# The potential for nature-based solutions to improve energy efficiency and workplace wellbeing within Aotearoa New Zealand businesses

A thesis presented in partial fulfilment of the requirements for the degree of Master of Environmental Management at Massey University, Auckland, Aotearoa New Zealand.

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# Abstract

As global environmental concerns grow alongside increasing energy demand and the need to transition to renewable resources, organisations face challenges in improving the energy efficiency of their premises. At the same time, workplace wellbeing and the role of thermal comfort has emerged as critical factors in businesses' performance. There is thus growing recognition of the relationship between workplace wellbeing and energy efficiency. Nature-based solutions are sustainable, holistic strategies that utilise living systems to address environmental and social challenges such as water management, biodiversity, and climate mitigation. But they also offer significant potential to improve energy efficiency and workplace wellbeing.

In this context, the aim of this research is to systematically review the literature documenting existing nature-based solutions that have the potential to enhance energy efficiency and workplace wellbeing within current business premises; and to develop a framework for identifying and implementing these solutions. The research was conducted through a comprehensive literature review and 25 semi-structured interviews with a range of experts including architects, engineers, construction consultants, sustainability consultants, property managers, landscaping professionals and academics in the ecology, construction, and research sectors. This research seeks to address the gap in the application of ecological knowledge to energy efficiency and workplace wellbeing within existing business premises in Aotearoa New Zealand.

It was found that there is significant potential to use vegetation strategically for these outcomes through five key functions: shading, humidity balancing, air filtration, wind protection, and visual and acoustic enhancement. Systematic analysis of these factors informed the proposal of six potential nature-based solutions: outdoor free-standing vegetation; vertical green systems; pergolas, awnings and other outdoor structures; balconies; living roofs and indoor vegetation. The research also highlighted the need to consider Aotearoa’s unique cultural context and identity; the use of native versus exotic plants; the importance of existing policies and frameworks; the inclusion of mātauranga Māori; the barriers posed by a lack of community ecological literacy; and a need to reframe the concept of place-based, nature-based solutions. This research concludes by presenting a systematic, step-by-step framework that businesses can use to assess their current premises and methodologies for implementing nature-based solutions for energy efficiency and workplace wellbeing.

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# List of Acronyms

| | |
|---|---|
| ANZ | Aotearoa New Zealand |
| BRANZ | Building Research Association of New Zealand |
| EE | Energy efficiency |
| HVAC | Heating, ventilation, and air conditioning systems |
| ILO | International Labour Organization |
| ISO | International Organization for Standardization |
| NBS | Nature-based solutions |
| NDD | Nature-deficit disorder |
| NZGBC | New Zealand Green Building Council |
| SBS | Sick building syndrome |
| UHIE | Urban heat island effect |
| VGS | Vertical green system |
| WHO | World Health Organization |
| WW | Workplace wellbeing |

# Chapter 1. Introduction

## 1.1. Research Background

### 1.1.1. Broad Context

As global environmental concerns intensify, the need for sustainable development is becoming more urgent (Brundtland, 1987; Hulme, 2020; International Union for Conservation of Nature and Natural Resources et al., 2002; Meurk et al., 2007; Sarre, 2018). Among the most pressing challenges is the energy crisis, which, among other factors, was driven by fuel shortages and record energy prices in the early 2020s (International Energy Agency, n.d.). This led to failed delivery of the targets set for the 7th Sustainable Development Goal that aimed to provide access to affordable, reliable, sustainable, and modern energy sources globally. It demands a transition to renewable energy sources from an environmental perspective, a long-term financial aspect, and a significant improvement in energy efficiency (EE) (Henley, 2015; Raworth, 2022; UN Department of Economic and Social Affairs, 2025, p. 7). In parallel, workplace wellbeing (WW) has emerged as a critical factor in organisational performance, employee satisfaction, and overall societal health, given that globally at least 300 million workers live with anxiety and 280 million with depression (International Labour Organization, 2009; WHO & ILO, 2022). WW relates to employees' health and work-life aspects that can be linked to energy by considering thermal comfort and air quality (Givoni, 1992; Lygum et al., 2023; Mangone et al., 2014; Pearson-Mims & Lohr, 2000). Furthermore, connection between WW across urban environments and the lack of daily experience of nature is well established (Li, 2018; Lottrup et al., 2013; Louv, 2011; Mangone et al., 2014; Petersson Troije et al., 2024; Wohlleben, 2021).

In this context, nature-based solutions (NbS)—strategies that leverage natural systems to address societal challenges—offer a promising avenue to tackle both EE and WW simultaneously. NbS have traditionally been associated with large-scale environmental interventions such as wetland restoration, forest regeneration, and urban water management. These projects often focus on climate resilience, biodiversity conservation, and ecosystem services (Brears, 2022; Cassin, 2021; DGB Group, 2023; Ettinger, 2024; Forest and Bird, 2024). While their benefits are well-documented, the potential for NbS to be applied at a micro-scale—within individual business premises—to improve EE and WW has received limited attention. This research seeks to bridge that gap by exploring how vegetation and other natural elements can be strategically integrated into existing business premises and buildings to provide the benefits.

Aotearoa presents a unique context for this investigation. For instance, although a high proportion of electricity in the national grid is derived from renewable sources (85.5% in 2024), it only represents 45.5% of the country's total energy use, with the rest depending on fossil fuels, much of which is imported (Ministry of Business, Innovation & Employment, 2025a). To achieve the country's objectives of energy independence and transitioning to renewable energy resources, overall electricity production would need to increase, while per capita consumption would need to decrease, thereby increasing efficiency (Ministry of Business, Innovation & Employment, 2017). Conversely, the country's urban environments have been experiencing a decline and an inequitable distribution of green spaces (Auckland Council, 2019; Morgenroth et al., 2020; Newton et al., 2022). The country's temperate climate, diverse and isolated geography, and strong cultural ties to nature, particularly through mātauranga Māori, offer both opportunities and challenges for implementing NbS.

Existing research on EE tends to prioritise engineered solutions—such as insulation, heating, ventilation, and air conditioning systems (HVAC), and passive design principles—while overlooking the potential contributions of vegetation. Similarly, studies on WW often emphasise psychological and ergonomic factors without fully considering the impact of natural elements. Where vegetation is included, it is frequently treated as an aesthetic feature rather than a functional component of building performance. Moreover, the literature reveals a lack of interdisciplinary approaches that integrate environmental science, architecture, business management, and cultural perspectives.

### 1.1.2. Personal Context

Based on my professional experience across various businesses in Aotearoa and Argentina, the paradigm of infinite and continuous financial growth has prompted critical reflection in both my professional and personal life. Consequently, the imperatives of systems thinking and efficiency have gained significance, guiding my career and academic pursuits. Throughout my work with different organisations and mentoring them in the implementation and ongoing management of environmental systems, this theme frequently emerges. The pursuit of infinite growth inherently leads to perpetual resource consumption and depletion, ultimately benefiting a limited segment of the population. Additionally, the concept of human resource efficiency—specifically, the optimal number of employees required to perform tasks and methods to enhance this efficiency—has also garnered attention. It is intriguing to observe that efforts to improve human resource efficiency aim to maximise productivity with fewer personnel, whereas resource efficiency efforts, such as energy consumption, aim to maximise production in proportion to its energy use, but still with a higher overall utilisation.

As an Argentine born who moved to Aotearoa New Zealand (ANZ) in my late 20s, 11 years ago, I may still have what could be considered an outsider's perspective, but with relevant life experience in the country. As a generalist or ‘jack of all trades’, I have had the chance to work for many businesses in the past two decades in the hospitality, winemaking, IT, coffee & tea, and environmental services industries. I have formal studies in business, the environment and wine. From my background, coming from a country with a more collective culture, higher uncertainty avoidance, and a short-term orientation due to an unstable political and financial environment (The Culture Factor Group Oy, 2023) I have seen firsthand how limited resources within a growth paradigm postpone any long-term environmental action policy. However, I was also exposed, and sometimes forced, to move forward doing my best with the resources I had available, focusing on improving the quality of life, not only for myself, my family, but also for my friends and neighbours. That different perspective, alongside my current roles as an environmental mentor for businesses, could have triggered my desire to research affordable, simple solutions for businesses of all sizes to implement and profit from, while benefiting employees and neighbours as a collective. I hope this research will help translate a vast amount of research by others, and some by me, into practical guidance for business owners, CEOs, and other managers seeking to increase their environmental performance by applying fundamental principles that affect them, their workplaces, and the business holistically.

## 1.2. Problem Statement

Globally, sustainability guidelines emphasise the need to address the energy crisis as countries transition to sustainable energy sources. This transition highlights the need to generate energy from renewable sources while improving the efficiency of its use. (Brundtland, 1987; Hulme, 2020; International Energy Agency, n.d.; International Union for Conservation of Nature and Natural Resources et al., 2002; Meurk et al., 2007; Sarre, 2018). Moreover, international reporting and frameworks are highlighting the need to connect these goals to nature, enabling a holistic approach for sustainable development (UN Department of Economic and Social Affairs, 2025; UNEP-WCMC, 2025). Nature-based solutions have been identified as key strategies that would allow this transition with a long-term sustainable perspective; nonetheless, these solutions are suggested to be for cities as a whole, and with a focus on water management and overall nature (Brears, 2022; Cassin, 2021; Chen & Jim, 2008; Forest and Bird, 2024; Ignatieva et al., 2008; Jim & Chen, 2009; Meurk et al., 2013). One focus of this research is to explore the potential of specific nature-based solutions to be implemented at a smaller scale on business premises.

In addition, if these nature-based solutions can be applied at a smaller scale, I intend to explore whether they can deliver energy efficiency improvements and how energy efficiency can also influence workplace wellbeing. Energy efficiency improvements are positively correlated with building occupants’ (employees) thermal comfort, or how pleased they are with their work environment and the temperature in their workplace and achieve WW (Emetere, 2022; Gonzalo & Vallentin, 2014; Liu et al., 2022; Lygum et al., 2023; Mangone et al., 2014). Such improvements are most likely to appeal to businesses and encourage them to invest in nature-based solutions.

## 1.3. Research Aim & Objectives

This research seeks to address the practice gap between existing literature and expert insights on the one hand, and applications to business premises for EE and WW on the other. In this context the emphasis will be on incorporating vegetation to improve EE and enhance both, thermal comfort and employee wellbeing.

Research Objectives:

- To systematically identify and review existing NbS documented in literature that have the potential to enhance energy efficiency within current business premises.
- To investigate the potential benefits of indoor and outdoor vegetation for improving workplace wellbeing.
- To develop a framework for identifying key areas for energy efficiency improvements in business premises, and to determine suitable NbS interventions aimed at reducing energy consumption while simultaneously promoting workplace wellbeing.

This research is significant for several reasons. First, it addresses a critical gap in the literature by examining the intersection of NbS, EE, and WW within business environments. By focusing on existing premises rather than new constructions, the study offers practical solutions that are accessible to a wide range of organisations, including small and medium-sized enterprises.

Second, it contributes to developing a framework that integrates scientific evidence, expert perspectives, and cultural considerations, thereby enhancing the relevance and applicability of NbS in Aotearoa.

Third, the research has the potential to inform policy and practice by demonstrating the financial viability and environmental benefits of NbS. In a country where energy consumption is rising despite a strong renewable energy sector, improving EE through natural interventions can reduce operational costs, enhance employee wellbeing, and support national sustainability goals. Furthermore, by suggesting the incorporation of mātauranga Māori, the study promotes a more inclusive and holistic approach to environmental management.

Finally, the research responds to the growing demand for workplace environments that support mental health, productivity, and social equity. As businesses seek to attract and retain talent, the integration of nature into the workplace can serve as a strategic advantage, fostering a sense of belonging, reducing stress, and enhancing overall job satisfaction.

## 1.4. Thesis Structure

This thesis consists of six chapters. Chapter 2 explains the methodology employed in the research. It details the literature review process and explains the planning and execution of the interviews.

Chapter 3 then presents a comprehensive literature review, which was divided into five key themes. First, it introduces the overarching concept of NbS within its broader context. Second, it analyses the global and urban-scale energy crises, the role of energy efficiency in addressing climate and business solutions with particular emphasis on Aotearoa. The concept of thermal comfort is defined and developed, serving as a bridge between energy efficiency and workplace wellbeing. Third, I consider the application of vegetation for enhancing thermal comfort in workplaces and how this relates to wellbeing. Fourth, the importance of connecting to indigenous knowledge - mātauranga Māori - is highlighted in the ANZ context. Finally, five key factors identified from the literature are proposed for evaluating the effectiveness and efficiency of each proposed NbS within the framework.

Chapter 4 then presents the findings from the interviews with experts in the field, which are systematically organised around the themes in the literature review, and further refined by incorporating additional perspectives that emerged during the interview process. This chapter begins with an exploration of NbS and examines how the proposed solutions in this study can be contextualised within that conceptual framework. The analysis then considers the implications of these solutions for EE and WW. Subsequently, key topics derived from the interview data are examined, including cultural considerations specific to Aotearoa, the potential application of mātauranga Māori, policy-related elements, voluntary frameworks, biodiversity, and ecological literacy. The section concludes with a synthesis of the barriers and opportunities identified by the interview participants.

Chapter 5 presents the proposed framework, which encompasses a set of recommendations and solutions derived from the conducted research. It begins with suggesting a refined definition of NbS, emerging from the initial research phase. Subsequently, the chapter proposes a starting point to cloak this research and its framework within mātauranga Māori. The discussion then outlines specific, actionable solutions, grouped in six categories, to address the identified issues, emphasising their capacity to enhance EE and WW by considering the five factors outlined in Section 3.5. The chapter concludes with a step-by-step guide in implementing these solutions.

Finally, Chapter 6 returns to the problems identified in Section 1.2 and the three objectives set, to assess if these were addressed and achieved. The three objectives have been achieved by exploring different ways vegetation can improve EE while also improving the wellbeing of its occupants. Moreover, in Chapter 5, a systematic framework is presented to help organisations assess their premises and consider implementing some of the solutions proposed. In addition, Chapter 6 outlines two noteworthy concepts raised during the research, the overall concept of NbS, and the inclusion of mātauranga Māori within the framework. Finally, the research's limitations are highlighted, along with potential future research.

# Chapter 2. Methodology

## 2.1. Research Design

Following Creswell & Creswell's (2023) systematic framework, the first step is to identify the key research problem and research aim and objectives, outlined in Section 1.2. The aim of this research is to fill the knowledge and implementation gaps that may improve EE and WW in commercial buildings through incorporating plants and other natural elements.

I shall develop a business case framework with practical applications to satisfy both academics and business operators. As such, the intended audience is business owners and senior leaders within organisations involved in sustainability, operational, and process management, who need to comprehensively understand the core issues and be receptive to specific solutions relevant to their premises (Creswell & Creswell, 2023). It is thus important to present the framework and steps clearly, simply and systematically.

To fulfil the research's aim and objectives, two research methods were used (Illustrated in Figure 1). First, an extensive literature review was undertaken to identify existing NbS applied to EE and WW initiatives, and to assess the scope of the NbS concept to verify that these solutions can be classified as nature-based. Secondly, 25 in-depth semi-structured interviews were undertaken with a range of key stakeholders from both Aoteaora and abroad, to learn from their experience with NbS, and its application for EE and WW in existing business premises.

Figure 1: Qualitative Research Methodology Sequence

| | LITERATURE REVIEW | EXPERT INTERVIEWS | INTERPRETING RESULTS | FRAMEWORK DEVELOPMENT |
|---|---|---|---|---|
| Step 1 | Nature-based Solutions Concept & Strategies | Identify industries and roles | Transcribe & summarise findings from interviews. | Develop guidance to identify key problems addressed by solutions. |
| Step 2 | Evidence of NbS on EE and WW. | Identify experts and reach out. | Cross-reference the literature review with interview results. | Develop a step-by-step approach guided by international best practice. |
| Step 3 | Search for NbS strategies and their application for EE & WW. | Develop interview questions. | Identify connections and gaps within both processes. | Graph and exemplify solutions to be implemented, encouraging native flora species. |
| Step 4 | Connect knowledge and keywords across different disciplines. | Book and undertake Interviews. | Develop research factors to bridge knowledge gaps. | Provide evidence to create a business case for its implementation. |

## 2.2. Literature Review Process

The purpose of the literature review was to identify existing NbS that could be retrofitted and applied for EE and WW purposes, and to examine the breadth of the NbS concept to ensure these solutions could be classified as such.

The initial phase of the literature review involved identifying keywords that would facilitate the selection of relevant literature (Creswell & Creswell, 2023, Chapter 2). This was challenging because the concept of NbS is relatively recent and primarily associated with major water management and conservation initiatives such as planting wetlands and forests. Relatively few studies using this terminology to describe interventions to improve energy efficiency and workplace wellbeing. As such, an important task was to define the concept of NbS. This included a comparison with analogous concepts. The process of identifying suitable keywords across diverse industries and their application in relevant scholarly works and reports yielded an extensive list of keywords. For example, in search of targeted solutions involving plants for energy efficiency (EE) and workplace wellbeing (WW), keywords such as plants, trees, greenery, vegetation, landscaping, garden, green walls, and green roofs were employed. This complexity was encountered not only within the English literature but also in the translation of these keywords into Spanish, Portuguese, French, and Italian. Keywords, such as the ones mentioned before, were translated into these languages to increase the number of potential results. This led to some cited literature available in other languages, such as Bustamante (2009) in Spanish, Scherer (2014) in Portuguese and Seidel (2021) in French. Some keywords used in other languages, for the case of solutions, allowed to find resources that could then be made available in English. An example is the case of the words 'sombra' (shade) and 'toldo' (awning) to find SingularGreen's (n.d.) website, based in Spain.

It was pertinent to note that most of the literature identified was available in English, as academic publications often included translations or are initially published in this language. This linguistic factor also enabled me, the researcher, to access literature from a wide range of nations, including China, India, and Korea, among others.

Different databases, search engines and platforms were used during the research, which allowed the identification of a vast range of academic and grey literature in electronic reading, video and audio formats.

The databases used for each type of content format are:

- Google Search Engine: Government organisations' reports, news/blog articles and industry standards.
- Google Scholar: Academic articles.
- Massey University's Virtual Library: Academic articles and e-books.
- Audible and Libby: Audiobooks.
- TED and YouTube: Videos and Conferences.

The use of databases was combined with known research techniques, such as:

- Snowball or Citation Chaining (Cranfield University, n.d.): Which involves researching across the articles cited within the articles found.
- Special Issues (ScienceDirect, n.d.): Using ScienceDirect special issues tools that publish articles with related topics and themes.
- Recommendation or word of mouth: Significant topics and research articles were also added during the interviewing process, by pursuing interviewees' recommendations and reading suggestions.

When undertaking the literature review, two key challenges were relevant to note:

1. A significant amount of formal research and reports found were directed or developed for policy purposes, and;
2. These primarily focused on theoretical frameworks and potential large-scale projects for cities, regions and countries.

These two elements emphasised the need for more research focusing on a smaller scale to improve practical implementation. For this research, I aimed to scale down broader effects to identify individual benefits for business premises and to find specific, workable solutions that could address the same problem locally. Additionally, the consideration of these two challenges typically centres on project development from its start but often overlooks existing infrastructure or capabilities for retrofitting solutions. Overall, this underscores the need for further research and practical guidance on these elements, a topic that was also included later in the qualitative research for additional development.

Initially, I read the abstract and skimmed through each document, or potential source. If the source focused solely on EE and WW using manufactured solutions, these were normally excluded, unless they highlighted some level of comparison with natural solutions. When the focus was on NbS, or vegetation, for EE or WW, the document was fully read, and notes were added in the same citation software to avoid re-reading to find key data, dates, or concepts highlighted throughout the text. Given that most documents focused on NbS for warm or tropical climates, more extensive research was required to ensure a balance of sources that could highlight benefits in colder climates.

Each source was also tagged by key topics and/or industries, that would help grouping and finding key topics across the literature reviewed by searching in Zotero for the tags. 48 tags were used to label the content in alphabetical order: Air Quality, Balconies, Biodiversity, Building, Canopy, Capital, Climate, Climate Change, Co-benefits, Concept, Data, Ecosystem Services, Energy, Energy-Efficiency, Evapotranspiration, Finance, Framework, Global, Health, Indoor, Indoors, I-tree, Landscaping, Living roofs, Mātauranga, Measurement, Methodology, Native, Nature, Orientation, Outdoors, Pergola, Photo, Privacy, Shading, Social, Thermal Comfort, Tools, UHIE, Urban, VGS, Video, Water, Water Management, Weather, Wellbeing, Wind, and Workplace.

In total, 165 sources were selected, citing documents from 1984 to 2025. These can be identified by type as:

- 60 Journal Articles, Papers or Theses.
- 50 Webpages or Electronic News.
- 25 Reports or Standards.
- 17 Books.
- 11 Photos.
- 2 Videos.

A challenge encountered during the keyword identification process was the variation in terminology across disciplines and industries. For example, the term ‘nature-based solutions’ prompted results mostly through water management solutions at the city level. When researching keywords such as ‘vegetation’ for EE or WW, more specific solutions such as VGS or living roofs came up, with a scientific and research background. The keyword ‘landscaping’ was more widely used across the building sector. Lastly, the term ‘plants’ was more commonly found among WW-related literature, mainly in their implementation in offices mainly.

Throughout the literature review and tagging process, themes and industry sectors were identified as significant to the research. These can be found mapped out in Figure 2, with the three key sustainability domains — environment, finance, and social — represented by primary colours. Sustainability is positioned at the centre, blending these three domains, while the relevant sectors between them are colour-coded by mixing these colours.

Figure 2: Literature Review Themes and Interconnectedness


*Conceptual map that shows the literature reviewed by themes and how these are connected. The three key sustainability themes, environment, finance, and social, are represented by primary colours. Sustainability is positioned at the centre, blending these three domains and colours, while the relevant sectors between them are colour-coded by mixing these colours.*

As the research scope was refined, some topics that had been researched in depth were presented more superficially to pursue a holistic approach that identified a broad range of co-benefits. Some of these sources and topics initially reviewed were excluded and not shown in the mapping of Figure 2. Examples of these topics that were shortened include NbS in water management, direct applications to conservation, climate change resilience and adaptation. Another relevant topic reviewed but not directly addressed was policies promoting the application of NbS, as the focus was on implementing voluntary, bespoke solutions for existing premises and reasoning their financial viability, regardless of whether local or national governments eventually mandate them.

Not all the literature incorporated was identified or examined prior to the writing process. Some sources were introduced subsequently to facilitate graphical representation, and all arguments were thoroughly supported by pertinent experts within the field. Furthermore, during the interviews, additional topics and considerations emerged, revealing gaps in the existing research and necessitating a critical review to determine their relevance within the scope of the study. An example of a topic subsequently included is the concept and further development of ‘co-benefits’ in relation to the primary NbS under discussion. ‘Co-benefits’ emerged as a central concept when evaluating a holistic approach to NbS. Conversely, a topic ultimately excluded concerns the reduction potential of plants from electromagnetic waves emitted by office devices. This was omitted due to existing legislation that requires manufacturers to set a maximum electromagnetic radiation threshold for devices, rendering it a comparatively insignificant issue to address. As with the initial resource process, all new literature found relevant was added into Zotero, tagged and classified accordingly.

After that process, all notes were copied and pasted into the document, with their appropriate citations and under the correct chapter and section, forming the backbone of the literature review writing process.

Once the writing process began, some sections and chapters were relocated to establish a systematic, logical order for developing the concepts and topics throughout the thesis.

## 2.3. Interviews

Because there is very limited existing literature directly addressing the specific topic of this thesis, it was necessary to engage directly with experts from relevant sectors. In this context, in-depth, semi-structured interviews were conducted with a range of stakeholders to enhance understanding of the subject matter by incorporating diverse perspectives and insights (Creswell & Creswell, 2023).

