridgeandsmitharchitects.com or
- Professor Robyn Phipps, R.A.Phipps@massey.ac.nz

APPROVED BY MASSEY UNIVERSITY HUMAN ETHICS COMMITTEE on 3rd October 2017 for a period of three years from 3rd October 2017 to 2nd October 2021 Reference Number: 4000018524

8.4. Appendix D: The centres' floor plans

Table 8-1 The key to the ECE centre building plans. Each element was used to determine the safest and most optimal location for each SKOMOBO monitor. It also includes floor finishes.



Plugs
SKOMOBO
Heat Pump
Door - Solid
Door - Stable
Door - Glass
Window - Fixed
Window – Covered over with art work/posters
Window – Fully Openable
Window – Partially Openable
Sun Path
Vent
Extract vent
Solid floor
Carpet

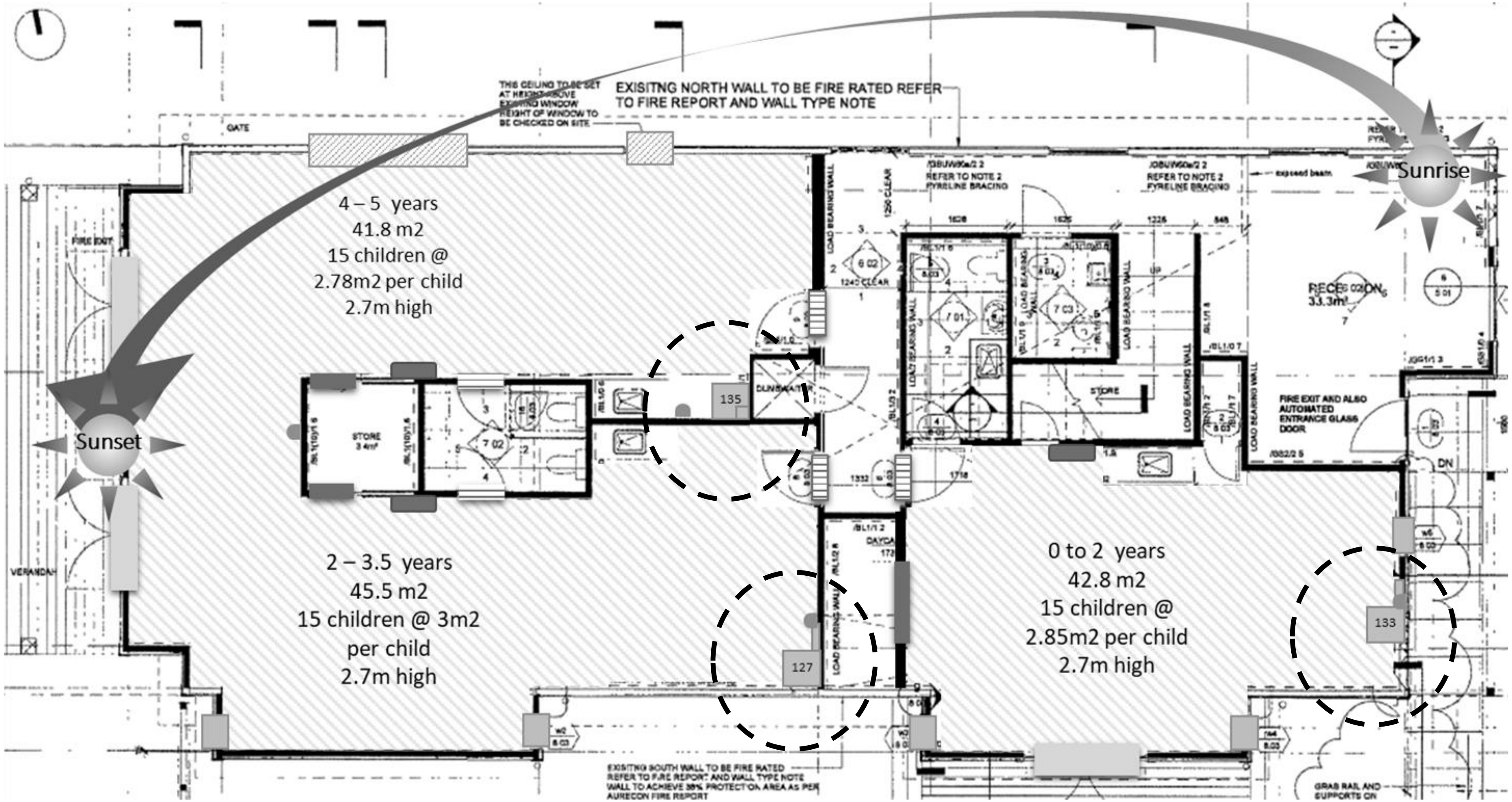


Figure 8-5 Plan of Centre one, including the placement of SKOMOBO monitors within the dashed circles.

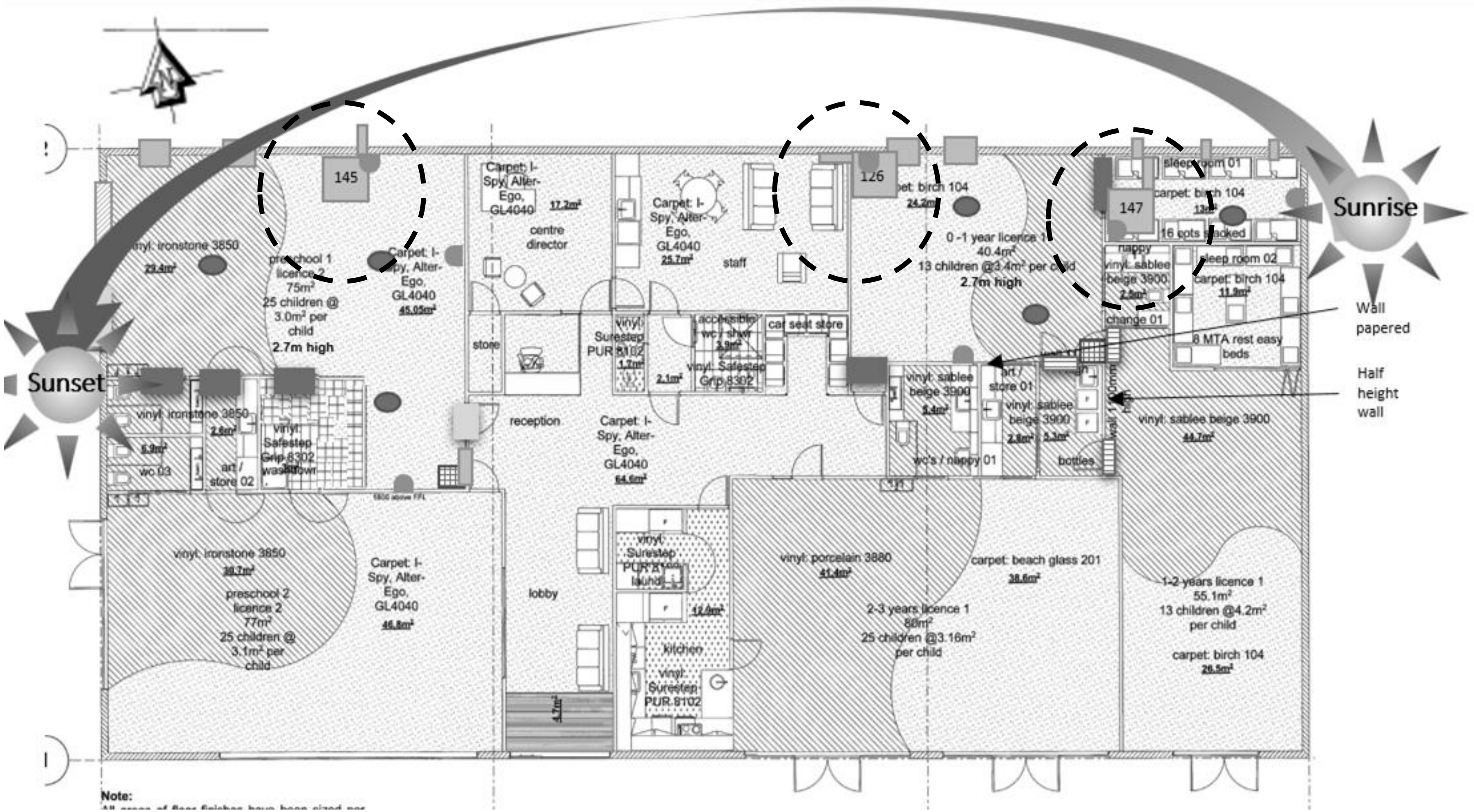


Figure 8-6 Plan of Centre two, including the placement of SKOMOBO monitors within the dashed circles.