A systematic approach was employed to purposefully select participants for this research (Creswell & Creswell, 2023). Based on the industry sectors identified during the literature review process, illustrated in Figure 2, I noted down existing contacts I had in my LinkedIn account with expertise in these areas, primarily focusing on those with experience in ANZ, though not limited to this region. This was the case of several architects, engineers, and sustainability managers. I also identified gaps in expertise within my contacts, for which I asked for recommendations from my supervisors and existing contacts. Further ecologists and academic contacts were identified and approached via email following these recommendations. In addition, I reached out through LinkedIn to people I had no connection with or recommendation for, given their specific roles in companies in the landscaping, interior plant design and sustainability spaces. This last approach provided the fewest interviews but was effective in finding some key experts across the interior landscaping design and workplace wellbeing fields I identified during the literature review. Finally, in accordance with prior formal work permissions and an ethics-approved process, selected project champions from the Enviromark Programme at Toitū Envirocare were also invited to participate.

Before conducting any interview, I applied to Massey University’s Ethics Committee for approval in accordance with the Code of Ethical Conduct for Research. The process included highlighting any conflicts of interest with clients and potential interviewees, the level of involvement required, and clearly setting out the interviewees' rights and conditions when agreeing to undertake the interview. To comply with the Ethics Committee requirements, interviewees were sent an information sheet with a summary of the research and a consent form that explained their rights (See Appendix 1). Interviewees were required to formally acknowledge their agreement to participate before the interview by returning a signed copy of the form, or by recording a formal verbal agreement of the same terms before recording the interview.

A total of 25 interviews were conducted between May and August 2025. Each interview lasted approximately an hour, with one interview lasting just under 45 minutes and others extending up to two hours. Of these, 20 interviews took place via video call, while 5 were held in person in an informal and relaxed setting. Among the participants, 15 were female and 10 were male. 21 participants currently reside in ANZ, with only four located abroad.

Table 1: Overview of Participants' Relevant Experience Across Key Industry Sectors & Roles

| Industry Sectors or Roles<br>Areas of Expertise | Number of Participants with relevant experience |
|---|---|
| Architects (Commercial & Residential) | 5 |
| Engineers (Water Management & Restoration) | 2 |
| Construction Consultants | 7 |
| Construction Researchers (Energy-Related) | 2 |
| Sustainability Consulting – Building Sector | 6 |
| Sustainable Property Managers | 2 |
| Urban Ecologist & Academic Researchers | 5 |
| Landscaping & Urban Forest Professionals | 4 |
| Nature & Wellbeing-Health Researchers | 4 |

*Note: The figures shown represent the participants' multiple experiences across different roles, rather than a combined total for all 25 participants.*

The distribution of participants' roles and industries exhibited considerable variation over the course of their careers. Consequently, the figures presented in Table 1 reflect the participants' experiences across various roles, rather than constituting a cumulative total for all 25 participants. In Table 2, the total number of participants is categorised within their primary professional role or industry sector.

Table 2: Overview of Participants' Current Role or Industry Sector

| Current Industry Sectors/Role | Number of Participants |
|---|---|
| Architects (Commercial & Residential) | 5 |
| Engineers (Water Management & Restoration) | 2 |
| Construction Consultants | 1 |
| Construction Researchers (Energy-Related) | 2 |
| Sustainability Consulting – Building Sector | 5 |
| Sustainable Property Managers | 1 |
| Urban Ecologist & Researchers | 4 |
| Landscaping & Urban Forest Professionals | 3 |
| Nature & Wellbeing-Health Researchers | 2 |

*Note: The figures shown represent the total number of participants', 25 participants.*

A semi-structured questionnaire was developed to facilitate the interviews (Appendix 2). These questions were not disseminated to the interview participants in advance, nor did any of them express a desire to receive them beforehand. Additionally, participants were not instructed to conduct any prior research, and detailed descriptions of the topic were intentionally omitted. This methodological choice was guided by the issues highlighted in the literature review process in Section 2.2, pertaining to the conceptual challenges associated with NbS and the scarcity of literature addressing the topic and scope under consideration. The deliberate decision to refrain from introducing bias or offering suggestions prior to the interviews aimed to ascertain whether participants had previously contemplated the research topic and whether they possessed a conscious, experiential understanding of applying NbS within the specified context.

The first six interview questions centred on the overarching concept of NbS, seeking to understand the interviewee's experiences regarding both the theory and practical implementation of such approaches. This allowed the interviewee to recount pertinent field experiences that extended beyond the immediate topic and scope of the research. Subsequently, a more thorough elucidation of the topic, its parameters, and the conceptual framework of NbS was provided. Following this, the interview transitioned to more targeted questions designed to gain insights into the interviewee's specific experiences with NbS and its potential applications relevant to the research's focus, thereby eliciting more nuanced and detailed responses.

The interview questions were then divided into two sections to distinguish between questions for researchers and practitioners. However, during the interviews, it became clear that this division was not rigid, and questions were asked across both groups depending on how the conversation unfolded. The interviews followed a relaxed and exploratory style, allowing the interviewer to steer the discussion while letting participants share their experiences and expertise without strict guidelines. The main goal of this approach was to explore topics that might have been overlooked during the literature review. Given the wide range of knowledge and experience among the interviewees, many questions were not relevant to everyone. Additionally, some conversations led to the introduction of new questions and topics. An example was an interview with a government official in the regional environmental sector, who shared his experience working with businesses and specific research related to community and NbS. Another example involved a Māori architect whose background prompted discussions of solutions within a mātauranga Māori framework, and cultural diversity within Aotearoa's population.

The interviews included questions that diverged from the main topics and scope, for example, regarding policy. These questions were approached differently for each interviewee and aimed to explore their experience with policy, as well as to enquire if any of these applied to private businesses and led to positive outcomes. Additionally, the last three questions incorporated other co-benefits, such as conservation-biodiversity enhancement, which are beyond the scope of this research. However, these aspects helped explore the interconnections of these co-benefits and provided a holistic understanding of the interviewees' perceptions.

During each interview, participants' responses were recorded in a Google Form containing the interview questions, which were later exported to a spreadsheet. Each interview was also recorded and transcribed to capture questions and discussions not included in the prepared Google Form, which were then rearranged and curated during the qualitative analysis. In addition, key themes were identified among these and organised for discussion in the research.

Throughout the interviews, several recurring themes emerged, and similar answers recurred among some interviewees, particularly the architects. However, it is important to note that, despite the topic's nature and scope not being focused on a specific industry or role, the interviewer did exhaust all discussion topics. Participants from different backgrounds highlighted factors that could have been included in the research.

Several of the participants showed strong interest in the topic, as they expressed that it had not been presented or considered in the way the research suggested. These participants offered their support and assistance beyond the interview, which also helped shape the results presented. Some of the key elements further introduced included a deeper exploration of native flora and mātauranga Māori.

## 2.4. Conclusion

Overall, the research, while characterised by an academic format, is explicitly aimed at business practitioners, specifically owners and managers, and provides a systematic, step-by-step methodology for identifying and implementing NbS for EE and WW in ANZ. The study adheres to the Creswell & Creswell's (2023) framework, integrating a comprehensive systematic literature review with semi-structured interviews. The literature review comprises 164 sources from diverse disciplines, spanning various publication types, which were systematically categorised by sector and topic using tagging. A total of 25 semi-structured interviews were conducted in accordance with approved human ethics protocols, involving experts in architecture, engineering, sustainability, ecology, landscaping, and wellbeing. These interviews addressed a wide range of topics, including the conceptual definition of NbS, practitioners' experiences with NbS, the barriers and opportunities encountered in promoting NbS projects, and an initial approach through the lens of mātauranga Māori. The findings from the literature review and interviews were subsequently analysed and synthesised to develop a pragmatic framework for business implementation.

# Chapter 3. Literature Review

The objective of this chapter is to synthesise relevant literature to establish a foundation to consider specific nature-based solutions (NbS) to improve energy efficiency and workplace well-being in existing business premises in Aotearoa New Zealand (ANZ). It will serve as a cornerstone for developing the framework for businesses to consider the implementation of NbS within their existing operations, as presented in Chapter 5.

This chapter is structured into five sections. Section 3.1 examines the concept of NbS, analysing its scope and application within the research framework while adopting a holistic perspective that considers potential co-benefits and trade-offs. Section 3.2 contextualises energy issues at the urban level while also considering ANZ's climate, defines EE, and introduces the topic of thermal comfort and air quality. Section 3.3 consolidates and elaborates on the concept of WW, exploring its relationship with thermal comfort and access to nature. Section 3.4 proposes an initial framework to enable more effective integration of mātauranga Māori (Indigenous knowledge). into this research, and Section, 3.5 develops five critical factors intended to ensure a holistic and robust consideration of the solutions proposed in this study.

## 3.1. The Concept of Nature-based Solutions

Before exploring the potential for NbS to contribute to improved EE and WW, it is necessary to first define the concept of NbS. This section summarises the concept of NbS from the literature reviewed in Section 3.1.1. Additionally, the concept will be discussed based on insights from the qualitative research in Section 3.1.2. In Section 3.1.2, the ideas of 'co-benefits' and 'trade-offs' within the context of NbS will also be examined, as these are vital for implementing solutions and understanding their benefits and objectives. Drawing from the previous sections, in Section 5.1, a new definition of NbS will be proposed and explained, for the purpose of collaborating on future research and scoping NbS from a broader perspective.

### 3.1.1. Nature-based Solutions in the literature

With the growth of cities and the idea of 'concrete jungles' in the 18th century, urban planning and landscaping evolved to consider factors beyond accommodation, transport, physical services and aesthetics (Cassin, 2021). In the late 1990s and early 2000s, limitations in conservation actions worldwide alongside the acknowledgement that humankind has failed to consider ecology when facing societal issues and understanding that we are reaching the limits of the Earth's planetary boundaries (Brears, 2022; Cassin, 2021), the concept of green infrastructure was popularised for urban environments, focusing on better urban water management and addressing the heat island effect.

The definition most frequently cited within the literature defines NbS as:

> *"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" (European Commission, n.d.).*

NbS aim to address societal challenges by promoting transparent, realistic, and financially viable green growth, future-proofing societies, and increasing wellbeing (European Commission: Directorate General for Research and Innovation, 2020, p. 34). NbS take a holistic approach that delivers a wide range of co-benefits, including health, social, financial and environmental benefits. Research suggests that NbS are not a new concept (Cassin, 2021). There is evidence of indigenous people applying these principles as part of their traditions and culture in Peru and Hawaii, among other examples. However, contemporary applications of NbS have increased in the past couple of decades as a broader way to address societal challenges by applying natural ecosystem processes.

Two key concepts that underpin the concept of NbS are ecosystem services (De Groot et al., 2002; Jim & Chen, 2009) and natural capital (Constanza et al., 1997; Constanza & Daly, 1992).

Ecosystem services are services provided by natural biotic organisms or abiotic processes, individually or as a whole, which create a positive feedback loop with existing urban and rural ecosystems (Brears, 2022; De Groot et al., 2002; Jim & Chen, 2009; Meurk et al., 2013). Ecosystem services include:

- Provisioning services: Products that come from ecosystems, from primary industries such as food and fibre, water, energy, and structural support.
- Regulating services: Benefits that help maintain or underpin ecosystem balance, such as climate, disease biocontrol, air quality, water quality and runoff regulation, stormwater attenuation, pollination, natural hazards resilience, and erosion prevention/tree planting.
- Cultural services: Non-material benefits from entertainment, tourism and recreation, as well as educational, spiritual and religious purposes.
- Supporting services: Foundational services that support all the above, including soils, nutrients, and water availability.
- Intrinsic services: These are services that are deep-rooted in nature, such as the services of providing food and habitat for native biodiversity. Kawa, Māori indigenous

law, provides further examples of these intrinsic values and services in the personification of ecosystems (Cribb et al., 2024).

Supporting and intrinsic services are also known as passive values, which may not immediately or directly benefit humankind. These can be defined in financial terms as opportunity costs; the foregone potential use and resultant loss in revenue or earnings when an ecosystem is changed or lost. An example is the intrinsic services of nature to people's wellbeing, with recent studies and research suggesting stronger links between access to nature and wellbeing (Li, 2018; Meurk, 2022; Petersson Troije et al., 2024). It is also relevant to note that these passive and intrinsic services convey bequest values, which are the values perceived of the place and its use for future generations, a key to Māori multi-generational perspective (Cribb et al., 2024; Meurk et al., 2013). Meurk et al. (2013) emphasises the importance of bequest values, suggesting that urban ecosystems in ANZ should be designed to address passive services, or values, and would benefit from incorporating mātauranga Māori (Walker et al., 2021).

To assess the costs and benefits of NbS, some authors have also classified ecosystem services using a financial-market approach. The monetary value of these services is calculated as the potential financial direct value of the products or services produced (opportunity costs), such as agricultural food production or potential tourist recreational services. In addition, indirect values, such as cultural services, can be included. These financial values, delimited by areas such as regional or local councils, become the region’s natural capital. Constanza & Daly (1992) explain that *“capital is a stock that yields a flow of valuable goods or services into the future. The sustainable flow is natural income; the stock that yields the sustainable flow is natural capital.”*

Patterson & Cole (2013) explore multiple frameworks for valuing ecosystem services and further develop the work initiated by Constanza et al. (1997), which highlighted the significant limitations of assigning a monetary value to services that have explicit and implicit value to society and can be perceived differently by many. Patterson and Cole (2013) suggest that it is important to consider the risk of applying international data directly to Aotearoa‘s context, as it may not be applicable given the unique biogeography and biodiversity of its remote location. The country’s reliance on and financial focus on primary industries and tourism are key factors. Moreover, the service value division overlaps, and there is a need to avoid double-counting the perceived value in the final equation.

Meurk (2022) suggests that current natural ecosystem services value frameworks often fail to understand and quantify externalities of activities on biodiversity and cultural values, resulting in a ‘tragedy of the commons’ effect. Externalities are unexpected costs or benefits that emerge from society's utilisation of ecosystem services. For example, some externalities are becoming more evident in the context of extreme weather events, as seen in the 2023 Auckland floods (Auckland Council, 2024). The floods highlighted how current real estate development strategies failed to consider the ‘external’ value of natural waterways, wetlands, and biodiversity hotspots, which are essential considerations during severe weather events.

Among the different categorisations that Brears (2022) developed for NbS, one focuses on their implementation. Brears (2022) outlines five main categories of NbS based on their main objective, or solution to specific societal challenges. These are:

- Restoration: Used for ecological restoration and widely applied in the agricultural sector where land is available.
- Issue-specific: Focused on ecosystem adaptation and risk reduction.
- Mitigation management: Used to reduce strain on water networks and coastal management.
- Protection: Used for conservation purposes in protective areas.
- Infrastructure: Used in natural and green infrastructure or building design.

Beyond these specific purposes, NbS have the overarching goal to contribute to long-lasting ‘regeneration’ of natural ecosystems, and therefore, mitigation and resilience from an environmental, social and financial perspective (Meurk et al., 2013). The concept of NbS is broad, still evolving, and can be used in different contexts and scales (Brears, 2022; Cassin, 2021).

NbS can be applied as broadly as at the biome scale, encompassing large-scale projects that seek to follow nature’s cycles. Wohlleben et al. (2016, pp. 86–90) explain how inland forests can act like water masses — seas or lakes — by the amount of water they hold within their leaves and trunks, and by shading the soil to prevent rapid evaporation. These inland forests help maintain the water cycle balance in landlocked regions by evapotranspiration, as one of many other ecosystem services. Following this principle, the restoration or reforestation of forests in continental regions can affect the natural water cycle, helping address problems such as water quality and scarcity, even up to 650 kilometres from the coast (Wohlleben et al., 2016).For example, Pure Advantage & Tāne’s Tree Trust (2023), have proposed the largest NbS in Aotearoa, named ‘Recloaking Papatūānuku’. The project aims to reforest and regenerate 2.1 million hectares of indigenous forest across private and public land, actioned by local communities and iwi (Indigenous tribes) and informed by mātauranga Māori. The aim is to protect the country's freshwater sources and marine ecosystems, improve soil quality, encourage the repopulation or regeneration of native fauna and flora, increase carbon sequestration, and promote land diversification for climate resilience.

Within the literature reviewed in this study, the concept of NbS is more commonly used to describe interventions at a city or regional level in relation to water management, carbon sequestration, air filtration, wind management, biodiversity enhancement and other co-benefits which will be discussed in Section 3.1.2. Some examples of city-level NbS include planting wetlands to reduce flooding effects or mangrove forests to mitigate erosion in coastal areas. Central to this research topic, urban NbS aim to reduce the heat island effect and the city's overall energy demand by providing natural cooling and insulation effects (Ignatieva et al., 2008), while contributing to improving air quality and the wellbeing of its citizens (European Commission: Directorate General for Research and Innovation, 2020).

The concept of biomimicry overlaps with NbS to some extent, in that both use natural, or nature-inspired processes and services, helping deliver a solution or strategy to solve a societal issue, and can be recreated from artificial or engineered methods (Benyus, 2002). However, a key differentiator of NbS's value proposition is its holistic regenerative capabilities and co-benefits. Benyus (2002) defines biomimicry as the process of mimicking or mirroring natural processes or designs to increase the efficiency, effectiveness and delivery of these processes, requiring less ongoing maintenance and being more resilient. For example, this is the case of employing the Namib desert beetle's design for water harvesting in dry regions, designing wind turbines following Humpback whales' fins, and more commonly seen when designing aeroplanes inspired by the wings of birds. Some studies, such as Clegg's (2023), use the term biomimetics, which overlaps with biomimicry but tends to focus specifically on developing technology inspired by solutions in nature. For example, Velcro was inspired by the thorns on the burdock seeds and their capabilities.

For the purpose of this research, this thesis takes a localised or 'micro' approach by considering the effects of smaller-scale NbS by using natural vegetation, its services and abilities to achieve increased EE on existing business and industrial buildings and how these would also increase the wellbeing of its occupants (European Commission: Directorate General for Research and Innovation, 2020, p. 4). It is essential to note that, through the literature reviewed, the concept of NbS was scarcely mentioned in these cases, although it appropriately suits the overall concept. Therefore, other terms or keywords were used, such as ecosystem services, the use of vegetation, also referred to as plants or greenery, and access to nature or green spaces. Moreover, the application of NbS to individual buildings has been construed by transferring conclusions to a smaller scale when appropriate.

### 3.1.2. Nature-based Solutions' Co-benefits & Trade-offs

After conceptualising NbS as the initial step to understanding its potential, the next step is to highlight its holistic reach and co-benefits, as well as limitations and trade-offs.

NbS offer many co-benefits that encompass ecosystem services beyond their primary intended purpose. These benefits can be significant. A local example of this is the 'Sustainable Water Management' project at the Auckland Botanical Gardens, which spans 16 hectares and includes a wetland and swales. The project primarily serves to regulate services for water management, effectively reducing runoff and mitigating flood risks in South Auckland. Additionally, it facilitates the reuse of water within the Botanical Gardens and helps to filter it (Auckland Botanic Gardens, n.d.-b). The project also provides various other regulating services, such as erosion control, further flood risk reduction, pollination services, and the mitigation of urban heat effects in the surrounding environment. It also delivers intrinsic values and services by supporting local biodiversity and conservation efforts. Additionally, it offers cultural services by providing a recreational and tourist area while conserving plants that are culturally significant for Māori.

Meadows describes the holistic system's approach underpinning NbS as 'Defying the Disciplines' (2009, p. 183). She argues that solutions to complex multi-dimensional problems cannot be one-dimensional or viewed through a single lens, as doing so is more likely to lead to unsustainable outcomes by prioritising one perspective and neglecting others. It has been suggested that significant NbS, such as wetlands, reforestation, or regeneration projects, could yield a 2.8:1 return on investments when considering their co-benefits (González-García et al., 2025). While large-scale NbS are outside the scope of this research, localised or small-scale NbS at a site level also deliver co-benefits.

To identify the co-benefits associated with specific solutions, it is necessary to adopt a holistic perspective on the site's surroundings, including the green corridors that may connect—or currently disconnect—the site from other areas of ecological significance (Ignatieva et al., 2008; Meurk et al., 2007, 2013).

The most notable co-benefits identified through the literature review on the use of vegetation for enhancing EE and promoting WW in business environments include:

- Contributing to efforts to mitigate climate change by facilitating carbon sequestration.
- Providing habitats that support biodiversity.
- Alleviating pressure on the stormwater management system.
- Enhancing climate resilience in the face of floods and landslides.
- Improving air quality that subsequently offers health benefits.

- Increasing property values.
- Helping to reduce social inequalities in the area.

(Baró et al., 2015; Chen & Jim, 2008; Ettinger, 2024; Excell & Jain, 2024; Food and Agriculture Organization of the United Nations, 2016; Forest and Bird, 2024; Ignatieva et al., 2008; Jim & Chen, 2009; Kardan et al., 2015; Meurk et al., 2013; Meurk, 2022; Morgenroth et al., 2020; Newton et al., 2022; Seddon et al., 2020; Stanley, 2025; Wohlleben, 2021)

A study conducted by McPherson et al. in Chicago (1997) highlights the potential to monetise various co-benefits associated with urban greenery. Their findings indicate that adding just 10 trees per block could enhance perceived property values by as much as $10,000, with costs ranging from $300 to $5,000. This increase in greenery not only benefits property values but also contributes to improved public health by reducing the prevalence of cardiovascular and metabolic conditions. Moreover, the additional greenery in neighbourhoods can aid in bridging the socio-economic gap within cities (Excell & Jain, 2024; Newton et al., 2022). For instance, both local and international research suggests that green coverage in urban areas can serve as a new metric for social disparity, revealing a positive correlation between financial wealth and canopy cover in urban neighbourhoods (Excell & Jain, 2024; Newton et al., 2022). In Aotearoa, for example, it has been observed that neighbourhoods in South Auckland possess the least amount of green canopy cover, which coincides with communities facing significant economic challenges and limited preparedness for climate change-related weather events (Auckland Council, 2019; Newton et al., 2022). Research by Excell and Jain (2024) in the United States supports this notion, particularly regarding educational institutions. Their work indicates that increasing vegetation around schools can alleviate the demands on mechanical ventilation systems while also helping to bridge social gaps and reduce inequalities.

However, co-benefits cannot infinitely accrue their advantages, as certain attributes may compete with one another, leading to what are known as trade-offs (González-García et al., 2025). Identifying these trade-offs is essential for evaluating the sustainability of NbS, as it ensures that these benefits do not cannibalise one another and disrupt the natural balance (Castro et al., 2014; Meadows, 2009). Unfortunately, it has been observed that comprehensive interdisciplinary studies addressing this issue are relatively rare (Castro et al., 2014). Stanley (2025) emphasises three common actions which trade-offs in urban environments across Aotearoa are frequently overlooked. One is that the introduction of plant species as part of NbS can result in the loss of native biodiversity by outcompeting indigenous species, which may also fail to support native fauna. The second one is the standardisation of local urban landscapes and an excessive focus on tidiness can lead to a decline in native biodiversity, for example, the Pohutukawa *(Metrosideros excelsa)* becoming a monoculture in some of Auckland's neighbourhoods. Lastly, there is a misconception and a lack of knowledge about developing habitats for pollinators, focusing on bees, which are predominantly exotic in Aotearoa. These three common actions negatively contribute to ongoing hidden costs for conservation efforts, pest control, and landscape maintenance funded by the public (Stanley, 2025).

Trade-offs can not only go unquantified, with detrimental results, but the lack of consideration of trade-offs can lead to missed value in climate change strategies. For instance, research dedicated exclusively to urban reforestation in specific cities for carbon sequestration found that this strategy yielded minimal significant results. This study's shortcomings are attributed to the models used for sequestration and the assessment of the strategy's financial viability, which relied solely on the singular monetary value of carbon credits (Baró et al., 2015). A holistic and interdisciplinary evaluation would likely have produced markedly different results (Castro et al., 2014).

## 3.2. Energy in Context

Understanding the broader context, whether on a planetary or city level, is crucial for identifying and implementing NbS at a local site level. Therefore, it is vital to first define the problem: global energy demand is increasing due to new climate patterns and human behavioural trends. Simply increasing energy production to meet this demand is not sustainable, as it will cause further environmental degradation. In particular, the focus of this thesis is the energy used for heating and cooling business premises[1].

Section 3.2.1 will delve into the problem's context at a macro scale. Then, Section 3.2.2 will describe the concept of energy efficiency and its relevance to this research, followed by an application of this concept specifically to Aotearoa's climate and weather in Section 3.2.3. Finally, Section 3.2.4 will define and examine thermal comfort and air quality, which serve as the link connecting these concepts to people's comfort and wellbeing.

### 3.2.1. UHIE's Energy Demand by Mechanical Ventilation

Throughout history, humans have instinctively sought comfortable temperatures for which their bodies are adapted. This quest for warmth or coolness is deeply rooted in humans' survival instincts, which can be exemplified in humans' evolution with our need to seek shelter,

[1] Energy demand for lighting, cooking, transportation and other purposes is out of scope for this research as the NbS this thesis focuses on do not have a direct effect on reducing these demands.

and in our early use of fire as an energy source to warm ourselves. This last need was one of the key focuses in the history of civilisation, allowing humans to survive in climates outside their thermal comfort zone. However, with the advent of electricity, technology has advanced in the past century, and with it, the demand for cooling has grown exponentially. By 2050, energy requirements for cooling are expected to exceed those for heating (Henley, 2015). This increase in demand for cooling is due to several factors, such as energy availability (in the form of oil), technology becoming more affordable, and the increasing effect of global warming. In addition, current building and urban design practices have also exacerbated the demand for cooling in cities, including those in Aotearoa, underscoring the crucial role of urban planning and design in addressing these challenges.

To understand the energy demand for heating and cooling changes in a business building, it is important to understand the broader urban heat island effect (UHIE) concept, coined by Luke Howard back in 1833 (Zhang et al., 2014). Anthropogenic heat is the exothermic process by which human activities and our bodies produce heat from daily activities such as cooking, heating, driving vehicles and simply moving around (Dhakal et al., 2022; Zhang et al., 2014). The heat concentration increases with the number of people in the same place, and from the absorption, diffusion, and refraction effects of surfaces, such as concrete and metal, that now cover most surfaces in cities. Cities create a phenomenon known as the concrete canyon (Chen & Jim, 2008, p. 58), with buildings on both sides of the street trapping heat and creating wind corridors.

The UHIE is just one aspect of the energy consumption challenge, as it focuses on the warming effects of cities. In temperate climates such as Aotearoa, UHIE can increase energy demand for cooling in summer but may, conversely, reduce energy demand for heating in winter. Aotearoa's climate is also characterised by high winds, with some areas being more affected than others. Wind is a significant factor in cities' energy demand as it can increase air exchange rate in buildings (Gonzalo & Vallentin, 2014), leading to increased energy demand in summer and winter from the loss of artificial heating and cooling used to achieve a comfortable indoor temperature in buildings. The 'concrete canyon phenomenon' (Chen & Jim, 2008, p. 58) can have a different level of impact depending on the urban design, location and climate. To combat the UHIE and heating and cooling losses from winds, research suggests using trees, green spaces and greenery throughout cities (Chen & Jim, 2008; Dhakal et al., 2022; Food and Agriculture Organization of the United Nations, 2016; Ignatieva et al., 2008; Jim & Chen, 2009; Meurk et al., 2013; Morgenroth, 2022; Morgenroth et al., 2020; Zhang et al., 2014).

Chen & Jim (2008) suggest that the increased vegetation at the bottom of the 'canyon' (i.e., footpaths) helps by shading the street and buffering extreme wind movements, creating a cooler and more stable microclimate. A stable microclimate buffers extreme high and low temperatures, which results in a reduction of energy losses from buildings' artificial heating and cooling systems. Dhakal et al. (2022) suggest that vegetation and wood reduce the absorption and diffusion of heat by concrete, while leaves' evapotranspiration effect can help reduce overall temperature between 1°C and 5°C in the localised area. Evapotranspiration cooling effects are a consequence of the heat absorption from the environment when water from the surrounding greenery evaporates (Jim & Chen, 2009). Zhang et al.'s (2014) research in Beijing results show that greenery could absorb $3.33 \times 10^{12}$ kJ via evapotranspiration in summer, which is equivalent to reducing $3.09 \times 10^{8}$ kWh of energy used in cooling in the city, and saving 60% of energy. Moreover, it is suggested that a mature tree can release 380 litres of water into the atmosphere in summer through evapotranspiration, helping cool down the surrounding environment. McPherson et al.’s (1997) research in Chicago demonstrates how a row of trees on the street’s east side could reduce cooling energy demand between 2% to 7% in summer.

Beyond the temperature regulation effects that vegetation has at a city level, plants and trees also support mechanical ventilation systems, also known as heating, ventilation, and air conditioning systems (HVACs), by improving air quality (Chen & Jim, 2008; Ignatieva et al., 2008; Jim & Chen, 2009; Meurk, 2022). Essentially, vegetation’s photosynthesis process provides oxygen, which is vital to human life. Additionally, the overall botanical respiration process helps reduce air pollutants and compounds such as sulphur dioxide, nitrogen oxides, and ozone through dry deposition. This process involves the transportation and absorption of pollutant particles into plants' stomata during respiration, followed by their fixation within the plant or in the soil.

In the context of Aotearoa, Meurk’s (2022; 2013) research on ecosystem services highlights the crucial role of tree canopy and green spaces in climate regulation, with both acting as insulation for buildings and mitigating the UHIE. In addition, Meurk emphasises that despite higher initial costs native greenery is more cost-effective in the long term as it requires less maintenance from councils, aiding with biodiversity strategies and accentuating local identity. Morgenroth (2022) assessed the most significant cities in Aotearoa to determine the optimum green cover threshold. This depends on the biome they are located in and their context, resources and geography. He recommended a 20%-30% cover for cities in forest biomes (most of the North Island) and 16%-24% for cities located in grassland biomes (Canterbury, Otago and Southland). Currently, Wellington is one of the few ANZ cities within the recommended threshold for canopy cover (30.61%), while Auckland and Christchurch are both below, with 18% and 13.5% respectively. Throughout the literature review, most NbS studied and applied in cities focused on issues of overheating and the need for cooling, particularly in countries closer to the tropics. Nonetheless, by carefully researching wind strategies and vegetation insulation effects, significant research on retaining heat in cold-weather climates was found. As explained in Section 3.2.3, both strategies are relevant for implementing NbS in temperate climates such as in Aotearoa.

### 3.2.2. Energy Efficiency

Energy Efficiency (EE) is a fundamental concept in building design and performance. It refers to the performance of tasks with the least net energy possible for its end use (Ministry of Business, Innovation & Employment, 2017, p. 24). Increased efficiency can be achieved through technology or systematic processes and methods that produce the same results with less energy, thereby conserving energy. In building performance, the reduction of energy consumption, typically in the form of electrical power, can be achieved through more efficient heating, cooling, insulation and other specific actions that apply to particular buildings, industries, or machinery.

Building principles play a significant role in the EE of buildings. The design of a building, including its orientation, size, shape and colour can directly impact its energy performance. These parameters are considered when deciding on and implementing NbS, but are not a NbS on their own, and therefore outside the scope of this thesis.

In particular, the focus of this research are NbS that can help reduce energy use for heating, cooling, and artificial ventilation. Depending on the building, artificial ventilation can be performed all year long and may also include factors such as air filtering for internal air quality control. This section will focus on the scientific literature documenting actions to reduce energy loss from a building envelope while maintaining an appropriate indoor air quality using outdoor and indoor vegetation. It is worth noting that EE is positively correlated, but not equal to, thermal comfort, a subjective area involving occupants' feelings of comfort, which can vary among individuals. Building occupants' behaviour and activities directly affect EE and comfort in a building. Section 3.2.4 will further discuss thermal comfort and introduce and discuss the concept of WW.

Solar irradiation is a crucial factor to consider when designing and managing the energy performance of a building (Heisler, 1986). The sun provides renewable energy at no cost, making it important to maximise its benefits through strategic exposure and access indoors via windows. At the same time, managing excessive solar irradiation is vital to prevent overheating and minimise visual glare discomfort. Gonzalo & Vallentin (2014) refer to this consideration as "orientation" under the Passive House Institute standard. Developed in Germany during the late 1990s, the passive design framework sets strict certification criteria to create highly energy-efficient buildings by considering building’s orientation, layout, insulation, window design, thermal mass, shading and ventilation systems to reduce the use of heating and cooling.

The concept of orientation can also be viewed as a NbS by designing a building that optimally utilises sunlight or minimises exposure based on specific circumstances. This idea will be explored throughout the research to evaluate the impact of solar irradiation and the use of shading for improved EE; however, it is not practical to modify the orientation of existing buildings.

It is essential to note that the implications of orientation and sun exposure vary between the northern and southern hemispheres. In the northern hemisphere, building guidelines in countries aiming to use the sun to help heat the structure suggest that buildings’ openings face south, while those in the southern hemisphere suggest buildings should face north to maximise sun capture (Building Performance, 2022; Gonzalo & Vallentin, 2014). Consequently, the findings and recommendations from northern hemisphere research will be inverted for application in Aotearoa. It is also important to note that sun exposure and ideal orientation may differ based on local climate (sun through latitude, wind, cloud prevalence, humidity): research in warm climates focuses on cooling buildings, while in cold climates, the emphasis is on warming them. In temperate regions like most of Aotearoa, adaptations may need to accommodate both heating and cooling options depending on the season.

Another crucial factor influencing the EE of buildings is air exchange (Heisler, 1986). The air exchange rate has a direct impact on EE—an increased exchange rate translates into inefficient use of heating and cooling energy. Air exchange occurs due to temperature differences between indoor and outdoor environments, leading to air movement through cracks and gaps in the building façade. Gonzalo and Vallentin (2014) explain that air exchange is a fundamental principle of the passive house design standard, underscoring the importance of constructing airtight buildings, and relying on the use of HVACs for air exchange, cooling and heating. These considerations are particularly relevant in Aotearoa, where windy climates often result in elevated air exchange rates, measured in terms of volume of air exchanged per hour.

The final factor to consider is heat conduction, which refers to the transfer of temperature between indoor and outdoor environments through conduction (Heisler, 1986). The insulation materials and components within a building's envelope—such as the floor, walls, roof, and windows—play a crucial role in minimising energy gains and losses resulting from external influences, air exchange, and heat conduction. The effectiveness of these materials in resisting thermal flow is quantified by a measure known as the R-value ($m^2{\cdot}K/W$); a higher R-value indicates greater thermal resistance and superior insulation performance (Building Performance, 2022; Gonzalo & Vallentin, 2014). Insulation is recognised as the most significant contributor to a building's EE and is typically an engineered component designed to maintain a stable internal temperature. Section 5.2 will identify and discuss NbS that can enhance existing artificial insulation and, in certain cases, serve as viable alternatives.

As an overarching and summarised strategy for temperate climates, the US Department of Energy (n.d.) and Landscape for Life (n.d.) suggest:

- Winter:
  - Maximise sun exposure
  - Deflect winds from the south[2]
- Summer
  - Maximise shade
  - Tunnel tropical winds

These sources highlight that the correct landscape design can reduce houses' indoor energy consumption up to 40% (Landscape for Life, n.d.; U.S. Department of Energy, n.d.).

### 3.2.3. Understanding Aotearoa's climate to identify energy efficiency challenges

To apply the findings of existing research about NbS in Aotearoa, the first step is to understand the country's climate and the challenges and opportunities it presents in different regions. Understanding local climatic conditions is key to developing possible solutions, as the solutions identified in this research will not apply equally to all sites nationwide. By first defining the climate and the typical weather at the site that will be assessed, it is possible to determine the problem(s) that can potentially be addressed by NbS. For example, some premises will suffer extreme overheating in summer, others extreme cold in winter, while others have only moderate cooling and heating demands depending on the season. Some premises may have an area that will differ from the rest due to its location or from the activities performed and machinery used in that area.

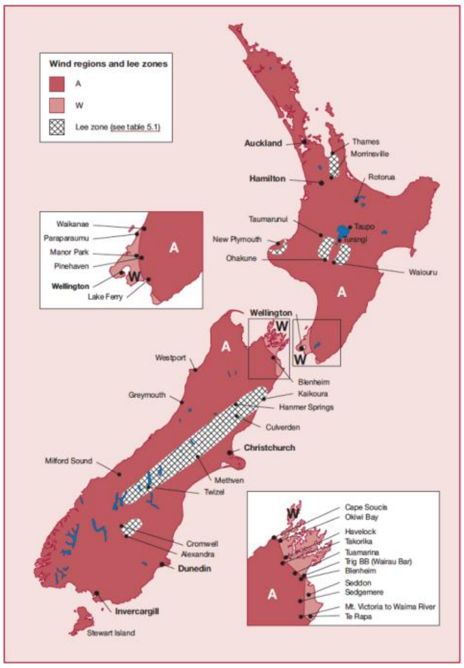
Aotearoa is an archipelago comprising two major islands in the South Pacific Ocean, stretching for 1,500 km from latitudes 34° to 47°, and 700 smaller islands mostly surrounding these two. The North Island is 113,729 sq km and exhibits predominantly rolling hill country-like topography. The South Island is 150,437 sq km and contains the Southern Alps, which

[2] The original source, the 'US Department of Energy' and 'Landscape for Life' stated North, but this was changed to suit the southern hemisphere.

divides the island vertically from north to south, with plains to the east. The country is geologically defined by its volcanic and earthquake activity, located in the Pacific 'Ring of Fire' (Te Ara Encyclopedia of New Zealand, 2020).

Aotearoa is exposed to west tropical and Antarctic winds reaching the mainland with significant rainfall. It is predominantly identified as a coastal and windy environment, with some exceptions inland in the centre of the North Island and some sheltered areas in the South Island's Southern Alps. Average wind speeds range from 9 km/hr in some parts of Otago to 20 km/hr in Wellington. Winds are seasonal, with the strongest winds occurring from mid-October to mid-January, and milder winds from April to August. Wind gusts are common in coastal areas, with winds in the Wellington region averaging 61 km/hr over 198 days per year (Macara, 2018). Standards New Zealand (2011) has assessed the country's winds and divided them into two regions and lee zones (Figure 3). The 'A' region covers most of the country, except for the area surrounding the Cook Strait, which was labelled 'W'. There are also lee zones, areas where the local topography conditions wind currents by increasing the wind speed significantly in comparison to the rest of the region. Lee zones are present on the centre-east side of the South Island (Covering Kaikoura, Hammer Springs, Culverden, Methven and Twizel), and south of Lake Tāupo in the North Island (Around cities as Turangi, Ohakune and Waioru). Lee zones are different and more site-specific, ranging from low to high, with a special category named 'Specific Engineering Design' for zones with extreme wind gusts (BRANZ, n.d., 2018, 2024).

Figure 3: Wind Regions & Lee Zones Map




*The map shows wind regions and lee zones in Aotearoa (Standards New Zealand, 2011).*

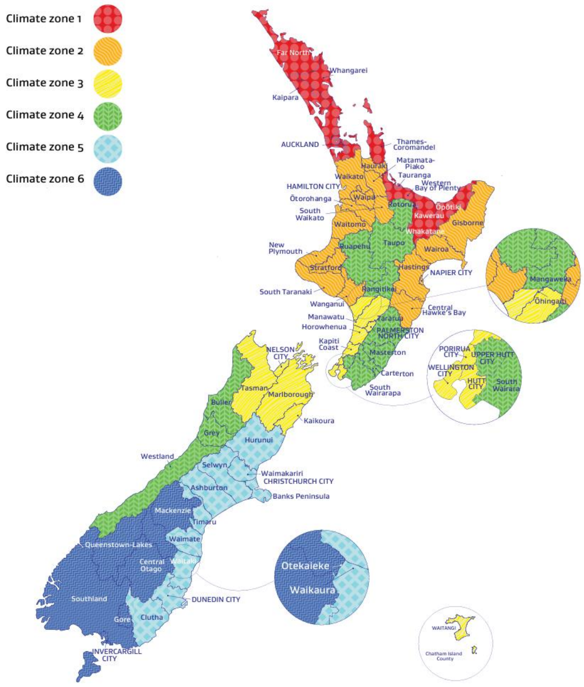
Aotearoa is considered a temperate country with maritime weather. Thermal amplitude is not extreme, with summer temperatures rarely exceeding 30°C. Normal summer afternoon temperatures range between 18°C to 24°C and fall to -2°C to 8°C overnight in winter (Macara, 2018).

Rainfall varies by region. Otago is the driest region, with rainfall averaging 350 mm/y, and the West Coast is the wettest region, recording 4000 mm/y of rain. Total rainfall peaks at 10,000 mm/y in the Southern Alps, with these mountains separating the two extreme regions.

However, the average rainfall across most of the country ranges from 1000 mm/y to 3000 mm/y (Macara, 2018).

To help the construction industry better assess the climate effect in buildings and their energy performance, the national government entity Building Performance (2022) developed an interactive map that highlights rainfall areas and the six climate zones (Figure 4), outlining broad EE considerations for the national building code of practice. For a breakdown of climate zones by territorial authority see Appendix 3. BRANZ (2024) has identified nine climate zones for the nine largest urban centres across the country.

Figure 4: Map of Aotearoa’s Climate Zones




*The map shows ANZ's climate zones by territorial authorities (Building Performance, 2022, p. 20).*

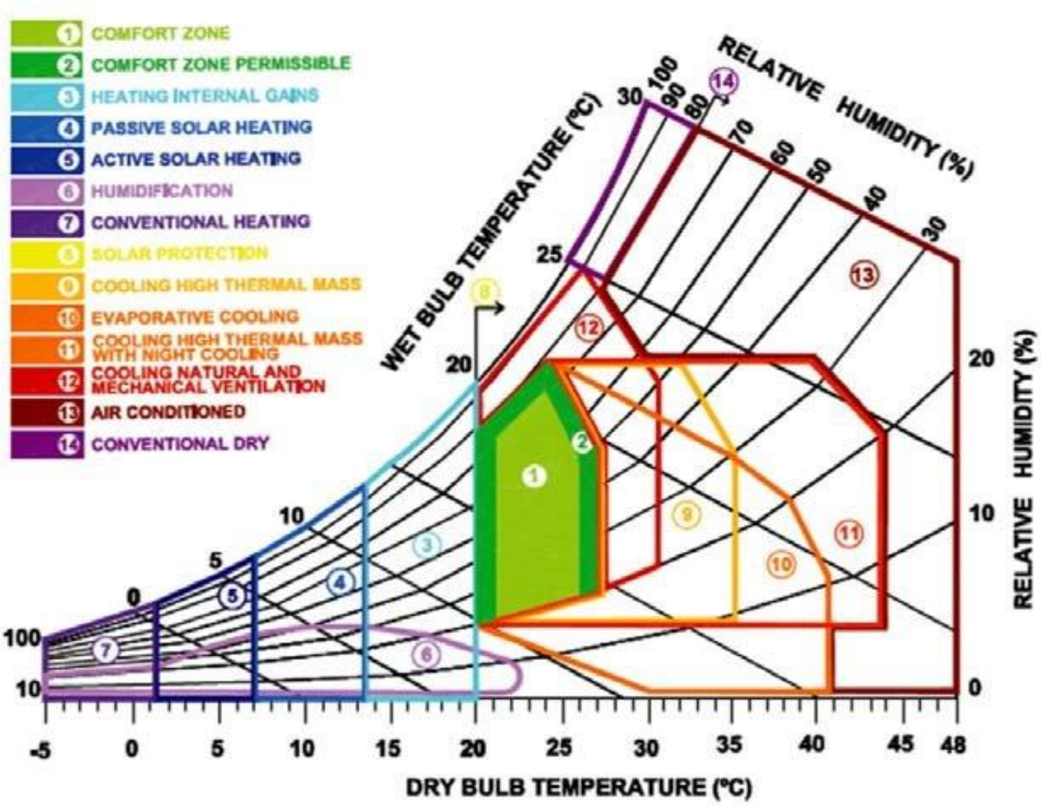
## 3.2.4. Thermal Comfort & Air Quality

Thermal comfort and air quality are key considerations in work environments that lead to energy demand from HVAC systems and significantly affecting EE. This approach underscores the necessity of integrating human factors into the design and operation of energy systems, thereby fostering optimal occupant satisfaction while promoting sustainable energy practices (Gonzalo & Vallentin, 2014, p. 12; Liu et al., 2022).

Thermal comfort refers to an individual's subjective feelings about temperature in a given environment (Emetere, 2022, Chapter 3; Mangone et al., 2014). In essence, it signifies the satisfactory sensation of not feeling too cold or too warm. Achieving thermal comfort involves managing two key factors: temperature and moisture, the latter typically measured by relative humidity, which fluctuates with temperature changes. As the temperature rises, the air has a greater capacity to retain moisture in the form of vapour. Since thermal comfort is subjective, there is no universal formula to define it. However, literature suggests acceptable ranges for thermal comfort typically fall between 18-20°C to 24-27°C, with relative humidity levels ranging from 20% to 80% (Gonzalo & Vallentin, 2014; Mangone et al., 2014; Vadoudi, 2018).

Figure 5 illustrates Givoni's (1992) Bioclimatic chart outlining passive design solutions to achieve thermal comfort over a psychrometric chart. The psychrometric chart illustrates the relationship between temperature and relative humidity (Givoni, 1992; Vadoudi, 2018), along with other important details, such as the identification of dew points. The chart highlights the typical optimal thermal comfort range marked in green. This chart also showcases, in different colours, potential passive design solutions under specific temperature and relative humidity that can help achieve thermal comfort when conditions fall outside the ideal range, and can be potentially enabled by the use of NbS by modifying one or more of the key factors from Section 3.5.

Figure 5: Givoni's Bioclimatic Chart




*The graph shows a bioclimatic chart, over a psychrometric chart, outlining passive design solutions to achieve thermal comfort (Givoni, 1992; Vadoudi, 2018).*

Pursuing the objective of an airtight building envelope to seek EE (discussed in Section 3.2.2) often leads to a decrease in natural ventilation by preventing the use of operational windows, or by developing buildings without operational windows, becoming further reliant on the use of HVAC systems (Gonzalo & Vallentin, 2014; Wolverton et al., 1984; Wu & Flemmer, 2020). It raises concerns about indoor air quality from inorganic oxides from breathing, and pollutants such as airborne contaminants from combustion (e.g. cigarettes and indoor fires, volatile organic compounds (from cleaning and building products - formaldehyde), and bio-contaminants (mould, fungi, and bacteria) (BRANZ, 2025). Therefore, HVAC systems not only cool, heat and manage relative humidity, but also provide sufficient fresh air via filtration of pollutants. On advice from Old & Jones' (2024) Ministerial briefing, they advised Aotearoa's Minister of Health that ventilation-air exchange rates within public areas and workplaces needed improvement to a) increase cognitive function, b) reduce exposure to pollutants and c) reduce the spread of airborne diseases, such as COVID. They suggested that further research was required to achieve both optimal air quality and EE, as some solutions have showed counterproductive results.

## 3.3. Workplace Wellbeing

As discussed in Section 3.2.4, energy and its associated demands play a pivotal role in the enhancement of workplace wellbeing, primarily through their direct influence on thermal comfort. This section examines the influence of natural elements on workplace wellbeing (WW), extending beyond the conventional focus on energy factors. Section 3.3.1 will first discuss humans' connection to nature. Then, Section 3.3.2 will explore the specific benefits nature, and particularly vegetation, can provide to employees, and Section 3.3.3 will consider how this connection can be integrated into the workplace environment.

### 3.3.1. Humans' Connection to Nature

It has been proposed that the intrinsic connection between humans and nature is genetically encoded, akin to the innate bonds observed in other mammals and animals, predating our cognitive awareness of such relationships (Li, 2018; Louv, 2011; Wohlleben, 2021; Zhong et al., 2022). The relationship between humans and nature has been extensively examined within the literature, which emphasises the imperative for human beings to maintain a sustained connection with the natural environment. This relationship has been explored across various domains, including personal natural affinity, human health, social dynamics, and architectural design (Kaplan, 1995; Li, 2018; Livni, 2019; Louv, 2011; Meurk et al., 2013; Newton et al., 2022; Robinson et al., 2022; Wohlleben, 2021; Zhong et al., 2022).