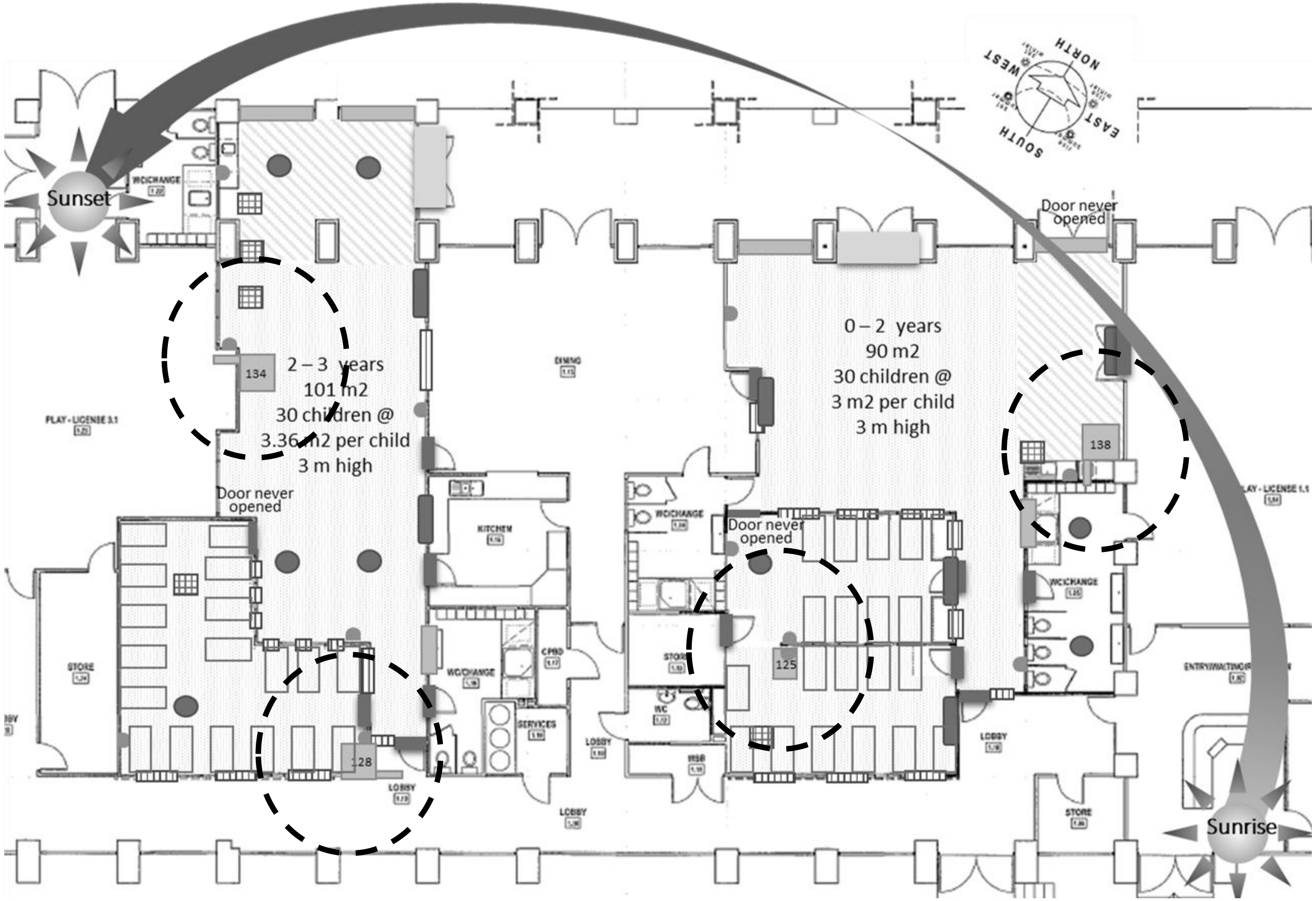


Figure 8-7 Plan of Centre three, including the placement of SKOMOBO monitors within the dashed circles.