From a historical and humanistic perspective, Kaplan (1995, pp. 172–173) investigates the concept of soft fascination. This concept refers to the human capacity to appreciate natural elements such as clouds, sunsets, snow patterns, and the movement of leaves, which facilitates a state of effortless contemplation or meditative engagement. Kaplan characterises this state as 'being away', a form of daydreaming where the individual's mind detaches from immediate surroundings but remains physically present. Moreover, simply diverting gaze, such as looking through a window, can suffice to induce this state. Kaplan elucidates that natural environments provide access to this cognitive process by being sufficiently complex while maintaining an inherent limit or boundary. For example, a small green space or backyard may not need to be large; instead, creating trails or pathways around it can introduce enough variability and engagement to enhance the perception of spatial expansiveness. Japanese gardens exemplify this principle through the practice of miniature landscape design, or miniaturisation. Additionally, Kaplan emphasises the importance of environmental compatibility—spaces that are appropriately designed to serve their intended purpose. Natural environments are typically highly compatible, demanding less effort compared to urban settings.

Louv (2011) explores human beings' natural connections with the environment, and more specifically, the lack of this connection from a health perspective, which he named nature-deficit disorder (NDD). While this disorder is yet to be considered a formal medical diagnosis, Louv explains how the lack of contact with nature can contribute to attention difficulties and higher rates of psychological and physical conditions and encourages people to take their recommended dosage of ‘Vitamin N’ (N for nature). A comparable concept was suggested by Glenn Albrecht, the term ‘psychoterratica,’ denoting the adverse impact on human mental health caused by disconnection from nature (Livni, 2019). Both Louv and Albrecht concurred that generational disconnection from the environment also precipitates a decline in ecological literacy, a concept Albrecht referred to as ‘ecoagnosy.’ This decline contributes to a negative feedback loop, further distancing humans from nature (Livni, 2019; Louv, 2011).

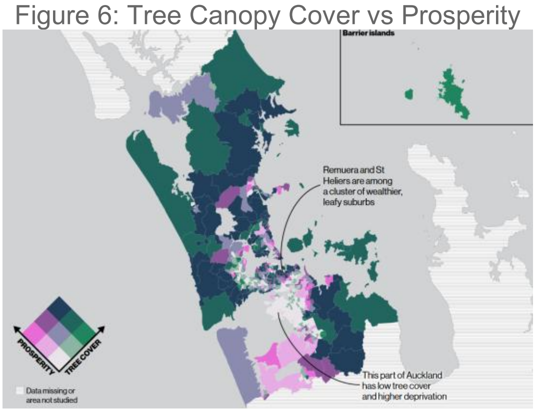
The notion of Shinrin Yoku, commonly referred to as 'forest bathing', is a way to connect with nature, and can serve to counter the lack of contact with nature highlighted by Kaplan, Louv, and Livni. Coined by Tomohide Akiyama in 1982 and extensively popularised through Qing Li’s scholarly work, this concept has garnered scientific validation (Li, 2018; Wohlleben, 2021). It posits that immersing oneself in a natural environment, specifically by engaging in walking activities within forested areas, can significantly enhance individual wellbeing. Empirical research indicates that forest bathing and other ways of connecting to nature, are associated with measurable physiological benefits, such as reductions in heart rate and cortisol levels, which are indicative of decreased stress (Li, 2018; Robinson et al., 2022; Wohlleben, 2021). Consequently, these physiological changes are correlated with an improved immune response, underscoring the therapeutic potential of nature-based interventions.

From an architectural perspective, a key concept is ‘biophilia’, defined as the innate love for all living organisms, which was introduced by Erich Fromm in 1964. This concept has been interpreted and applied in various contexts, notably within the architectural and design sectors as ‘biophilic design’ in the 21st century, a term popularised by Edward Wilson (Zhong et al., 2022). The biophilic design framework delineates three primary methodologies for integrating natural elements into built environments. The first method, named ‘nature incorporation’, involves embedding natural components—such as vegetation, water features, and natural air circulation—within or in proximity to architectural structures. The second method, ‘nature inspiration’, entails drawing geometrical patterns, colours, and textures from natural systems to inform design aesthetics. The third method, ‘nature interaction’, emphasises creating spatial and functional relationships that promote reciprocal engagement between occupants and natural elements (Zhong et al., 2022). This thesis primarily concentrates on the first and third approaches, examining how vegetation can be incorporated into, and how interactions with, natural elements can be facilitated within organisational settings. The second approach aligns more closely with the principles of biomimicry or biomimetics, which often lead to engineered designs inspired by nature without directly involving nature. In contrast, ‘nature interaction’ pertains specifically to human engagement with natural elements within the context of workplace environments. This approach is critical for the scope of this research and will be explored in greater detail in Section 3.3.2. It is also relevant to note that while artificial vegetation might be considered as a potential component within a biophilic design, it is an artificial representation of nature, and as such falls outside the scope of this thesis, as it serves only an aesthetic purpose, and the environmental impacts of artificial plants are negative rather than positive.

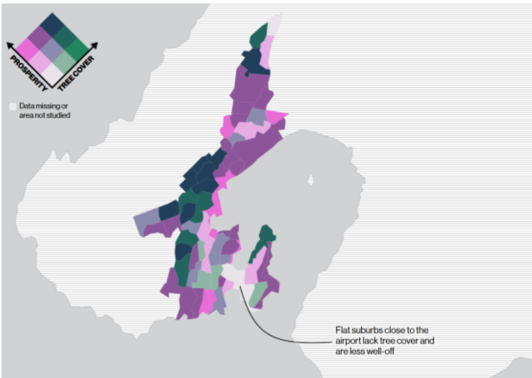
Following considerations of nature, health, and built environment factors, and prior to an examination of workplace environments, it is imperative to analyse the social implications of nature within urban contexts. Robinson et al.’s (2022) research critically explores underrepresented connections between biodiversity and health on a broader scale. His research highlights the importance of prioritising the health of indigenous populations, demonstrating how biodiversity loss disproportionately impacts these groups due to their intrinsic connection to natural ecosystems, with a positive correlation observed between their health outcomes and biodiversity levels. Robinson et al. (2022) also investigated the relationship between access to natural environments and socio-economic equity, positing that addressing biodiversity loss can enhance social equity within urban settings. This last connection emphasised in Robinson’s analysis has also been extensively examined by other researchers, some of whom are cited in section 3.2.1. In the context of ANZ, Newton et al. (2022) cross-referenced maps of tree cover with data on prosperity across major urban centres. The findings from this study demonstrate a significant association between access to natural environments and social equity, as illustrated in Figure 6. These results are further corroborated by the Auckland Urban Forest Canopy Cover report and the city's 2050 urban development strategy, which indicate that areas such as South Auckland—characterised by comparatively lower levels of prosperity—exhibit reduced access to roadside trees, parks, and other green spaces (Auckland Council, 2019; Golubiewski et al., 2020).

In addition to the factors discussed in this section, the context of Aotearoa reveals concerning trends in land use. Prior to human discovery and occupation, the country was 80% covered by indigenous forests, which has now declined to approximately 34% (Haggerty & Campbell, 2009; Land, Air, Water Aotearoa, n.d.). According to reported changes in land cover from 1996 to 2018, the trend is not improving. Within this 22-year time span, there has been a 12% increase in exotic forests, a 10% rise in cropland, a 15% growth in urban areas, and a 39% expansion of artificial bare areas. Notably, there has been no significant change in the percentage of indigenous forest, along with a slight 2% decline in native shrubland (Land, Air, Water Aotearoa, n.d.). This data underscores that while reserves and protected areas may safeguard certain locations, ANZ is still experiencing a substantial loss of natural spaces to urban and artificial bare areas, leading to a diminishing connection to nature in the environments where most people live.

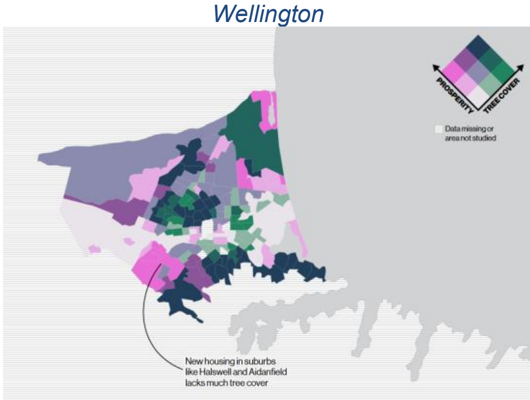
Figure 6: Tree Canopy Cover vs Prosperity




*Auckland*




*Wellington*




*Christchurch*

*The maps show the three largest urban centres in Aotearoa, cross-referencing tree cover in shades of green with prosperity (wealth) in shades of pink (Newton et al., 2022).*

### 3.3.2. Benefits of integrating nature in the workplace environment

Following an initial understanding of the influence of plants and nature on human wellbeing, the subsequent phase of the research involved focusing specifically on their effects within workplaces. The term 'workplace' is used broadly herein to encompass various settings, including office spaces, commercial establishments, manufacturing facilities, warehousing areas, and outdoor environments on these premises. Notably, existing literature predominantly concentrates on office workers and, occasionally, commercial settings. Nevertheless, the findings and interventions from this research are generalisable across different types of premises, provided that the implementation of NbS do not compromise food safety or pose health and safety hazards to occupants. For example, the use of plants in food manufacturing areas is typically prohibited due to concerns related to food safety, although such restrictions do not extend to break areas, corridors, or communal spaces.

This section examines the benefits of integrating nature in the workplace for workers by enabling access to and adding indoor and outdoor vegetation. It is well-documented that outdoor settings significantly influence employees' work experiences (Lottrup et al., 2013). Historically, the view from the window has been among the most studied elements; however, recent research is increasingly focused on gaining a deeper understanding of employees' interactions with nature and exploring ways to enhance access to natural elements throughout the workday. The discussion is organised around specific benefits, supported by evidence drawn from the existing scholarly literature.

Wellbeing, broadly defined as an overarching sense of personal and psychological health, manifests in diverse forms. It is a central focus within scholarly research, encompassing a wide spectrum of positive outcomes. These outcomes often catalyse further beneficial changes that can substantially impact employees' professional development, work performance, and work-life balance (EMS Business Redefined, 2024; Lottrup et al., 2013; Lygum et al., 2023; Petersson Troije et al., 2024).

The literature considers the concept of wellbeing through the evaluation of various parameters. As outlined in Section 3.3.1, one parameter is the influence of natural environments on stress reduction (Elliott, 2023; EMS Business Redefined, 2024; Lottrup, 2012; Lottrup et al., 2013; Lygum et al., 2023; Petersson Troije et al., 2024). Empirical evidence suggests that access to natural elements and vegetation within workplaces can enhance wellbeing by up to 15% through stress alleviation (Root in Nature, 2024). Furthermore, research conducted by Petersson Troije et al. (2021, 2024) indicates that nature provides a significant benefit to workplace wellbeing, offering a multisensory experience that engages visual, olfactory, and auditory senses. This sensory engagement fosters relaxation and stress relief. Additionally, outdoor environments are posited to serve as refuges where individuals can find relief from intense emotional states, which are typically associated with stress but may also include anger (Lottrup et al., 2013). From a health and safety workplace perspective, reducing stress also helps mitigate the risk of repetitive strain injuries and other hazards frequently associated with office environments and repetitive tasks (Petersson Troije et al., 2024).

An additional element is proposed by An et al. (2016), who suggest that increased exposure to nature and vegetation correlates with heightened job satisfaction among participants. Supporting evidence from various studies indicates a positive relationship among job satisfaction, depression, and anxiety (Fjeld et al., 1998; Lottrup et al., 2013; Petersson Troije et al., 2021, 2024), suggesting that increasing job satisfaction can help reduce anxiety and depression, and vice versa. Moreover, direct access to natural sunlight as part of access to nature has also been associated with a potential reduction in depression by up to 58% within occupational settings (Lottrup, 2012; Root in Nature, 2024).

Many researchers agree that introducing more nature and vegetation into workplaces increases workers' productivity (EMS Business Redefined, 2024; Fjeld et al., 1998; Lottrup, 2012; Lottrup et al., 2013; Petersson Troije et al., 2021, 2024; White et al., 2023). In addition to the positive aspect of wellbeing previously mentioned, increased productivity can also be explained from many different perspectives.

One way to increase overall employee productivity is by reducing employees' fatigue and increasing their recovery speed. The study performed by Fjeld et al. (1998) comparing offices with and without vegetation concludes that vegetation can reduce fatigue by up to 30% by enhancing the air quality of the space. Moreover, another study suggests that it helps diminish rumination and procrastination, and therefore avoids fatigue, improves employees thinking skills and makes them more alert (Petersson Troije et al., 2021, 2024).

A different approach to increasing workers' productivity is by enhancing cognitive resilience (Elliott, 2023; White et al., 2023). Cognitive resilience refers, for example, to the capacity to maintain focus on a task and includes the ability to recover from mental fatigue to continue the task. White et al.'s (2023) study suggests that nature contact aids in increasing the 'mental bandwidth' and restores exhausted attention resources. In that way, workers with access to nature can benefit from a longer attention span, longer working memory and faster recovery, resulting in higher productivity.

Alongside the benefits of cognitive resilience are those of emotional resilience, which enables individuals to better manage work-related challenges and complex interpersonal situations, thereby potentially increasing overall productivity (Petersson Troije et al., 2024; White et al., 2023). This capacity is connected to the wellbeing benefits previously mentioned of nature's capacity to reduce anger, anxiety and depression. This reduces tiredness and increases the speed of recovery (Petersson Troije et al., 2021).

Providing outdoor working spaces can also strengthen interpersonal relationships within workplaces (Lygum et al., 2023; Petersson Troije et al., 2024). Empirical research conducted in office environments indicates that outdoor settings can contribute to improved communication and social interactions among colleagues. Participants in these studies reported that meetings and conversations held outdoors tend to be more relaxed, reduce hierarchical barriers, and promote greater openness in communication (Lottrup et al., 2013;

Petersson Troije et al., 2021). From a more individual perspective, employees who had the chance to work outside expressed that these added a new ‘dimension’ to their work environment, and gave them a sense of autonomy and trust from their managers (Petersson Troije et al., 2024).

Businesses can also profit from the benefits that vegetation and access to nature have on other factors. For instance, workplaces with vegetation see a 10% reduction in absenteeism from sick and stress-related conditions (Root in Nature, 2024). Fjeld’s et al. (1998) study on workplace air quality supports this trend highlighting how plants help clean indoor air and reduce the transmission of diseases.

Boosting creativity has been highlighted as another benefit of vegetation within workplaces (Elliott, 2023; EMS Business Redefined, 2024; Lottrup et al., 2013; Root in Nature, 2024). Research indicates that access to natural environments and the integration of vegetation within the workplace may enhance cognitive functioning (Petersson Troije et al., 2021, 2024) and problem-solving skills (Elliott, 2023), by providing a conducive environment for reflection, inspiration, and innovative thinking.

Overall, incorporating vegetation and natural elements within the workplace - although sometimes challenging to quantify across different contexts and populations - demonstrates significant benefits to businesses. These can also be identified and measured from a people and culture perspective, as the overall effects of these suggest improving job satisfaction, work-life balance and thus employee retention (An et al., 2016; Petersson Troije et al., 2021; Root in Nature, 2024).

### 3.3.3. Considerations to enable nature within workplaces

Considering the wellbeing benefits associated with incorporating vegetation within work environments and facilitating access to natural elements for employees, it is essential to examine practical strategies for effective implementation. Whether the integration involves indoor plantings or outdoor landscapes, existing literature and experiential insights from both industry practitioners and researchers offer valuable guidance on methodologies for successful application or potential pitfalls to avoid.

For example, Mike Robinson (2018), a New Zealander entrepreneur based in Canada, recounts his experience in a TED Talk. His wife proposed the idea of placing a small plant on each employee’s desk, allowing employees to select from several plant options and subsequently naming these plants as if they were colleagues. Initially, Robinson was sceptical of this approach, concerned that it might lead to inefficiencies and unnecessary expenditure of time and resources. However, the initiative proved to be successful. Although some time was dedicated to plant care, the intervention fostered increased employee engagement, enhanced job satisfaction, and contributed to creating a more welcoming office environment. This example illustrates that implementation strategies do not necessarily require substantial financial investment or extensive resources to achieve positive outcomes.

Konijnendijk (2024) proposes four fundamental principles for integrating nature into urban environments, which are equally applicable to individual premises. These principles include:

- Proximity: Making natural elements visible and accessible, for example, providing access to outdoor green spaces for activities like lunch breaks or work-related leisure, without necessitating travel away from the premises or integrating indoor plants when outdoor access is limited.
- Diversity: Designing functional and versatile environments that accommodate multiple uses - such as conducting work meetings, video calls, taking lunch breaks, or hosting various work functions - depending on the time of day.
- Connectivity: Including vegetation across more than one space and creating the likes of internal green corridors to connect them. Outdoors, connection could enable urban green corridors to benefit biodiversity.
- Equity: Ensuring equitable access to green spaces across all social strata, including various departments and hierarchical levels within the organisation fostering inclusive work environments.

An essential factor to consider is the availability of physical access to natural environments and vegetation. Although previous studies have suggested that visual access to nature can have beneficial effects within workplace settings (An et al., 2016; Elliott, 2023; Konijnendijk, 2024; Lottrup, 2012; Petersson Troije et al., 2021), empirical evidence indicates that direct physical access to green spaces is associated with more positive attitudes towards the workplace compared to employees with solely visual access to nature (Lottrup et al., 2013; Lygum et al., 2023; Petersson Troije et al., 2024). There are four key factors to consider for outdoor environments:

One of the key factors that employees highlighted across several studies was the need for outdoor green spaces to be safe. Outdoor spaces that feel unsafe can distract workers and unsettle them, preventing them from focusing on their task at hand, or relaxing during a break (Konijnendijk, 2024; Lygum et al., 2023; Petersson Troije et al., 2024).

The second factor highlighted by office workers is their dependency on their laptops and devices. Therefore, whether indoors or outdoors, access to wi-fi and, in some cases, electrical power was identified as a requirement to enable the use of other workplaces (Lottrup et al., 2013; Lygum et al., 2023; Petersson Troije et al., 2024).

The third consideration pertains to comfort and protection from environmental elements. Although outdoor environments are typically associated with favourable weather conditions, it is essential to incorporate a degree of comfort to accommodate less predictable conditions. For example, solar exposure can pose challenges such as sunstroke, sunburn, or undesirable glare on electronic devices like laptops. Additionally, wind can generate sensations of discomfort and coldness, potentially impeding productivity (Lottrup et al., 2013; Lygum et al., 2023; Petersson Troije et al., 2024; Stanley, 2025). Chapter 5 proposes practical strategies to implement a comprehensive range of solutions aimed at optimising comfort and safety within these environments.

The final aspect to consider is the comprehensive design of the outdoor environment. Empirical investigations indicate that there is no significant correlation between mowed grass and job satisfaction (Lottrup et al., 2013). In contrast, a study performed in Aotearoa suggests that a varied presence of trees, plants, flowers with a range of colours, shapes and aromas, has been associated with an enhanced sensorial experience, which can contribute positively to employee well-being by reducing cortisol levels (Souter-Brown et al., 2021). Furthermore, designing the space to facilitate pedestrian movement, as well as incorporating designated areas for sitting, working, and relaxing, promotes functional diversity and connectivity among employees (Konijnendijk, 2024; Lottrup et al., 2013; Petersson Troije et al., 2021).

While the considerations outlined in this section help develop practical strategies to encourage employees' use of vegetated spaces, it is equally important to recognise the behavioural challenges organisations may face in promoting such usage. Studies in this field show the presence of internal resistance and habitual barriers, with some participants expressing feelings of guilt when using these spaces, as they are seen as signs of laziness or a weak work ethic (Lottrup, 2012; Lottrup et al., 2013; Petersson Troije et al., 2021, 2024). To address these challenges, organisations need to understand the impact of cultural, gender, and generational factors. For instance, Petersson Troije et al. (2024) found that, due to historical gender biases, male participants tend to spend more time outdoors than females. Additionally, organisations need to understand the dichotomies and preconceptions surrounding outdoor work (if working outdoors is sometimes viewed as challenging the status quo). These are not inherently positive or negative, and should be perceived simply as different approaches. This became clear after COVID and the return to offices, especially since many companies encouraged outdoor work (or working from home) to reduce virus transmission. COVID, which forced many to work remotely, also highlighted the need to get outside, as people felt trapped indoors all day and sought refuge from overstimulating environments (Petersson Troije et al., 2024).

It is imperative to recognise that any modifications and enhancements within the workplace must be supported by explicitly articulated policies formulated by organisational leadership. Furthermore, this encompasses the pivotal function of leadership in fostering employee empowerment to influence and reshape their perceptions and attitudes (Petersson Troije et al., 2024). Following management systems best practice, these processes can be strengthened by being documented and reviewed periodically to ensure they are still fit for purpose (International Organization for Standardization, 2015; Toitū Envirocare, n.d.).

## 3.4. Exploring Mātauranga Māori

Given that this thesis is focused on the application of NbS in Aotearoa, it is important to consider the use of mātauranga Māori. This consideration emerged prominently during the interviews, as discussed in Section 4.7, with several participants emphasising its significance. However, in light of the positionality statement outlined in Section 1.1.2, an emphasis on this aspect requires careful navigation to prevent misinterpretation or cultural appropriation. This section aims to establish a foundational perspective for contemplating the potential of embedding mātauranga Māori within this research. Most critically, it seeks to promote its genuine and holistic implementation across Aotearoa's business environments, fostering an approach that respects and incorporates Māori knowledge systems.

In her publication titled 'Aroha', Elder (2020) emphasises Māori perspectives regarding the natural environment, which markedly diverges from predominant Western paradigms. For example, Elder elucidates how Māori tribal affiliations extend to encompass natural entities such as the ocean, lakes, rivers, and mountains. These geographical features are frequently articulated through 'Pepeha', a traditional introduction that signifies individual heritage and origins by referencing the watercourses and mountain ranges indicative of their iwi or region, thereby fostering a sense of grounding and belonging (Elder, 2020). Furthermore, Māori socio-cultural identity intricately integrates concepts of nature within their genealogical framework, known as 'whakapapa'. Supporting this, Yates (2019, p. 6) describes whakapapa as:

> "An ontological framework that attests to a multi-species lineage where earth, skies, rivers, and mountains, for example, have agency and importance as ancestral entities".

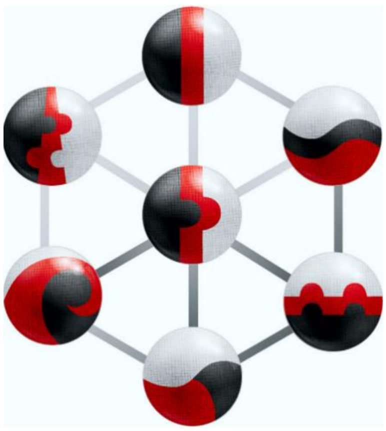
The prominence and authority attributed to nature and natural elements by the Māori community indicate that their perspective on NbS may significantly diverge from a Western utilitarian approach. The Māori worldview emphasises an intrinsic and holistic relationship with the environment. While these differing ideologies may sometimes lead to conflicts, they also present opportunities to develop diverse strategies for addressing environmental and climate change challenges from multiple perspectives (Elder, 2020).

An element that was commonly identified by both, Elder and Kaplan, was the admiration and contemplation of natural cycles and elements such as plants, flowers, clouds, and the ocean. Elder (2020) does it using the term 'joy in small things' and Kaplan (1995), as explained in Section 3.3.1,  named it 'soft fascination'.

Given the intent to integrate mātauranga Māori into the research framework and its potential applications, the concept and discourse surrounding mātauranga Māori was incorporated into the qualitative research interviews.

The Kaitiaki Atua framework developed by Walker et al. (2021), has the potential to serve as a foundation for embedding mātauranga Māori within this research. This framework was conceived with the purpose of environmental and spatial planning, focusing on harmony, the balance of natural forces and kotahitanga (unity – collective action) (Walker et al., 2021). It comprises seven deities, each representing a distinct Atua, or Māori deity. These Atua were deliberately identified and selected to embody specific values pertinent to environmental and spatial planning. Each deity is associated with a tohu (symbol) that visually signifies their presence within the framework, which is illustrated in Figure 7.

Figure 7: The Kaitiaki Atua Framework



**Tāne** symbolises birds and forests, and occupies a central position serving as the focal point of Walker et al. (2021)'s research into monitoring the health of indigenous forests from a Māori perspective.

**Tūmatauenga** represents people and warfare, encapsulating political & social issues.

**Rongomātāne** signifies agriculture and peace.

**Haumiatiketike** is associated with ferns and wild foods.

**Rūamoko** embodies geological phenomena.

**Tangaroa** governs the ocean and waterways.

**Tāwhirimātea** symbolises winds, clouds, and storms.

*Graphic design of Walker et al.'s Atua Framework (Walker et al., 2021).*

The other elements within the framework warrant significant consideration. For example, the hexagonal configuration echoes natural structures such as beehives and basalt columns, evoking perceptions of strength and stability. The Atua are systematically arranged in triangular formations, each set of three symbolising their whakapapa and denoting the interconnected relationships among Atua, iwi (tribes), and individuals. Additionally, this triangular motif is referred to as niho taniwha, a saw-edged pattern representing the “tooth of a supernatural being." The selected colour palette - comprising black, white, and red - is emblematic of Aotearoa’s traditional arts and the Tino Rangatiratanga (Māori flag).

This Atua framework, although not explicitly designed to address NbS within business premises, shares the significant component of being developed for the purpose of environmental and spatial planning that facilitates the integration of a holistic and integrated Māori cultural perspective. This shared element enhances the potential for applying a Māori worldview, thereby enabling a comprehensive and interdisciplinary approach informed by mātauranga Māori. Such an approach considers the interconnectedness of social challenges and natural environments by incorporating community participation and emphasising the sustainability of solutions for the well-being of both society and the natural world. As Walker et al. (2021) explains:

> *“Māori communities are blending together Māori and Western knowledge systems, building contemporary Atua frameworks to underpin their spatial planning tools and ground their practice of kaitiakitanga in te ao Māori. Are these approaches transferable from the rivers and forests to cities, from the natural to built environments? We contest that Atua frameworks have the potential to be an overarching point of reference within multiple spatial planning and resource management contexts”* (Walker et al., 2021, p. 97).

While the framework has certain limitations, such as being two-dimensional and having limited connections among ngā Atua, its successful application in various research projects (e.g. ‘Toitū te Whenua, Matatū ana te Wao Nui a Tāne’ and ‘Map-based tools for Community and Rūnanga-led sustainable town planning’) underscores its utility (Walker et al., 2021). Furthermore, it is posited that the framework serves as a foundational model, amenable to adaptation to specific geographical, iwi, and location contexts. The implementation of indigenous-centred approaches, therefore, necessitates active community engagement and Māori-led discussions to effectively tailor the Atua framework to local needs or develop alternative approaches for incorporating mātauranga Māori into the development and implementation of NbS (Walker et al., 2021).

## 3.5. Vegetation’s opportunity factors

To develop effective solutions for addressing EE and WW in existing business premises through the application of vegetation, it is essential to identify and emphasise five fundamental factors that such strategies will utilise to mitigate energy demand and enhance WW. These factors are shading, evapotranspiration, airflow, filtration, and visual and acoustic elements. The strategic application of vegetation to modulate these processes can significantly influence both the internal and external environments of buildings, generating a microclimate effect that not only supports EE initiatives but also improves WW outcomes. Within this section, specific NbS will be systematically examined and evaluated concerning their potential benefits and associated challenges pertinent to Aotearoa, taking into account local climatic conditions as outlined in Section 3.2.3.

### 3.5.1. Shading

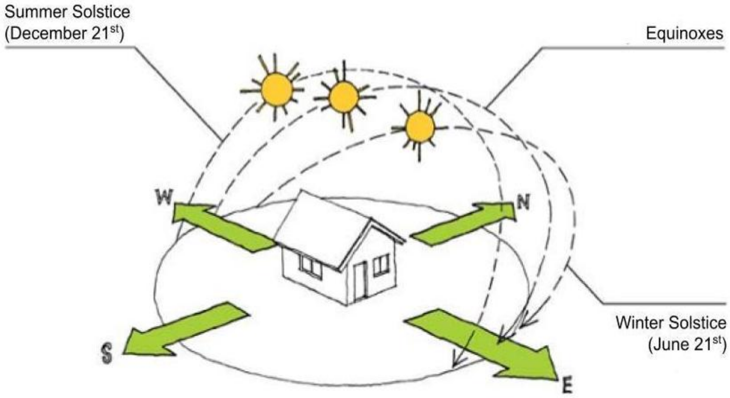
The effective use of shading, to either temporarily or permanently reduce the natural solar energy reaching specific surfaces, has been a foundational concept of building design for centuries. A notable example is the use of grapevines on pergolas or trellised awnings in southern European homes for over two millennia. This practice has been employed to provide shade for houses, internal patios, and galleries during the summer while also reflecting some heat back to the grapes, thereby promoting their ripening for consumption and winemaking (Fassaden Grün, n.d.; Scherer, 2014).

Solar exposure is a fundamental aspect of building design, with one of the initial steps in the building design process considering the building's orientation. This includes carefully planning the location, number, and shape of windows, among other factors. The orientation of buildings falls outside the scope of this research; from a practical standpoint, retrofitting or making minor adaptations to a building does not entail relocating it or completely redesigning its façade. However, this principle is critical when evaluating how a building is positioned to optimise solar energy exposure

Vegetation serves as a basic, versatile, and effective resource that can help manage solar radiation before it reaches the building envelope (BRANZ, 2024, 2025; Bustamante, 2009; Gonzalo & Vallentin, 2014; Kuhns, 1993; Macara, 2018; Misni, 2018; Raji et al., 2015). From a first principles approach perspective, effectively managing solar irradiation for the building is far more efficient than relying on engineered cooling or heating systems to mitigate its effects after the energy has penetrated the envelope or entered the interior.

In this context, it is important to understand the solar trajectory at the latitude of the building in order to effectively project and manage shade (Bustamante, 2009; Heisler, 1986). Figure 8 illustrates the daily solar trajectory, which begins at sunrise in the east and concludes at sunset in the west. In the southern hemisphere, optimal orientation for solar gain is to face north, while the opposite is the case in the northern hemisphere. Because the focus of this study is Aotearoa, guidelines and research undertaken in the northern hemisphere was adapted for use in the south. In addition to the daily solar trajectory, it is essential to consider the annual solar inclination for each season, with summer solar gain being the most significant and occurring at a higher angle compared to winter. Understanding the sun's trajectory is vital for modelling the shade that could be provided by vegetation.

Figure 8: Sun's Trajectory in the Southern Hemisphere




*Graphic design of the sun's trajectory in the southern hemisphere with regard to the terrestrial surface. Translated from the original source (Bustamante, 2009).*

From an EE and insulation perspective, using vegetation to mitigate solar irradiation to prevent overheating is effective due to plants' thermophysical properties (Jayalakshmy & Philip, 2010). Jayalakshmy and Philip (2010) demonstrate that the thermal properties of leaves - namely, thermal conductivity (the ability to transfer heat), specific heat capacity (the ability to absorb heat without an increase in temperature), and thermal diffusivity/effusivity (the ability to absorb heat and release it later) - are significantly superior to those of materials such as concrete, sand, and water. As a result, leaves, including dead leaves, effectively act as a heat sink.

In the context of WW, the regulation of direct sunlight exposure can significantly influence employees' wellbeing, mood, and overall productivity (Lottrup, 2012; Root in Nature, 2024). Implementing shading elements can also help mitigate glare and reflections, which may otherwise impair visual comfort and negatively impact employee performance (Mangone et al., 2014; Petersson Troije et al., 2024), as discussed in Section 3.5.5.

Shading provided by vegetation in temperate climates, such as Aotearoa, can effectively reduce heat gains during the summer months. For instance, shaded concrete surfaces are 11°C to 25°C cooler than those exposed to the sun in peak summer (Dhakal et al., 2022, p. 19). However, depending on the specific building and location, this may not be desirable in winter, when warming, rather than cooling is often a priority. According to Gonzalo & Vallentin (2014, p. 39), a practical guideline is to shade sun rays by 95% to 60% in summer and 10% to 30% in winter. A different approach is suggested by Waterfield (2011), who emphasises the importance of considering the distance and height of vegetation in relation to the building envelope, as these factors can influence sunlight exposure differently across seasons. The literature indicates that there is no universal solution applicable to all buildings in Aotearoa or beyond. The well-known phrase, "the right tree in the right place for the right purpose," captures some of this complexity, but the concept of 'right' and its broader applications to vegetation are difficult to define. Vegetation can provide shade through various strategies, which will be reviewed in Section 5.1.

### 3.5.2. Evapotranspiration

Evapotranspiration is a natural homeostatic process inherent to plants, which is similar to the way humans sweat. Plants lose water through the stomata on their leaves as they respire and photosynthesise. Thus, evapotranspiration can contribute to cooling the surrounding air as a result of the heat absorbed during the vaporisation of water from the surrounding foliage (Jim & Chen, 2009).

This process is often quantified by measuring the amount of water lost per tree or per square meter of vegetation, as well as by calculating the daily kilojoules of heat energy expelled (Jim & Chen, 2009). It has been estimated that an average mature tree can lose approximately 378.5 kg of water on a hot summer day. (Chen & Jim, 2008, p. 58). Research by Bakhshoodeh et al. (2022) aimed to differentiate the cooling contributions of shade and evapotranspiration from green façades, concluding that evapotranspiration accounts for 35% of the overall cooling effect.

For EE purposes, the primary focus of evapotranspiration is its cooling effect, which is particularly relevant in summer and is typically disregarded or viewed negatively in winter. However, evapotranspiration rates decrease during colder temperatures. It is also important to note that these rates increase with airflow or wind speed, which will be discussed in Section 3.5.3. Besides its cooling benefits for EE, the process of evapotranspiration has additional co-benefits related to NbS, as it supports the water regulation cycle. From a WW perspective, evapotranspiration helps reduce air pollutants as the added moisture assists in settling airborne particulates (Chen & Jim, 2008; Jim & Chen, 2009), which will be discussed in Section 3.5.4.

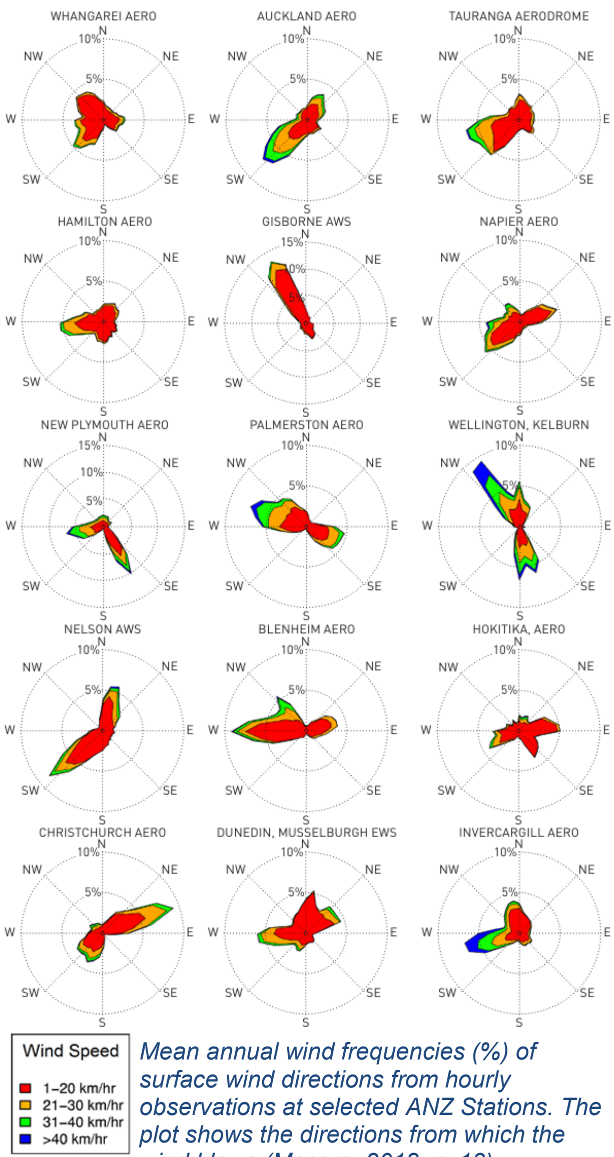
The same way evapotranspiration by outdoor vegetation contributes to the formation of microclimates around a site and helps mitigate the UHIE (Dhakal et al., 2022; Jim & Chen, 2009). Indoors, evapotranspiration can improve WW in naturally humidifying dried environments by HVAC systems and thereby help to alleviate ‘Sick Building Syndrome’ symptoms, such as dry skin and coughing caused by artificial ventilation (Fjeld et al., 1998; Liu et al., 2022; Raji et al., 2015). However, in extremely humid conditions, it can have adverse effects, leading to increased condensation and subsequently promoting mould growth, which can negatively impact indoor air quality (Mangone et al., 2014).

## 3.5.3. Wind - Air Flow

The third factor which needs to be considered is the velocity of air movement, specifically wind. As previously noted in Section 3.2.1 and 3.2.2, wind can enhance the air exchange rate within the building envelope and improve cooling through evapotranspiration from both the structure and the surrounding vegetation. However, this effect is heavily reliant on wind speed and direction, with warm tropical winds originating from the north and cold Antarctic winds coming from the south. Wind patterns and lee zones in Aotearoa vary across different climate zones and are influenced by factors such as ground roughness and natural topography, which urban landscapes may also modify (BRANZ, 2018; Chen & Jim, 2008; Macara, 2018, p. 13).

Understanding prevailing wind currents in Aotearoa, and average speeds in each region, is essential for developing an effective strategy to protect buildings from the wind. Macara (2018, p. 13) provides a graphic representation of the mean annual frequency of winds for 15 urban centres across Aotearoa (see Figure 9). For example, in Auckland, the predominant and strongest winds come from the southwest. As such, implementing a windbreak or shelterbelt to shield against the cold winds from Auckland's southwest could reduce heat loss, subsequently lowering energy demand for heating in winter. Conversely, in Gisborne, the prevailing wind originates from the northeast and typically travels at a slower speed. As such, suggesting a windbreak strategy in this region has the potential to enhance the microclimate for outdoor comfort, which may not significantly impact winter heat loss but could potentially decrease cooling demand during the summer months.

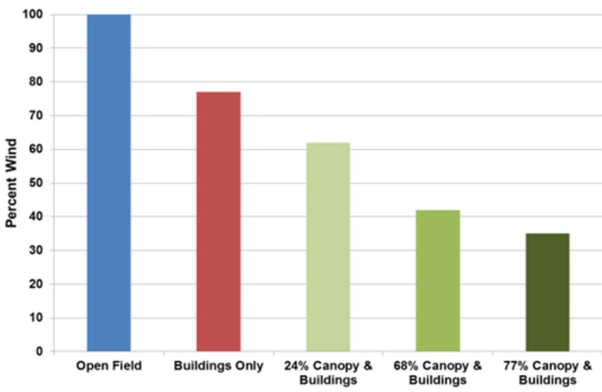
Figure 9: Mean Annual Wind Frequencies (%)




*Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected ANZ Stations. The plot shows the directions from which the wind blows (Macara, 2018, p. 13).*

Research by Potyondy (2013) indicates that more than one-third of a building's heating can be lost to wind infiltration. While it is not always possible to block or deflect winds, air exchange rates can be reduced by dampening them. Vegetation can play a vital role in slowing down winds as the friction applied by the leaves and the variable shape and surface of vegetation aid in decreasing wind speed around structures or sites (BRANZ, 2018). Overall vegetation, including deciduous trees during winter, can significantly reduce wind speed and associated heat loss. As illustrated in Figure 10, Potyondy's (2013) adaptation of Heisler's (1986, p. 4) research demonstrates that strategically planting trees around buildings can reduce wind speed by over 50%, especially with a canopy cover of 77%.

Figure 10: Resulting Winter Wind Speed at House Site from Obstructions within 300m (%)




*Graph showing the resulting wind speed at a given house site as a result of buildings and various densities of tree canopy (Potyondy, 2013, p. 45).*

Winds and overall air flow have shown to have a significant impact on thermal comfort. For instance, a wind speed of 6 m/sec can alter the perceived temperature from 15.5°C to 12°C (BRANZ, 2018). This effect underlines the need to manage this factor to boost thermal comfort.

BRANZ (2018) provides guidelines for managing wind around buildings in Aotearoa. These guidelines provide strategies that can help create a microclimate that enhances EE year-round and improving WW by increasing comfort in outdoor working areas (Petersson Troije et al., 2021, 2021). Moreover, windbreaks help to lower noise levels from outside the boundary, mitigating rain impact, and ultimately increase property value.

## 3.5.4. Filtration

The fourth factor pertains to the capacity of vegetation to filter air and consequently improve overall air quality. As outlined in Section 3.2.4, air quality has emerged as a significant concern within commercial environments. This is primarily due to the decline in natural ventilation in modern buildings, which increasingly rely on HVAC systems and artificial air filtration and moisture regulation (BRANZ, 2025; Elliott, 2023; EMS Business Redefined, 2024; Fjeld et al., 1998; Old & Jones, 2024; Wu & Flemmer, 2020). These ecosystem services, namely air filtration, oxygenation, and moisture management, serve to alleviate the burden on HVAC systems, thereby enhancing EE and improving WW (De Vries et al., 2023; Fjeld et al., 1998; Wolverton et al., 1984).

The process of photosynthesis offers a clearer explanation of the oxygenation mechanism, whereby plants utilise water, sunlight, and carbon dioxide to produce oxygen. Due to limited ventilation in many indoor environments, this process plays a crucial role in restoring and maintaining healthy oxygen levels (De Vries et al., 2023; Fjeld et al., 1998; Liu et al., 2022). In terms of air filtration, specifically the removal of airborne particulates, the related process of evapotranspiration occurs, as detailed in Section 3.5.2. As Meattle (2009) elucidates, plants are capable of “growing fresh air"—a phenomenon extensively studied by NASA for potential applications in sealed indoor environments in outer space.

Given the evidence on poor air quality in commercial buildings, the concept of Sick Building Syndrome (SBS) was coined in the United States in 1974. SBS describes a condition where occupants in office settings display symptoms such as fatigue, headaches, ocular and skin irritation, cough, and other respiratory issues attributable to compromised indoor air quality (Fjeld et al., 1998; Liu et al., 2022; van Wicklen, 2023; Wu & Flemmer, 2020). This phenomenon predominantly concerns indoor environments; and there is evidence demonstrating that plants can substantially improve indoor air quality, mitigating SBS symptoms, as well as improving overall air quality at a city or neighbourhood level, as discussed in Section 3.2.1.

The effects of SBS in indoor environments are not only attributed to the design of those spaces but also to occupants' behaviour in their use. Liu et al. (2022) emphasise that although buildings may have access to natural ventilation, their utilisation tends to decrease during the winter season due to heating requirements. Additionally, closing windows to mitigate noise pollution in urban environments, particularly near busy roads, further limits natural airflow (Lottrup, 2012; Petersson Troije et al., 2024). These findings suggest that incorporating indoor plants can serve as a beneficial strategy in many scenarios, contributing to improved indoor air quality even when outdoor access and natural ventilation are available. Indoor plants may serve as a means of ‘growing fresh air' and can reduce reliance on mechanically engineered air-purification solutions (Meattle, 2009; Wolverton et al., 1984).

### 3.5.5. Visual and Acoustic Effects

The last factor to consider are the benefits vegetation provides to the visual and acoustic senses. While these senses differ, the common factor considered is their ability to dampen, hide, or enhance the visual and auditory aspects in workplaces (De Vries et al., 2023; EMS Business Redefined, 2024; Lottrup et al., 2013; Lygum et al., 2023; Mangone et al., 2014; Pearson-Mims & Lohr, 2000; Petersson Troije et al., 2024).

For instance, as discussed in Section 3.3.2, the use of both indoor and outdoor spaces has been found to reduce stress, anxiety and increase performance. Indoors, strategically arranged plants can offer more privacy to workspaces, and increase the workplace attractiveness and overall satisfaction (De Vries et al., 2023). Another study suggests that indoor vegetation aids in reducing light glare and overall light levels (Mangone et al., 2014), by absorbing light for their natural processes, which are also connected to their intrinsic heat absorption capacity (Jayalakshmy & Philip, 2010). In their research, Pearson-Mims & Lohr (2000) suggest that plants can be key enablers in developing effective open-space offices, shifting from a cubicle design by replacing walls with plants which become a key design element. Offices designed with plants are perceived as more flexible, easier to remodel, and more pleasant (Elliott, 2023; Pearson-Mims & Lohr, 2000).

In terms of acoustics, outdoor vegetation has been shown to mitigate noise pollution emanating from busy streets or commercial districts (Chen & Jim, 2008; Jim & Chen, 2009). Additionally, outdoor greenery contributes to the attenuation of ambient noise through natural soundscapes created by wind interacting with foliage and the presence of birdlife (BRANZ, 2018; EMS Business Redefined, 2024). This phenomenon aligns with the biodiversity enhancement ecosystem service discussed in Section 3.1. In indoor environments, the benefits of vegetation appear to mirror those observed outdoors, as plants reduce indoor noise levels by partially absorbing sound, especially compared with rigid surfaces such as glass, hard flooring, and solid walls (EMS Business Redefined, 2024; Pearson-Mims & Lohr, 2000; Raji et al., 2015).

This last factor appears to have a more pronounced impact on WW. Nevertheless, the visual and acoustic effects also influence EE through external factors beyond the scope of this analysis, such as the need to increase screen brightness to mitigate glare and the use of noise-cancelling headphones or high-volume audio systems to mitigate auditory disturbances. Additionally, including this factor provides a holistic approach to ensure these two elements are considered when assessing the strategic solutions that all other factors will inform. In other words, when assessing solutions for shading or wind, the protection from sun or wind can also incorporate privacy elements and visual or acoustic benefits.

## 3.6. Conclusion

Overall, the literature presented in Chapter 3 indicates that, although the concept of NbS is not frequently associated with EE and WW purposes, this does not preclude their potential application. More importantly, the review underscores the significance of adopting a holistic perspective and advocating for the consideration of EE and WW alongside a diverse array of co-benefits, trade-offs, local climatic conditions, biodiversity outcomes, and cultural values.

Despite the growing recognition of NbS at the urban and regional levels, their implementation in individual business settings remains relatively unexplored.

Lastly, throughout the research, five key opportunity factors were identified. By harnessing the capabilities of vegetation to provide shading, enhance evapotranspiration, regulate wind, filter air, and offer visual and acoustic benefits, organisations can effectively reduce energy demand. This approach contributes to fostering healthier, more productive, and more satisfying workplace environments.

As a result, the findings of this chapter provide both the conceptual and practical foundations for the subsequent analysis and development of NbS and implementation frameworks, which will be addressed in the following chapters.

# Chapter 4. Perspectives from Experts on Nature-based Solutions for Aotearoa

This chapter presents the findings of the interviews undertaken with 25 experts on a range of dimensions of NbS. As discussed in Chapter 2, each interviewee was asked a series of open-ended questions (outlined Appendix 2). Their responses were then systematically analysed to identify and explore the key themes presented in this chapter. This chapter begins with the interviewees' perspectives on the conceptual framework of NbS and then examines the implications of NbS within the context of EE and WW. Most participants viewed the research topic and the proposed solutions as a novel area of inquiry. They noted their limited experience and exposure to NbS, particularly concerning EE and WW, and highlighted its potential for retrofitting through the integration of vegetation. Following the three exploratory elements previously mentioned, the analysis centred on organising the themes and topics that surfaced from these discussions. The final section provides a summary of the barriers and opportunities identified. While some of the interviews diverged from the planned interview questions, their value, given the calibre of the interviewees, was immense, highlighting knowledge gaps and challenging the existing research approach. The interviewees not only helped steer the literature review presented in Chapter 3 but contributed significantly to the development of the final framework presented in Chapter 5.