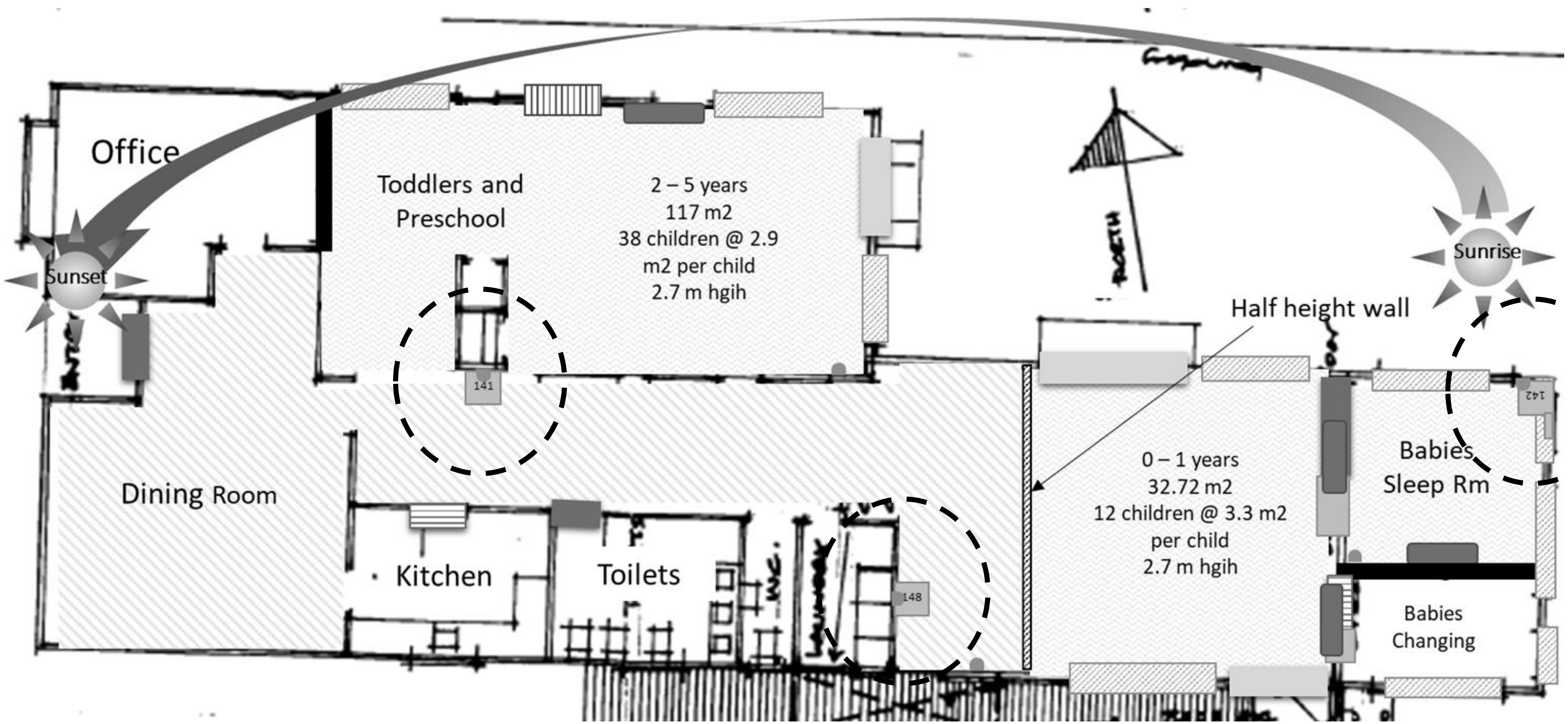


Figure 8-8 Plan of Centre four, including the placement of SKOMOBO monitors within the dashed circles.