## 4.1. Perspectives on the Concept of Nature-based Solutions

One of the initial questions posed to all interviewees was to define NbS in their own words. This question served two purposes. First, it provided insight into whether the experts had critically engaged with the concept, or its applications and implications. Second, it stimulated discussion about what they believe can, and cannot, be considered an NbS.

Despite being a concept that might seem 'self-explanatory,' participants had varied interpretations of what NbS entail. Most found it challenging to provide a formal definition and to delineate interventions that could be categorised as NbS. Participants who were not ecologists or in the academic environment were often surprised by this question, as they had not previously considered it. While the interviewees from the research sector did not have a formal definition, they appeared more at ease in articulating their own interpretations. This may stem from the fact that researchers typically have more experience in theoretical aspects, whereas participants such as architects, engineers and consultants tend to focus on the practical application of research.

Many participants agreed that NbS are characterised by several key factors:

- Sustainable: NbS need to be sustainable, long-lasting and possess a degree of self-sufficiency.
- Solution-oriented: NbS are developed to address and resolve a problem, which is inherently a human-made issue and societal challenge.
- Holistic: NbS simultaneously tackle a variety of issues, including water management, food security, and risk mitigation, among others.
- Bespoke: Recognising the unique nature of each problem and location, several participants argued that these solutions need to be tailored or explicitly framed for their context, rather than being viewed as standardised 'products' that can be implemented in a one-size-fits-all manner.

One theme that sparked differing opinions was the use of sustainably engineered products that could be made from natural ingredients or components and were biodegradable. Several participants working in the construction sector agreed that these could be regarded as an NbS, as the artificial materials created were based on natural elements. Conversely, many participants rejected this idea, arguing that these so-called 'solutions' were highly manufactured and engineered, and not 'alive', suggesting they would qualify as sustainable products but not as NbS. An example discussed was Respyre's (n.d.) concrete façade that enables the growth of moss. This product was well-regarded and perceived as sustainable mostly by architects, engineers and construction consultants interviewed. However, some participants argued that the concrete by Respyre is a product that can enable a sustainable, holistic, and effective solution, as long as it addresses a specific problem and is one of many elements that contribute to the development of NbS. This led to the exploration of the concepts of biomimetics and biomimicry, as discussed in Section 3.1.1.

There were also other key points that, although not particularly controversial, highlighted gaps in the research and sparked further ideas that were incorporated into the research.

One of the participants questioned whether doing 'nothing' could be considered a NbS, as the absence of human intervention and manipulation of an ecosystem will result in nature taking over. He explained:

> *"You could argue that doing nothing is a nature-based solution because nature itself will come back… nature-based solutions [are] our interpretation of what nature should look like in some ways, because nature doesn't always, you know, comply with what we want it to do"*

While this is an interesting point of view worth exploring further on how nature adapts in the absence of human interventions, it is outside the purpose of this research.

Another participant, knowledgeable in the concept, raised the fact that NbS should be developed with a focus on them being ‘reciprocal’. That is, that the relationship between the solution and humans had to be considered a symbiotic relationship, rather than one in which one party provides for the other. She explained:

> *“I see it with green roofs often – the most amazing roofs with the greatest overall values usually have people involved that interact with them frequently – the reciprocity benefits the person and the roof. Maybe that should be one of the key NbS concepts – reciprocity with nature.”*

This element was not found in the literature but was used in the suggested conceptualisation of NbS presented in Section 5.1.

Lastly, a Māori interviewee argued that the concept of NbS, as conceptualised in the academic literature, is rooted in a Western perspective that tends to divide nature from people, in contrast to Māori perceptions of humans as part of nature. He explained:

> *“Architecture is something I studied, but fundamentally for myself it's [informed by my] cultural background, … it's my culture's worldview of how we see things, and … [our] identity… There's the academic studies of architecture and in form and function... [which tends to separate] the man-made and the natural. So, you get that constant playoff as Māori… there was always a problem with that for me, and the fact is hard to separate yourself [from nature]…”*

This topic is further developed in section 4.7.

After the discussion of the concept of NbS was nearing its end during one of the interviews, a participant asked, “What is <u>your</u> definition of NbS?” The question led to further discussion, including the suggestion that there is room for improvement for the existing definitions found in the literature. The participant suggested and encouraged the inclusion of a definition that could lead to further discussion. Therefore, as part of this thesis I propose a new definition of NbS incorporating the lessons of this research in Section 5.1.

## 4.2. Nature-based Solutions and Energy Efficiency

When investigating whether EE strategies and applications were considered NbS and exploring participants’ knowledge and experience in implementing NbS, the findings were unexpected and led to a significant shift in the approach for the remainder of many interviews.

All participants possessed a foundational understanding of EE, with many having designed strategies or buildings aimed at enhancing energy efficiency. Notably, a substantial number of participants demonstrated practical experience with implementing NbS, specifically citing rain gardens, wetlands, green walls, and living roofs as prevalent examples. However, it became evident that these solutions were not typically conceived with EE objectives in mind; only 7 out of 25 participants recognised NbS's influence on EE. The primary focus of NbS had traditionally been oriented around water management, biodiversity conservation, and aesthetic enhancement. The EE benefits, or co-benefits, were frequently unrecognised and thus not leveraged in design processes.

No interviewees had experience in designing or implementing NbS specifically focused on achieving EE objectives. As such, some of the interview questions I planned to ask were not applicable, leading instead to in-depth discussions on the potential of using vegetation as NbS, with a focus on EE in existing buildings. For example, in some interviews, this discussion led me to ask, “Have you ever touched a plant leaf that will heat up in the sun?” which prompted a discussion about the intrinsic heat-absorption properties of vegetation, mentioned in Section 3.5.1, and facilitated a shift in the conversation towards contemplating some examples of NbS exemplified in Section 5.2. The conversation led to assessing the viability of some of the solutions presented, their retrofitting potential, and their comparison with those applicable solely during building design phases, as well as the role of policy in fostering or obstructing their implementation.

One of the architects interviewed questioned whether the ‘orientation’ concept during building design (outlined in Section 3.2.2) constitutes a NbS, arguing that the sun and its cycle are natural phenomena, and that its efficient use would be considered natural. Some other participants expressed confusion regarding this distinction, acknowledging the role of orientation in facilitating EE, yet considering it an elementary architectural practice that might not constitute a ‘solution’.

Interviewees also introduced the concept of Biophilia, which was explored relative to its implications for natural ventilation and lighting within built environments (explored in Section 3.3.1). Biophilia is fundamentally connected to the interplay between nature and human experience, with specific reference to seasonal cycles and natural elements integrated into architectural design. A salient discussion point centred on the deployment of potted or mobile vegetation throughout the year, with this research suggesting that such adaptable strategies can yield energy savings during both winter and summer seasons in temperate climates. Several participants noted that, despite the lack of observed implementation of these suggested solutions, the strategy aligns with biophilic design principles focused on seasonal adaptation, enhancing both EE and WW.

One landscape designer was unique in acknowledging the importance of strategically designed vegetation that not only enhances the environment but also incorporates considerations for EE in retirement villages and hospitals. Specifically, he mentioned that he ensures he strategically provides shade from vegetation for cooling, creating a microclimate, while avoiding the areas and rooms from being too dark.

Overall, while participants expressed no surprise when presented with potential solutions to improve EE and their subsequent implications—perceiving them as familiar rather than innovative—many struggled to recall instances of such solutions being considered or implemented. Participants proposed that a significant barrier to greater adoption was the prevailing lack of knowledge and exposure to these solutions.

## 4.3. Nature-based Solutions and Workplace Wellbeing

All participants concurred that having access to greenery and incorporating indoor plants is preferable to lacking them entirely. They acknowledged that perceptions vary and that not everyone has a fondness for plants or nature. However, they could not recall any instances where employees or customers expressed complaints about having an abundance of plants or requested their removal. Furthermore, all participants had encountered literature promoting the integration of greenery, which is generally perceived as beneficial in the workplace. Many had actively supported, participated in, or been involved in initiatives aimed at incorporating plants into their work environments.

In contrast to the implications for EE, the impact of NbS in the workplace was viewed from various perspectives by all participants, whether as employees, employers, or industry professionals. Participants had some or significant expertise in air quality and wellbeing, yet there was a notable emphasis on aesthetics. Moreover, aspects such as thermal comfort, noise control, and privacy as amenities were frequently overlooked.

An international expert researching the effects of employees working outdoors, in natural settings, or incorporating nature into the workplace was taken aback when asked if these natural elements could be classified as NbS. She explained that she had never considered them in that context, as her focus was on designing outdoor workspaces that facilitate a connection with nature, or on ways to bring natural elements indoors. Her research indicates that employees who have access to nature, even if it's just through a window, can experience reduced stress, enhanced productivity, and increased creativity. She emphasised that the evidence showing how nature can enhance workplace wellbeing has been thoroughly researched, with numerous studies and publications linking human wellbeing to natural environments. However, translating these insights into actionable government policies or practical applications in private businesses remains challenging. She pointed out key psychological barriers that hinder people from working outside, arguing:

> *“The biggest obstacle is that bringing work outside contradicts many ideas about being professional and ambitious.”*

She also noted that the benefits of such initiatives are difficult to quantify, complicating efforts to justify the associated costs.

A landscape architect noted that, in her experience in Aotearoa, greenery in workplaces is primarily viewed as an aesthetic amenity. She acknowledged that some of the key benefits, such as improved air quality and enhanced wellbeing, are leveraged by landscaping and interior plant design companies to promote their services. However, the primary focus on the inclusion and placement of plants tends to be for visual appeal, emphasising which plants can make a statement or fill gaps within a building. This contrasts with her prior experience working in Colombia, where, for example, living roofs are intentionally designed and utilised to optimise limited space, in compliance with national policies that mandate a minimum area of greenery for commercial premises.

One landscape designer emphasised that their work in retirement villages and hospitals necessitated a more strategic arrangement of greenery to facilitate occupants' access to and enjoyment of outdoor spaces. This consideration was a crucial requirement for their clients, as residents often encounter difficulties in accessing these natural areas due to limited mobility. Additionally, the presence of accessible outdoor spaces is deemed vital for the wellbeing of both retirees and patients.

A key point raised by several participants was their perception that many New Zealanders believe nature belongs outdoors, and that it is the Council's responsibility to manage ‘nature’ in outdoor settings. They argued that access to parks is generally sufficient for those who wish to utilise them. However, it was also noted that these green areas are primarily used only during lunchtime. Furthermore, many of these spaces consist mainly of mowed grass, which offer limited benefits for wellbeing and biodiversity. Additionally, these outdoor areas are seldom suitable for use in winter or inclement weather.

## 4.4. Aotearoa’s Unique Cultural Context

In addition to the key findings regarding NbS and their global applications for enhancing EE and WW, several important insights specific to Aotearoa warrant attention. This section will outline insights into cultural aspects related to risk mitigation, the value placed on tidiness within Kiwi culture, and the use of lawns.

When discussing the reason why certain NbS, such as for water management and climate adaptation, were more widely adopted than others, the issue of risk prevention came to the forefront. It was suggested that this emphasis is likely a result of an increased tendency toward uncertainty avoidance, stemming from the frequent and severe weather events experienced throughout the country. Consequently, strategies aimed at mitigating the effects of potential floods and tsunamis, regenerating forests after local fires, and sequestering carbon emissions, have become central to many initiatives that can be categorised as NbS. Additionally, the widespread understanding among citizens that a significant portion of the country's energy - 85.5% in 2024 (Ministry of Business, Innovation & Employment, 2025b) - is derived from renewable sources contributes to many underestimating the importance of reducing energy consumption. This mindset often persists unless a compelling financial incentive is present. However, this focus frequently overshadows the vital need for energy conservation, which remains a critical strategic element to address, regardless of the energy source. This oversight was identified as a barrier to the EE focus on NbS, as energy reduction is not being emphasised as an immediate problem or risk that requires attention.

One cultural element identified by an ecologist was linked to ANZ's 'Tidy Kiwi' culture. She pointed out that during her studies in urban settings, an important barrier to embracing more ‘natural’ environments was many New Zealanders’ strong appreciation for tidiness. This cultural emphasis often leads to excessive control over urban green spaces, making them appear aesthetically pleasing but largely 'artificial'. This topic, which emerged early in the interviews, was also incorporated into subsequent questions posed to participants, sparking discussions also about the use of native versus exotic plants and the perceived value - or lack thereof - of lawns.

Some participants suggested that the roots of the ‘Tidy Kiwi’ culture may be partially traced back to British, European, and certain Asian cultural influences. These cultures have historically developed distinctive styles of garden design that reflect their values and principles by shaping and controlling nature to symbolise their ideals. This includes the manipulation of plants, regular mowing of lawns, paving, and creating defined natural pathways. As noted in section 4.1, one participant emphasised that Western cultures often view themselves as superior to nature, treating it as a resource. In contrast, Māori culture embodies a fundamentally different perspective, seeing nature as an entity of which humans are a part, rather than as something to be owned. This distinction underscores the potential for integrating mātauranga Māori when considering NbS and their implementation, with the aim of enhancing the holistic potential of these elements by valuing them more holistically.

Several participants expressed concerns regarding the role of lawns in Aotearoa, highlighting prevailing misconceptions surrounding their maintenance and perceived simplicity. It was suggested that the cultural affection for manicured lawns may be influenced by media portrayals from the USA, where immaculate and monocultural lawns symbolise order, affluence, and pride. However, participants pointed out a gradual shift in this perspective, supported by extensive research indicating the limited ecological and natural value of lawns compared to native vegetation such as bush and forest.

For instance, a participant affiliated with local government in Auckland reported a transition in the designation of many previously mowed public spaces to 'no mow' areas, thereby allowing natural processes to take precedence. He also expressed that there are ongoing discussions regarding local bylaws that mandate the use of grass on berms, and potential exceptions to these rules provided that such changes do not pose health and safety risks to pedestrians.

An architect who participated in a project for Christchurch City Council argued against extensive lawn-mowed areas and advocated for increased planting of bush and forest vegetation within parks. To back his argument, he modelled the long-term financial implications of maintaining expansive lawn areas against other solutions, which are more expensive than forests and bushes.

A participant from the landscaping sector noted a trend among certain clients to embrace the regeneration of specific areas by either reducing mowing frequency or ceasing it entirely. This shift was particularly evident in challenging terrains such as slopes or flood-prone zones, where maintenance costs are substantial. By diminishing mowing practices, these clients enabled the potential enhancement of the intrinsic ecological value of such areas.

## 4.5. Native versus Exotic Vegetation

The use of native and exotic plant and tree species was a topic that provoked significant controversy. Although not a specific focus of the interviews, eight participants brought up the topic repeatedly throughout the interviews.

One participant argued that for NbS to be considered ‘nature-based’, ‘nature’ should be native; otherwise, they regarded the solution as artificial or human-made by introducing non-native species into an area. They explained:

> *“I think the tricky thing with using a nature-based solution with exotic plants ... It's again a form of engineering, because you're not using the local environment and the local nature.”*

However, other participants highlighted that drawing the line on nativeness can become blurry, with some considering an endemic species from Aotearoa’s South Island native to the country and could potentially be used for NbS in the North Island while others advocate for eco-sourcing, whereby plants are sourced as locally as possible. Notwithstanding, differences of opinion in how ‘native’ should be defined, most participants agreed on the importance of prioritising native species in NbS.

While the inclusion of exotic plants sparked considerable debate, two participants in favour of incorporating exotic plants cited several reasons for their stance:

- There is a lack, or insufficient variety, of native deciduous tree species capable of providing shading versatility throughout the seasons.
- Native species can be slow to grow or may not be suitable for specific applications, for instance the reduce number of deciduous varieties.
- Only a limited number of native plants are adaptable to indoor environments.
- Some exotic species are easier and more cost-effective to maintain compared to native species.

Two of the ecologists who were interviewed strongly advocated for excluding exotic species. They acknowledged that implementing such measures isn't always straightforward, but emphasised several critical and well-informed factors to consider, including:

- Native species are already adapted to the climate of Aotearoa and are likely to thrive in the long run.
- Native plant species provide essential food sources for native fauna.
- Although there is a lack of data available to better incorporate natives in urban environments, this should prompt further research rather than discourage their use.
- Non-managed exotic species can become a pest, and the potential costs associated with mitigating the effects of new pests outweigh the risks of introducing them.
- Native species contribute to cultural bequest values for people, creating a sense of place, as they embody our land/whenua.

Three other key points were highlighted and are worth considering.

> *One participant raised the point that some people can feel that Aotearoa's native vegetation is not as vibrant or eye-catching as some exotic varieties, and that in general, it tends to show only slight variation across seasons explaining: "… in Auckland, there's little to tell you that it's summertime from the plants point of view, from the native vegetation, other than the fact that the Pohutukawa was coming to flower… Whereas in other places, in the tropics you'll have things flowering that are just flamboyant in temperate climates…"*

She proposed that exotics, which offer sensory benefits like more diverse and vibrant colours and scent, should be included within NbS because their positive effects on mental health can be greater than those of native plants, especially in urban areas or buildings. Although there has been no formal research reviewed on this topic, it could lead to further investigation.

Another participant pointed out that using native species as monocultures, as several councils do, exemplified by the case of the Pohutukawa *(Metrosideros excelsa)* in Auckland, does not support sufficient biodiversity. This third point highlighted her preference for incorporating exotic species into the landscape over relying on patches of native monoculture.

In summary, most interviewees agreed that there is a need to focus on the use of native species, aiming to ‘raise the bar’ to enable more sustainable and holistic solutions that will deliver more co-benefits and reduce trade-offs.

## 4.6. Policy and Frameworks

Many of the participants discussed their experience implementing NbS for water management, which normally required council consent and optional promotion through voluntary frameworks. Consequently, whether these tools could facilitate and promote the adoption of retrofitted NbS for EE and WW was considered.

Most of the NbS examined in the research were unlikely to necessitate a specific legal framework or council approval, as they neither pertain to the building envelope nor are substantial enough to raise the council’s concern. However, several participants emphasised that guidance from the council could facilitate the implementation of these solutions, providing a sense of 'approval.' Most participants had experience working with councils or central government bodies and underscored the importance of offering clear instructions, guidance, and best practice approaches, similar to the manual developed by the Auckland Council for stormwater management devices (Cunningham et al., 2017). Such documents help validate and promote solutions while ensuring a best practice approach to their implementation. Participants also noted the significant role of government and councils in setting examples and exposing businesses to these solutions by 'walking the talk.'

In addition to legislative measures, discussions around voluntary frameworks and certifications emerged, particularly among participants in the construction industry who were typically engaged in their implementation and processes. A key point raised by nearly all participants is that these voluntary frameworks and certifications predominantly emphasise new building constructions, with very few addressing retrofitting. Furthermore, there are currently no frameworks specifically focused on NbS. While some frameworks may encourage NbS, the primary emphasis tends to be on ecolabels, the use of green construction products and sustainable procurement, engineered design and insulation, and the reporting of carbon emissions.

In Aotearoa, participants indicated that the most prevalent sustainability framework was Green Star (NZGBC, n.d.), which has recently undergone updates to its requirements to better address considerations related to biodiversity. Originally developed in Australia, the Green Star certification was adapted by the New Zealand Green Building Council to suit local contexts. The most commonly pursued certification pertains to new constructions; however, alternative certifications exist for smaller-scale renovations ('fitout') and for assessing overall building performance against sectoral benchmarks, predominantly utilised in office environments. Awareness of this certification was widespread among participants in Aotearoa. Those with experience in its application were generally satisfied with the scheme. However, they acknowledged that the framework captured only a limited proportion of ongoing work, partly due to its financial cost, which can be prohibitive for small and medium-sized enterprises.

Participants also noted that while the credit criteria that need to be followed for achieving the certification are both useful and explicit, certain trade-offs are evident, as some criteria do not align with perceived sustainability goals. For example, a participant recounted a fitout project where credits were forfeited for retaining existing whiteware rather than replacing appliances with more energy-efficient alternatives. Such replacements would have generated waste while delivering a negligible energy efficiency benefit, making the required approach less sustainable. Green Star promotes the inclusion of native outdoor vegetation and indoor plants but does not specify criteria on how vegetation should be employed as a sustainable solution. Rather, plant use is encouraged primarily by wellness, aesthetic, and natural criteria. Consequently, vegetation serves as an adjunct to building design rather than a core element that could significantly enhance EE and WW, or substitute engineered solutions such as shading, insulation, or wind protection.

Passive House certification was identified as another relevant framework, with all industry participants demonstrating familiarity and comprehension of its core principles. However, the discussion of its principles predominantly emphasised the ‘air-tight’ building approach and engineered solutions. Consequently, its considerations were not extended to encompass NbS implications or the integration of vegetation.

The other framework discussed was the ‘Living Building Challenge,’ developed by the Living Future Institute in the United States (2020). Several participants in the construction industry demonstrated familiarity with this framework, noting its reputation for being more comprehensive due to its integration of environmental and social sustainability principles. The framework is organised into 'petals,’ inspired by the structure of a flower, symbolising efficiency and embodying core components related to nature, energy, and wellbeing. This approach emphasises the utilisation of native species and the incorporation of vegetation to achieve a holistic ecological perspective. It is noteworthy that only seven projects have achieved certification under this standard within Aotearoa. Furthermore, while the emphasis on nature and wellbeing represents an advancement over existing local frameworks, it may be perceived as onerous and challenging due to the complexity involved in quantifying NbS, which are intended to be accessible and cost-effective for retrofitting purposes.

The conclusion of this study emphasises the necessity for the development of novel frameworks or legislative measures aimed at fostering and facilitating the adoption of NbS to enhance EE and WW. Participants acknowledged that it is neither sustainable nor feasible to rebuild or extensively renovate all buildings in Aotearoa. Moreover, it is not financially viable nor practical for small and medium-sized enterprises to pursue certification schemes to substantiate their claims. Therefore, several participants suggested that financial support mechanisms, such as low or zero-interest loans, could enable businesses to implement the proposed solutions. Additionally, some participants proposed the concept of annual tax incentives for the adoption and ongoing maintenance of these measures, which could yield benefits not only for the businesses themselves but also for their surrounding communities and neighbourhoods. While these elements extend beyond the scope of this research, they are pertinent considerations for future evaluation.

## 4.7. Considering Mātauranga Māori

Considering my heritage, background, and knowledge as articulated in the positionality statement (Section 1.1.2), the integration of mātauranga Māori was not inherently intuitive, partly due to concerns regarding potential perceptions of cultural appropriation. During the interviews, the inclusion of mātauranga Māori within the framework, or the intention to 'cloak' this research and final framework with mātauranga Māori, emerged as topics of discussion among six participants. These interviews underscored the recognition of the significance of mātauranga Māori to Aotearoa, suggesting that its inclusion should be considered to a certain extent rather than avoided entirely.

Initially, the discourse centred on the concept of NbS, specifically examining whether human beings should be considered within nature or separately to prioritise natural processes, encompassing all organisms except humans, as providers of solutions. This preliminary philosophical debate evolved into a more pragmatic discussion when several participants emphasised that, given NbS's objective of addressing societal challenges, humans bear a responsibility to contribute to the solutions they actively facilitate and to be recognised as integral components of nature. Furthermore, the inclusion of indigenous knowledge systems and cultural practices was regarded as essential by six of the participants. This perspective was exemplified by an Argentine architect whose research focused on the traditional ecological knowledge of the Guaraní community, particularly in the context of implementing NbS for food security and flood resilience within the Paraná River catchment. Similarly, other participants underscored the importance of incorporating Māori perspectives and mātauranga Māori in ANZ's NbS initiatives, highlighting the value of indigenous epistemologies in sustainable environmental management.

A participant with Whakapapa Māori (Māori Heritage) pointed out that, conceptually, NbS has a biased Western perspective, where nature and human beings are viewed as separate entities. Conversely, in mātauranga Māori, these are seen as interconnected, with Māori considering themselves part of nature and never 'owning it'. This is exemplified in the Pepeha, which describes, among other elements, the Maunga (Mountain) and Awa (River) to which they belong.

This participant recited a whakataukī (Māori proverb), "Ka Mua Ka Muri", meaning "Walking backwards into the future". This whakataukī conveys the idea that envisioning the whenua/land in its original state and working on restoring it will strengthen our connection to our whakapapa/heritage and guide us towards a more sustainable future.

The participant further acknowledged the intrinsic sense of community among Māori, which markedly contrasts with the predominantly individualistic paradigms observed in certain Western cultures that emphasise ownership and property rights. This emphasis on individualism may impede the adoption of a holistic approach by constraining the scope of consideration, thereby overlooking potential co-benefits and trade-offs from environmental and social perspectives.

Another participant emphasised the imperative of involving the community, including local Iwi and Hapū, in the consideration and implementation of NbS. However, it is pertinent to acknowledge that discussions with Iwi and Hapū have happened primarily on larger projects, predominantly on Council-owned land, and without specific emphasis on EE and WW initiatives. Nonetheless, the participant's research and experiential insights substantiate the notion that active engagement with local communities enhances the likelihood of successfully identifying value propositions and additional co-benefits. Furthermore, such engagement can facilitate community support for initiatives like the development of green corridors, which may span commercial, residential, and governmental land. Adopting a holistic and inclusive approach is thus more likely to yield solutions that are not only more effective and efficient but also capable of delivering a broader spectrum of benefits relative to the costs associated with implementation and ongoing maintenance.

Six interviews included a discussion about the potential value of applying the 'Atua Kaitiaki' framework developed by Walker et al. (2021) discussed in Section 3.4. These participants had no experience implementing an Atua framework; however, they all supported and encouraged embedding mātauranga Māori within the research to allow a holistic and sustainable approach, and to strengthen connections with local mana whenua.

In addition to the research semi-structured interviews conducted, I contacted Dean P. Walker and had a personal communication with him to discuss the viability of applying the Atua framework for the consideration and implementation of NbS in this research (D. P. Walker, personal communication, January 22, 2026). During the conversation, Walker agreed that the framework is highly malleable, allowing it to be implemented across different ecosystems, such as forests, freshwater courses or estuaries, and sites of varying sizes. For example, he mentioned a case of someone implementing it in a school. He acknowledged that there is potential for the Atua to change, given Aotearoa's different regions and Iwi, as well as the focus of its implementation. For instance, the Atua framework was initially used for freshwater and estuarine ecosystems, with Atua Tangaroa at its centre. Later, in his research, Walker applied it to forest ecosystems, having the Atua Tāne (the Atua of birds and forests) at its centre, as seen in Figure 7. He highlighted that if choosing a different focus for implementation, it would be relevant to consider a different Atua at its centre, and its surroundings, to better represent the elements within the scope of the framework.

Since a formal consideration of this integration falls outside the scope of this research, it is highlighted as a current limitation and as a suggested future research direction.

## 4.8. Ecological Literacy

Ten participants identified a lack of ecological literacy as a significant obstacle to the widespread implementation of NbS. The term 'ecological literacy' refers to individuals' understanding of ecological concepts, the understanding of socio-ecological systems and principles, and the ability to identify and recognise the messages from ecosystems and their relationship with humans' ecological thinking (Desmarais, 2024).

Numerous participants identified a deficiency in knowledge and understanding of fundamental botanical processes, including photosynthesis, evapotranspiration, and the inherent capacity of vegetation to absorb heat. These processes are critical to the ability of vegetation to provide effective shading, cooling, and moisture regulation—functions that are often undervalued. One of the ecologists argued:

> *"I think one of the most important things about nature-based solutions is moving away from hard engineering, so constraining and trying to control things like water and nature. Rather than using solutions nature already has."*

Typically, engineered solutions tend to replace or imitate these natural functions rather than integrate them. For example, participants from the construction sector emphasised that they often overlook the shading potential of leaves and trunks, which significantly exceeds that of most manufactured materials. Additionally, although the concepts of plant evapotranspiration—both indoors and outdoors—are recognised to some extent, they are rarely incorporated formally into design and planning processes aimed at enhancing energy efficiency or thermal comfort. Consequently, plants and landscaping are frequently excluded from initial building budgets, as benefits are regarded as negligible.

Several interviewees highlighted the importance of a holistic understanding of vegetation's co-benefits and associated trade-offs, aspects frequently overlooked by construction professionals. An illustrative example involves the selection of tree species, planting locations, and purposes. For example, considering planting a tree solely for shade often leads architects and construction practitioners to opt for engineered solutions such as awnings or roof-like structures, which provide comparable shading, require no growth period, and are often misperceived as lower maintenance. Five of the participants interviewed argued that adopting an interdisciplinary approach during the design process can enable trees to fulfil similar functions—offering shade—while also enhancing environmental benefits such as increased heat absorption, evapotranspiration-induced cooling, wind protection, habitat provision, aesthetic and acoustic enrichment, water retention, and soil erosion control, alongside recreational and cultural values. Integrating multidisciplinary perspectives in landscape and urban planning can thus enhance overall value creation while minimising resource utilisation. An ecologist interviewed shared this example:

> *"…I think about it in terms of sports fields for a moment, you know that a sports field has a function, we need people to have space to play sports. But you've also got a lot of people standing around watching and getting sunburn. The trees can be planted along the edges and provide benefits without compromising the sports field's function... So for me it's about what I say 'levelling up' and just adding co-benefit after co-benefit."*

Construction professionals emphasised the necessity for objective, formal methods to quantify and model these co-benefits and trade-offs. Just as architects and engineers use software to simulate shading and budget projects, the ability to model and assign monetary values to co-benefits could substantially support the development of compelling business cases, thereby facilitating the broad implementation of such solutions. However, interviewees agreed that no existing tools currently offer a comprehensive means to address all relevant elements holistically. Researchers have indicated that colleagues are working toward creating quantifiable, co-benefit-specific value propositions, though these innovations have yet to achieve widespread application. One software platform discussed—familiar to a subset of participants—was i-Tree (n.d.), a program utilising forestry data from the United States to evaluate urban tree benefits. While i-Tree predominantly serves an urban context, its 'i-Tree Design' module facilitates the assessment and projection of ecosystem services at a site level that includes water retention, energy savings, air quality improvement, and carbon sequestration. Local government bodies in Aotearoa have invested in customising the urban i-Tree tool with relevant local data (Morgenroth, 2023). However, the tool remains underdeveloped for site-specific applications within the Aotearoa context, particularly regarding its capacity to evaluate a comprehensive array of co-benefits, such as biodiversity values. Participants unfamiliar with the tool expressed enthusiasm about its potential or similar alternatives, whereas those with experience in its use highlighted certain limitations, particularly at the urban scale.

Data deficiency was a key limitation that some researchers highlighted through the interviews. One of the ecologists interviewed explained:

> *"For me, there' are some really big barriers around the data deficit we have around native plants, and how to grow them. And limited good examples of them being used, that people can look at, and then issues around purchasing them. So I mean, a classic example… [at two major local franchises that sell plants]…, where there are signs, and they say "Native Plants", but underneath, there's not a single native plant. So even if you want to do the right thing, it's impossible to source native plants."*

This topic directly aligns with the use of tools, such as i-Tree, which have a limited number of available native trees of Aotearoa for modelling. This limitation leads to the underuse of some trees and other plants with significant potential in Council plantings. Moreover, native trees and plants of Aotearoa were suggested to 'not fit' the most common concept of a 'tree', based on height, leaf disposition and a single main stem (Meurk, 2022). In Aotearoa, there are many bushes such as Karo *(Pittosporum crassifolium)* that can reach four metres tall, which are excluded from the tool as they do not meet typical tree criteria, but could still perform as such for purposes such as water management, wind protection, shading and mitigating UHIE.

Several participants also highlighted the lack of comprehensive data, experiential knowledge, or plant design expertise regarding the use of native plants in indoor environments. This gap was primarily attributed to a lack of documented experience and empirical data on the development and integration of native species in such settings. Additionally, three ecologists actively emphasised the relative ease of propagating and maintaining common exotic species—such as Pothos, Spider Plants, ornamental palms, and Dracaenas—tends to promote their preferential use, often resulting in their overrepresentation. One of these ecologists demonstrated the successful indoor cultivation of Kawakawa *(Piper excelsum)*, contingent upon appropriate placement. Conversely, another participant highlighted that the familiarity and convenience associated with common exotic species “lowers the bar” for further experimentation or research into native alternatives. Among the native plants occasionally employed indoors, ferns such as the Hen and Chicken Fern and Maidenhair were noted.

These ecologists collectively emphasised that the data deficiency in this context extends beyond modelling or software development; it pertains to the paucity of thoroughly documented and systematically gathered data specific to native plants. Furthermore, a fourth ecologist referenced the issue discussed in Section 4.5, which pertains to the naturalisation of exotic species in Aotearoa. This phenomenon can create confusion, leading the public to mistakenly believe that many naturalised species are in fact native. This point was corroborated by a participant who observed non-native species erroneously labelled as native in popular hardware and plant retail outlets nationwide.

The discussions surrounding eco-literacy underscore its potential role as a critical barrier to the implementation of NbS as delineated throughout the research. Moreover, within the context of Aotearoa, this issue assumes particular significance due to the country’s distinctive biodiversity, which is less likely to be examined by international organisations and consequently necessitates increased national and local funding to support its utilisation within NbS. This perceived limitation highlights a notable gap within the current scholarly literature, and participants suggested that addressing this gap could facilitate the broader integration of native plants in local environments.

## 4.9. Conclusion, Summary of Barriers & Opportunities

The expert interviews reinforced the significant potential for NbS to contribute to both EE and WW within business premises in Aotearoa New Zealand. While most participants were familiar with NbS in the context of water management, biodiversity enhancement, and climate adaptation, few had previously considered their use as a strategic tool to reduce energy demand and improve WW. The findings highlighted broad support for using vegetation as a multifunctional solution, while emphasising the importance of context-specific design, ecological literacy, native biodiversity, and the incorporation of mātauranga Māori. Participants identified both opportunities and barriers, including knowledge gaps, policy limitations, cultural perceptions, and challenges associated with measuring benefits. This section summarises the key takeaways from the interviews as described and discussed throughout this chapter.

Collectively, these insights refined the understanding of NbS within the Aotearoa New Zealand context and provided the practical and cultural considerations necessary to develop the framework presented in Chapter 5.

### 4.9.1. Barriers

Barriers to implementing NbS within business premises:

- The lack of ecological literacy among citizens is suggested to be a key barrier to their ability to perceive the holistic value of vegetation and the impact it can have on people's lives. (Section 4.8)
- The budgeting for NbS by focusing solely on the ongoing costs and maintenance of these, in comparison with engineered solutions, while foregoing its core value proposition and broader co-benefits. (Sections 4.1, 0, 4.3, 4.4 and 4.8)
- The lack of legal frameworks and certifications that holistically validate the use of NbS, which could be used for businesses' marketing purposes. (Section 4.6.)
- The misperception of humans' role within nature and of businesses' role within society leads people to think we own nature as a resource, rather than understanding that we are part of nature and that we are cannibalising our own resources. (Sections 4.1, 4.4, 4.5 and 4.7)

### 4.9.2. Opportunities

Opportunities identified that will help promote NbS within business premises:

- To facilitate the integration of vegetation into existing commercial premises through support from councils and government entities, thereby aligning with local environmental and social strategies.
- To promote research, experimentation, and the application of native vegetation within indoor environments.
- To enable environmentally sustainable actions across enterprises of varying sizes by ensuring approaches are feasible, cost-effective, and beneficial.
- To explore the potential of mātauranga Māori as a holistic framework for achieving environmental, social, and economic sustainability.
- To establish NbS as a fundamental component within the construction sector, fostering outcomes related to EE and WW.

# Chapter 5. Nature-based solutions for Energy Efficiency and Workplace Wellbeing, and Framework for Implementation.

Based on the literature review presented in Chapter 3 and the insights gained from interviews with domain experts summarised in Chapter 4, this chapter proposes a revised definition of NbS and makes recommendations for NbS suitable for implementation across various businesses in Aotearoa to improve their EE and WW. Section 5.1 elaborates on the concept of NbS and proposes a new definition. Section 5.2, categorises these solutions according to their implementation and potential locations, while also evaluating their effectiveness across the five opportunity factors delineated in Section 3.5. Section 5.3 then outlines a comprehensive, step-by-step framework to facilitate the systematic and logical consideration and adoption of these solutions.

## 5.1. Defining Nature-based Solutions

As discussed in Section 3.1, NbS are defined in a variety of ways within literature. Many definitions are quite broad, in some cases overlapping with other concepts such as biomimicry, biophilia and biomimetics. The literature reviewed, interviews and personal professional experience highlight that, while the concept is broad, it is currently used primarily to refer to water management solutions such as wetlands or forest regeneration (Brears, 2022; Cassin, 2021; Ignatieva et al., 2008; Pure Advantage & Tāne's Tree Trust, 2023; Sarre, 2018). As discussed in Section 4.1, the interviews highlighted some gaps in current definitions of the concept that could lead to misunderstandings and potentially limit is value. For example, some NbS literature focuses on these solutions purely in terms of providing its benefits to humans, while excluding these from being part of nature, perpetuating a problematic dichotomy between humans and nature that arguably contributes to many contemporary environmental issues (Brears, 2022; Cassin, 2021; European Commission, n.d.). Many scholars also focus exclusively on the direct benefits of NbS overlooking or underestimating the importance of co-benefits and trade-offs (Brears, 2022; Cassin, 2021; European Commission, n.d.). In pursuit of contributing to the existing concept of NbS, and by gathering ideas and information from the current literature and the interviewed participants, the following definition of NbS is proposed:

> Nature-based **solutions** are methods or strategies that utilise **living systems** to address social challenges. These are **holistic** and **sustainable** approaches that should **optimise** the **reciprocal** relationship between these systems and humans, who benefit from their **services** by leveraging their **co-benefits** and understanding their **trade-offs**.

Each of the keywords highlighted in bold is explained below:

- **Solutions**: NbS have a specific objective and are developed to address a particular problem.
- **Living Systems**: NbS are the sum of interrelated biotic and abiotic organisms; they can be adaptable, dynamic, self-sufficient and can display evolutionary behaviour (Meadows, 2009).
- **Holistic** and **Sustainable**: NbS adopt an interdisciplinary perspective to identify synergies, resulting in a value proposition that addresses environmental/natural, social/cultural, and financial issues in the long term.
- **Optimise:** NbS seek a systematic, logical prioritisation of benefits that enables the right amount and source of resources for achieving a sustainable and holistic solution.
- **Reciprocal**: NbS foster and enable a symbiotic relationship between nature and humans, aiming to benefit all parties.
- **Services**: NbS provide a range of ecosystem services that deliver a wide variety of benefits.
- **Co-Benefits**: NbS deliver more than a single service; it is vital to identify these systematically to align these co-benefits and deliver an optimised value proposition.
- **Trade-offs**: Potential trade-offs between co-benefits must be identified and carefully managed.

## 5.2. Nature-based Solutions for EE and WW

This section delineates the benefits and challenges associated with six categories of NbS with the potential to enhance EE and WW. These solutions are systematically categorised based on shared design and implementation considerations. To evaluate their prospective benefits and synergies in relation to the problem statement (Section 1.2) and to align with the stated aims and objectives (Section 1.3), each NbS is assessed in terms of five opportunity factors: shading, evapotranspiration, wind-air flow, air quality and filtration, as well as visual and acoustic factors, as outlined in Section 3.5. A summarised evaluation of these sections' solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider can be found Appendix 4.

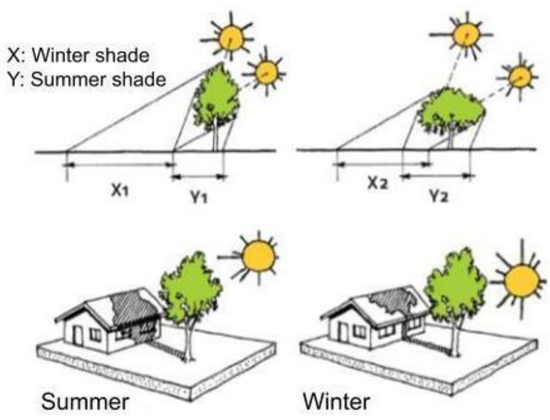
### 5.2.1. Outdoor Free-standing Vegetation

An outdoor space has significant potential for EE and for contributing to WW, as it allows direct planting of trees in the soil, facilitating the development of self-sufficient landscapes. Outdoor vegetation interacts more extensively with environmental factors such as weather, biodiversity, and urban exposure, allowing a broader spectrum of co-benefits to be realised.

Outdoor vegetation can significantly enhance the EE of buildings when it is strategically placed and thoughtfully designed. Trees and shrubs can either allow or obstruct solar energy from reaching the building's exterior, which is a crucial passive design principle (Gonzalo & Vallentin, 2014).

Figure 11 illustrates how tree shade can be modelled against buildings depending on the seasons. This process underlines the importance of selecting a suitable location for trees, or pruning them correctly, to achieve the best results (Bustamante, 2009). By modelling shade and its impact on buildings, Chen & Jim (2008) state that trees on the west side are the most impactful for shade, followed by the ones on the east and then south, in the Southern Hemisphere. In Victoria, Australia, Sustainability Victoria (2020) advises against planting evergreen trees in north-facing areas of a building, as these may provide summer shade but could lead to increased heating demands in winter, but this approach can be quite conservative if taken as a rule of thumb.

Figure 11: Tree Shade Modelling per Season




*The graph illustrates the use of vegetation to protect north-facing façades and windows from direct sunlight. Not considering specific latitude. Translated from the original source (Bustamante, 2009).*

Waterfield (2011) recommends planting deciduous trees to allow sunlight in winter and shade in summer. There are not many deciduous native deciduous tree species in Aotearoa, nonetheless, prioritising these would enable a wider range of co-benefits for the native biodiversity (Ignatieva et al., 2008; Meurk, 2022; Meurk et al., 2007). Some deciduous native species that are particularly suitable for shading purposes are the Kōtukutuku *(Fuchsia excorticata)* and the two varieties of Mountain Lacebark *(Hoheria glabrata & Hoheria lyallii)*(New Zealand Plant Conservation Network, n.d.-a). By understanding the sun's trajectory and the height differences across seasons, one can choose and maintain trees that facilitate sunlight reaching the building envelope, and indoors through windows. Another shading strategy to adapt between seasons is to perform crown lifting type of pruning which involves removing the lowest branches (30% maximum of total canopy per year), to allow winter sun to come through the below the canopy (Morris, 2013). Once sunlight reaches the building envelope, its internal temperature will largely depend on the insulation levels in the walls. Notably, the heat absorption capabilities of leaves are likely to surpass those of artificially engineered materials (Dhakal et al., 2022). Allowing sunlight to enter through windows raises the potential for overheating in summer; however, this feature can be strategically beneficial in winter.

To optimise warmth during the colder months, Waterfield (2011) suggests creating north-facing sun traps that incorporate both vegetation and masonry materials, such as stones, pavers, or concrete, to absorb solar heat and radiate it into the building's interior. This phenomenon is known as thermal mass in passive design, and is normally applied to elements that radiate inside the building (Gonzalo & Vallentin, 2014). A sun trap area can be a suitable space for incorporating an outdoor workspace, as the use of pavers and vegetation allows for installing some outdoor furniture which is connected and close to the main building, while also being better prepared for the weather, as the paved floor will dry faster. This idea is illustrated in Figure 12. Trees like the Kowhai *(Sophora microphylla)* can be suitable for areas needing partial shade, as their naturally light leaf density has a dampening effect on sunlight rather than completely shading the area. Additionally, some Kowhai *(Sophora microphylla)* varieties are semi-deciduous, as are other native species of Aotearoa (Auckland Botanic Gardens, n.d.-a). This offers more seasonal versatility, including during their flowering, enhancing the sensorial perception for WW and providing a broad range of biodiversity co-benefits (Elliott, 2023; Souter-Brown et al., 2021; Stanley, 2025).

Figure 12: Outdoor Working Space on Masonry

*The AI modified photo illustrates an outdoor work designed desk on masonry, which could be used for a sun trap outdoor area and the addition of trees, such as Titoki (Alectryon excelsus), for shading the desk. The original photo extracted from Nola's website and modified using AI replacing an umbrella with a tree (Google Gemini, 2025; Nola, n.d.).*

As discussed in Section 3.2.3, understanding the temperate climate of Aotearoa is crucial when evaluating solutions from other regions. Some solutions can be effective for summer, or tropical regions (Misni, 2018), but can have negative effects in winter, or colder climates, when there is a need to address increased heating demands in winter (Dahanayake & Chow, 2017; Raji et al., 2015). This is applicable when designing an outdoor space that enables employees to work comfortably outside, it is essential to follow the key guidelines set forth in Section 3.3.3 (Lygum et al., 2023, 2023; Petersson Troije et al., 2021). Careful consideration should be given to allowing sunlight to the area while incorporating shaded spots to provide cooling during the summer months. Figure 13 and Figure 14 provide two examples of possible designs for shaded outdoor workspaces.

Figure 13: Fixed Outdoor Working Space

*The AI generated photo illustrates how to create weather-proof and fixed outdoor working spaces that can be used for one or two people to work or have a break. The desk design was extracted from Nola's website and the background modified using AI (Google Gemini, 2025; Nola, n.d.).*

Figure 14: Connected Outdoor Work Area

*This AI modified photo illustrates an outdoor working area connected with a path. The original photo extracted from Nola's website and modified using AI to add the climbing plant (Google Gemini, 2025; Nola, n.d.).*

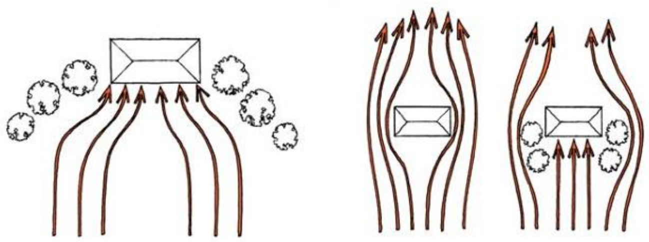
Research conducted in Australia by Berry et al. (2013) reveals that the presence of dense vegetation and a tall tree canopy results in significant reductions in the external wall surface temperature, as well as a 1°C decrease in the air temperature situated between the trees and the building. This indicates substantial benefits for human thermal comfort in the areas surrounding the building. Furthermore, the effectiveness of vegetation in providing shade is influenced by its distance from, arrangement around, and canopy structure relative to the building. Aotearoa has a broad range of small native trees, or tall tree-like native shrubs (Meurk, 2022), such as Karo *(Pittosporum crassifolium)*, Kapuka *(Griselinia littoralis)* or Tarata *(Pittosporum eugenioides)* (Auckland Botanic Gardens, n.d.-a; Forest & Bird, 2020) that can be effectively used for shading. Berry et al. (2013) also caution that placing trees too close to the building's envelope to optimise shading can adversely and persistently impact the building's foundations.

Wind is the next factor to consider for outdoor vegetation for EE and WW. Section 3.5.3 explained the dynamic of wind in relation to EE. In addition, it is worth noting that winds are identified as a significant barrier to getting employees working outside (Petersson Troije et al., 2021).

When considering windbreak it is essential first to understand the region's prevailing wind currents, as explained in Section 3.5.3. This initial assessment will inform future decisions on directing winds toward or away from the building based on local wind direction trends. Next, it is important to take into account the local topography and surrounding environment, including the proximity to hills, cliffs, or neighbouring buildings of varying heights (BRANZ, 2018; Chen & Jim, 2008; Macara, 2018, p. 13).

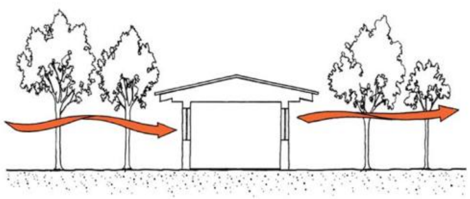
Achieving complete wind protection is widely regarded as nearly impossible. Kuhns (2012) recommends striving for 60-80% protection around buildings and 40-60% in open spaces. Bustamante (2009) suggests that if possible, direct desired winds, warm winds in winter and cold winds in summer, to facilitate natural ventilation by directing them toward the building. Depending on wind strength, he suggests that soft wind currents should be directed towards the building, as illustrated in the right diagram in Figure 15. On the other hand, stronger wind currents are encouraged to be partially left directed and partially deflected, as depicted in the right diagram of Figure 15 (Bustamante, 2009). Shrubbery can be strategically employed to enhance wind flow towards operable windows on the ground floor, thereby facilitating natural ventilation, as long as the tree canopy is designed to allow it (BRANZ, 2018). This dynamic is illustrated in Figure 16.

Figure 15: Vegetation Layout to Enhance Natural Ventilation:
*Horizontal View*



*The image illustrates how trees and shrubs can deflect wind to improve natural ventilation (Bustamante, 2009).*

Figure 16: Vegetation Layout to Enhance Natural Ventilation:
*Vertical View*



*The image illustrates that trees with a high canopy next to ground-floor windows enable natural ventilation (Bustamante, 2009)*

Protecting buildings from cold winds in winter is particularly important, with the potential to lower heating costs by 20% to 40% (Heisler, 1986; Kuhns, 2012; Peterson, 2016). Studies suggest that an effective shelterbelt should focus on deflecting prevailing winds away from the building or dampening them (slowing them down), rather than aiming to dam (block) their impact (BRANZ, 2018; Bustamante, 2009; Waterfield, 2011). Figure 17 illustrates the difference between these two effects, showing how damming the wind can create unexpected gusts between vegetation. In addition to determining the optimal distribution of trees to protect buildings, it is essential to consider the outdoor areas these trees will shield, particularly outdoor workspaces designed for employees to enjoy. Creating a comfortable microclimate by effectively deflecting medium to mild winds can help facilitate the use of these outdoor spaces (Petersson Troije et al., 2021).

Figure 17: Deflecting vs Damming Wind

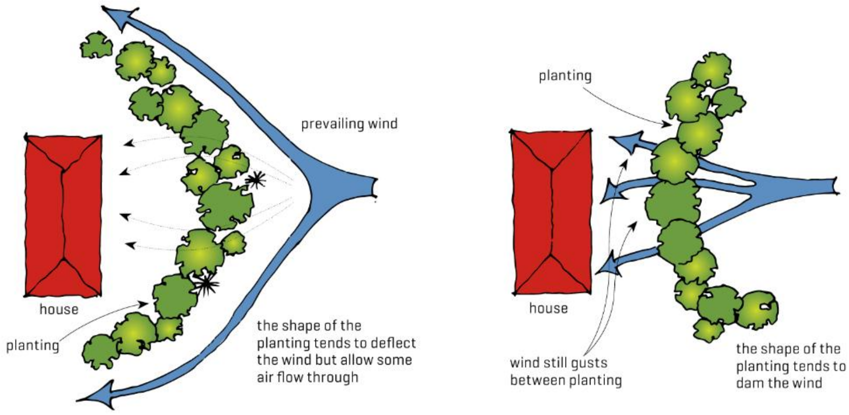
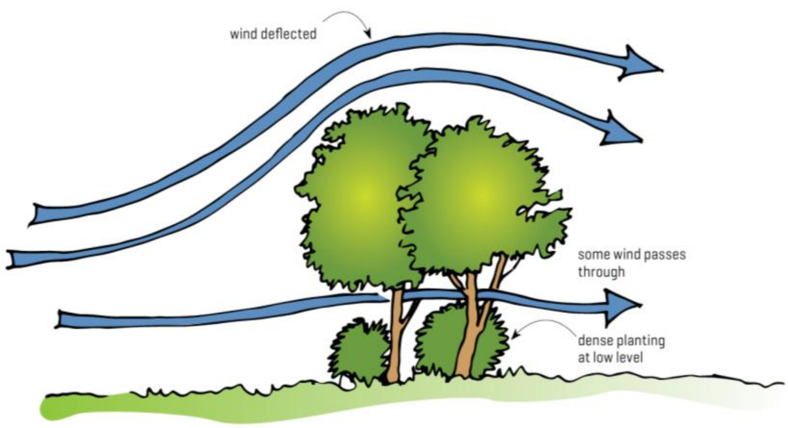



*Diagram showing the effect of deflecting the wind rather than dam it* (BRANZ, 2018).

To enhance a shelterbelt's ability to deflect winds while ensuring adequate ventilation and manageable maintenance, a diverse array of shrubs and trees with varying heights and densities that can mutually support each other should be used (Figure 18). Selecting vegetation that is endemic to the region may also provide a more cost-effective solution, as it typically requires less maintenance (BRANZ, 2018). Considering the incorporation of deciduous species may also be beneficial to complement shading strategies, as they can effectively reduce wind speed even when devoid of leaves (Kuhns, 1993, 2012; Peterson, 2016). Alternatively, the combination of low shrubs, medium-height evergreen trees, and tall deciduous trees can provide shade in summer and facilitate sunlight during winter while offering wind protection throughout the year (Kuhns, 2012). Depending on the wind strength and the site's exposures, as well as the soil type, a wide range of native trees and shrubs can be used

Figure 18: Effective Shelterbelt




*The image illustrates the shelterbelt effect on wind using different height vegetation (BRANZ, 2018).*

to build a shelterbelt. For instance, most flaxes are tolerant of wind, as well as the Taupata bush *(Coprosma repens)*, which can reach a few metres tall, and the Pohuehue *(Muehlenbeckia complexa or australis)*, which can grow on existing structures. Cabbage Trees *(Cordyline australis)* are also very tolerant of wind, and while they may not cover a large amount of space, they can be grouped with other trees, such as Puka *(Meryta sinclairii)*, Rewarewa *(Knightia excelsa)*, Mānuka *(Leptospermum scoparium)*, Pohutukawa *(Metrosideros excelsa)* and Nīkau palms *(Rhopalostylis sapida)* (Auckland Botanic Gardens, n.d.-a; Forest & Bird, 2020).

A common misconception is that trees offer minimal value for taller buildings. However, windbreaks can reduce wind speed by a factor of 30 times their height (Kuhns, 2012). Another common misconception is that they are less effective than engineered solutions like fences and walls. In reality, the flexibility of branches and foliage allows vegetation to reduce wind speed by bending with the wind, whereas rigid structures, whether vertical or horizontal, can inadvertently increase wind speed through gaps if not designed and appropriately positioned (BRANZ, 2018; Kuhns, 2012; Waterfield, 2011). Furthermore, utilising a combination of compatible solutions can provide additional benefits beyond increased EE, such as lot division, privacy, visual amenity and biodiversity. To establish a shelterbelt more quickly, a combination of slow-growing species and fast-growing species is recommended. If fast-growing exotics are used, there is potential to remove the exotic species once the natives have become established (BRANZ, 2018).

In addition to the shading and wind factors previously considered, it is important to consider the visual and acoustic factors when designing an outdoor workplace to encourage WW. Figure 19 illustrates a hypothetical outdoor office space that could be used for meetings, individual work and breaks. Surrounded by trees and greenery, this area has the potential to enhance the microclimate by reducing outdoor noises from the city, generating pleasant ones from the birds and the leaves moved by the wind (BRANZ, 2018; EMS Business Redefined, 2024). Moreover, the hedges and vegetated pergolas help visually and physically subdivide the

Figure 19: Hypothetical Green Workspace

*This AI-generated image showcases a hypothetical outdoor office workspace that makes use of green shading plants growing on pergolas, hedges and trees, helping to reduce wind speed, and hedges subdividing the environment to create a sense of privacy among workspaces (Google Gemini, 2025).*

environments giving a sense of privacy, while offering employees an outdoor open space to work in (Lottrup et al., 2013; Petersson Troije et al., 2024).

The final environmental factors to consider for outdoor settings are evapotranspiration and air filtration. As discussed in Sections 3.5.2 and 3.5.4, these two factors are interrelated, with evapotranspiration contributing to air purification processes. The impact of these factors may be less pronounced outdoors compared to enclosed spaces. However, when considered at an urban scale, the widespread implementation of strategies related to these factors can yield significant environmental benefits, as elaborated in Section 3.2.1. Notably, the cooling effect of evapotranspiration can be most effectively observed when seated beneath a tree, as opposed to shaded areas created by artificial shading devices (Bakhshoodeh et al., 2022; Jim & Chen, 2009; SingularGreen, n.d.), thereby highlighting the importance of vegetation as a natural cooling strategy over engineered solutions.

The key requirement to maximise the EE and WW benefits of outdoor free-standing vegetation is to carefully consider what type of vegetation to plant and where (Kuhns, 1993). When strategically selected and positioned, nearly all outdoor vegetation can have a positive impact on a building's EE. Co-benefits of outdoor free-standing vegetation include reducing soil erosion (Kuhns, 2012; Waterfield, 2011), improving air quality by capturing dust and toxic particulates from the air (EMS Business Redefined, 2024; Jim & Chen, 2009), and reducing noise pollution from busy roads by absorbing some of the road noise and generating a pleasant sound with its leaves (BRANZ, 2018; EMS Business Redefined, 2024). However, if not carefully selected and situated, vegetation may have little to no impact and, in some cases, can even produce negative effects by overshading or blocking natural ventilation, thereby decreasing EE.

It is recognised that not all business premises may have access to outdoor space or, even if such space is available, there might be limitations on the physical area suitable for planting vegetation. However, the incorporation of external free-standing vegetation is considered a valuable component in developing an effective EE and WW strategy for a building, and it is strongly encouraged whenever feasible.

For a summarised evaluation of this section's solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.1 Outdoor Free-standing Vegetation.

### 5.2.2. Vertical Green Systems

An alternative method for incorporating outdoor vegetation is the use of Vertical Green Systems (VGS), sometimes also referred to as green walls. VGS can be established with the use of trellises, or by growing climbing plants against the wall. In contrast to the solutions discussed in Section 5.2.1, VGS are not free-standing. While there are no documented records detailing the earliest use of climbing plants on walls, it is known that vines and roses have been utilised in the Mediterranean since the third century CE (Scherer, 2014). Today, various examples VGS have been designed using diverse approaches. Some of these use climbing plants that attach directly to external walls, also known as green façades. Others, use wired trellises and planters as illustrated in Figure 20. Felt systems can also be used, these are made of permeable plastic cloth with plants within pockets, which are attached to façades. Sometimes, a combination of these can be designed.

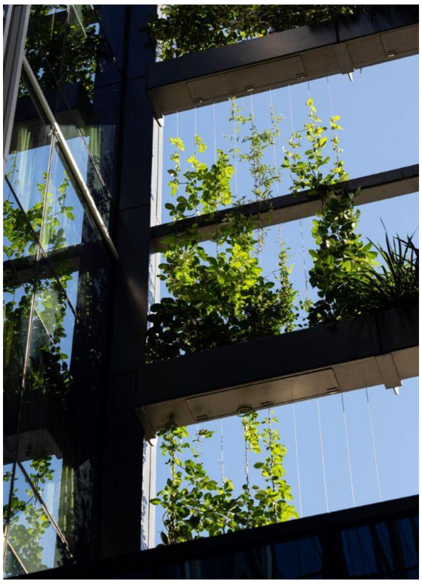
The implementation of VGS has been the focus of several studies investigating their impact on thermal control and EE in both tropical and cold climates, with varied findings. From the perspective of WW, these have mostly been considered indoors, which will be discussed in Section 5.2.6, however the amenity of VGS outdoors can also apply to WW by enhancing thermal comfort and the availability of nature around the work environment (Elliott, 2023; White et al., 2023).

Dahanayake and Chow (2017) investigated the passive mechanisms of VGS and their role in energy savings through providing shading, thermal insulation, evapotranspiration, and serving as a wind barrier within urban environments. Utilising specialised software tools such as EnergyPlus and FASST, Dahanayake and Chow modelled the shading and insulation capacities of vegetation, alongside a hydrothermal model for evapotranspiration. Their study was conducted in two cities: Hong Kong, characterised by a maritime climate with temperature ranges between 9°C and 33°C, and Wuhan, China, which exhibits a continental climate with temperatures ranging between -4°C and 39°C. The findings indicated that the integration of VGS contributed to a 3% reduction in cooling energy consumption during the summer months; however, an increase in energy consumption for heating was observed during winter. When net energy savings were evaluated, Hong Kong yielded an overall saving of 2% while Wuhan recorded a modest 0.3%, leading to the conclusion that such savings may not justify the costs incurred. Similarly, Stec et al. (2005) conclude that VGS provide good shading results in summer but can reduce EE in winter. Note that the cost analysis performed was limited to energy consumption and does not quantify other co-benefits delivered by the VGS.

Research conducted by Dahanayake and Chow (2017) and Stec et al. (2005) highlights a contentious debate surrounding the utilisation of VGS. Given the shading potential of VGS on specific walls and the water flow through these systems, they demonstrate significant cooling capabilities. However, this may inadvertently lead to increased heating requirements during winter months in climates such as Aotearoa's. It is therefore recommended that, through careful assessment of VGS placement, system design, and local climatic conditions, such negative effects can be mitigated. Additionally, the unidimensional energy efficiency analysis presented in the study overlooks the potential benefits derived from other factors associated with VGS, such as evapotranspiration, wind protection, and noise reduction. VGS offer a range of co-benefits, including enhanced biodiversity, air filtration, water retention, and overall improvements to urban amenity and environmental quality.

Ip et al. (2010) approached the assessment of VGS through a different lens, focusing specifically on the use of Virginia Creeper on building façades as a form of passive solar control. Their study aimed to utilise the plant as an outdoor window green curtain for managing sunlight exposure by pruning it in winter to maximise solar gain and allowing it to grow and shade during summer. By employing solar transmissivity sensors, they developed a mathematical model that assessed the coverage and performance of VGS over a two-year time frame. Results indicated that the air in proximity to the plant was cooler than the air near masonry shading devices, achieving temperature reductions of 4°C to 6°C during summer, which significantly enhanced thermal comfort. Nonetheless, the study also highlighted potential drawbacks, including diminished natural ventilation and limited access to natural light due to the dense foliage. Continuous maintenance to manage leaf distribution emerged as a requirement, making the application of this strategy feasible only for buildings equipped with operable windows.

Figure 20: Shading from Outdoor VGS



*Photos of an example of a VGS at the Hotel Grand Chancellor in Auckland (GreenAir, n.d.-a)*

Figure 20 demonstrates a local example of vegetation being used in this way, this type of VGS facilitates shade provision without entirely obstructing natural light. Additionally, it contributes to wind and airflow regulation, thereby helping to create a microclimate. Through evapotranspiration, the system can enhance cooling and air filtration. Moreover, the presence of plants helps reduce glare from the building's glass façade and mitigates sound reverberation within the space.

The potential benefits highlighted before are also relevant to the literature review conducted by Raji et al. (2015) on the impact of VGS on the energy performance of buildings, concluding that VGS can occasionally be more efficient than traditional blinds in reducing HVAC loads. These systems can achieve a temperature reduction of 1.6°C to 3.3°C in their vicinity through the process of evapotranspiration. The effectiveness of this cooling effect depends on the distance from the VGS to the building, with the closest positioning (15 cm) being the most effective. VGS can provide shade coverage ranging from 12% to 45%. They also create an insulating layer that helps reduce wind speed around the building, thereby mitigating temperature loss at night. The study highlights that orientation is a crucial factor in determining how VGS can reduce reliance on HVAC and recommends managing foliage to reduce shade during the winter season to avoid increased heating costs. In addition, it encourages the use of VGS against other artificial engineered solutions such as blinds, which will be further discussed in Section 5.2.6.

Another relevant study carried out in a temperate-cold climate similar to Aotearoa's, was conducted by Cameron et al. (2015) in the UK, using brick-made cubicles to evaluate the impact of green walls in maritime-temperate climates. These cubicles were equipped with a thermostat and maintained at a consistent temperature of 16°C, allowing a comparison between exposed cubicles and those covered with climbing plants. The findings suggest that green walls serve as effective insulation against extreme weather conditions, including snow, cold, rain, and peak summer temperatures, with their effectiveness levelling off during transitional seasons or less severe weather. Specifically, in snowy conditions, the energy demand for planted cubicles was reduced by 26% compared to those without plants. In freezing or cold conditions accompanied by wind and rain, planted cubicles exhibited approximately 40% greater EE. During rainy weather, these planted cubicles demonstrated a 3% increase in EE, attributed to the foliage keeping the walls dry and thereby reducing heat loss. Conversely, in cold or moderately windy yet sunny conditions (such as March in the UK), the difference in EE was negligible unless the cubicles were fully covered, which is an unlikely scenario for actual buildings. Overall, their results indicate that VGS effectively trap heat and minimises heat loss from the building envelope. Additionally, the foliage provides protection to the warm boundary and increases aerodynamic resistance, which helps reduce wind speed around the envelope. These conclusions are consistent with those of Raji et al. (2015), as previously described, and Tan et al. (2020), who concluded that a room with VGS achieves

Figure 21: Workshop with Green Façade

*This photo showcases a truck workshop in Auckland, whose façade was covered by a crawling plant. This photo was extracted from Google Maps from a real workshop and modified using AI to erase or blur all written content to ensure privacy (Google Gemini, 2025; Kizildere, 2017).*

energy savings throughout the year, with 30% more savings in summer than in winter due to shading.

The application of creepers as a form of VGS can often lead to a more accessible, cost-effective, and efficient way to create greenery, even in situations where bare ground is limited. One notable example is a truck workshop façade in Auckland portrayed in Figure 21, where soil availability is constrained yet has been effectively adorned with creepers. According to the study by Cameron et al. (2015), this workshop benefits from a layer of shade that not only cools the surrounding environment but also protects the building from wind exposure. Additionally, research conducted by Perini and Rosasco (2013) in Europe indicates that this particular type of VGS is the most financially efficient option, even under what they deemed the 'worst-case scenario' over a 20-year period. Their findings suggest that this system incurs the lowest costs for setup, maintenance, and decommissioning, while providing substantial energy savings, social and environmental benefits, and an increase in property value (Perini & Rosasco, 2013).

Regrettably, while I was unable to locate empirical evidence, a first principles approach suggests that vegetation solutions in industrial settings may lack the energy savings benefits, primarily because these facilities typically lack HVAC systems and, consequently, do not incur energy consumption related to them. However, the benefits of thermal comfort for occupants are more pronounced, especially since these premises are often poorly insulated, heated, or cooled. In this context, vegetation serves as a significant contributor to enhancing thermal comfort.

When selecting native species for use in VGS, it is essential to consider factors such as site conditions, water availability, and system design. For example, Puawananga (*Clematis paniculata*), an evergreen, woody vine capable of reaching heights of up to nine metres, can be employed to facilitate climbing on walls and fences. This species is noted for its fragrant flowers; however, its viability may be affected by site-specific factors and water accessibility. Additional commonly used flowering species include New Zealand Jasmine (*Parsonsia heterophylla*) and Carmine Rātā (*Metrosideros carminea*). Although less visually prominent, a variety easy to shape and cultivate, exhibiting tolerance to drought and wind stress, is the Pohuehue *(Muehlenbeckia complexa or australis)* (Auckland Botanic Gardens, n.d.-a; Forest & Bird, 2020; New Zealand Plant Conservation Network, n.d.-b). Unfortunately, no native species were found that will directly cling to the wall; nonetheless, climber plants such as the Creeping Fig (*Ficus Pumila*) can be suitable in specific urban spaces with appropriate and periodic pruning to prevent its uncontrolled growth and propagation.

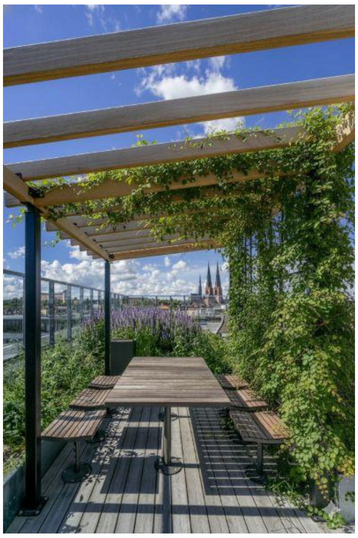
The findings throughout the research presented in this section highlight the importance of considering local climate, environmental context, and specific objectives when assessing the efficacy of VGS. While VGS are primarily recommended for warmer climates, they have also been recognised for their EE benefits in temperate regions, while also enabling a range of benefits for WW, and society as a whole (Ignatieva et al., 2008; Jim & Chen, 2009; Perini & Rosasco, 2013; Raji et al., 2015; Scherer, 2014). Pérez et al. (2022) conclude that the orientation of VGS and their ability to allow sunlight to reach the envelope during winter are critical factors in evaluating their success and cost effectiveness for improving EE. Feng & Hewage (2014) emphasise that the choice of plants and the system used to support them also significantly impacts the success of VGS. The use of planter modules and trellises tends to be more effective than using a felt system, as they require less maintenance, thus reducing costs and enhancing the capacity to improve air quality by capturing pollutants in the soil. From a water resource perspective, green façades that use climbing rooted plants directly on the ground have shown to be more water efficient than other VGS (Bakhshoodeh et al., 2022). It is also suggested that integrating outdoor free-standing vegetation with VGS could enhance connectivity between buildings and surrounding vegetation, thereby accelerating the benefits as vegetation matures (Berry et al., 2013).

For a summarised evaluation of this section's solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.2 Vertical Greening Systems.

### 5.2.3. Pergola, Awnings & Other Outdoor Structures

Other ways to incorporate vegetation into the existing built environment include using structures such as pergolas, shades, and awnings. As mentioned previously, the use of awnings and pergolas for shade has its origins in the Mediterranean region, where they were used not only for shade but also for fruit cultivation, particularly of grape vines (Fassaden Grün, n.d.; Petschek & Gass, 2011). These structures were designed using supporting frames and sometimes trellises to allow vine-like plants to grow on them, creating a canopy. These canopies were used as building extensions or to connect two buildings.

Figure 22: Outdoor Break or Meeting Space



*The photo modified by AI illustrates a terrace or outdoor break area that can also be used for meetings. The original photo extracted from Nola's website and modified using AI to add the climbing plant (Google Gemini, 2025; Nola, n.d.).*

Pergolas are typically found in the form of arcades with an arch-shaped or flat canopy, and are frequently closed on the sides as well (Petschek & Gass, 2011). Alexandri & Jones' (2006) research suggests that pergolas and other outdoor vegetated structures absorb heat energy from both short and long waves, thereby serving as an insulation method between the ground and the sky. With shading and evapotranspiration effects, these solutions are deemed the most efficient for achieving thermal comfort in summer or warm climates. Moreover, outdoor vegetated structures can provide co-benefits such as privacy and increased visual amenity in the workplace (Petschek & Gass, 2011). For example, Figure 14 and Figure 22 illustrate pergola-style structures that, with the use of vegetation, create a shaded and comfortable space for employees to work. Additionally, these structures feature a green wall on one side, which serves as a wind shelter and creates a sense of privacy.

For areas that lack the space for a structure or for vines to grow, the Spanish company Singular Green developed sail-like shades that can be attached to existing walls and support a thin layer of substance with specific plants to grow, creating a sail-like cover or green shade (SingularGreen, n.d.). The plants are selected to optimise absorption of carbon dioxide and nitrous oxide gases and have the power to reduce energy consumption by shading and evapotranspiration by 130 watts per hour, per square meter. These green sails were estimated to reduce temperatures by up to 7.C when compared to standard shade structures (Bakhshoodeh et al., 2022). Figure 23 Illustrates a hypothetical working space that can be created using sail-like shades that can be installed over impervious surfaces such as a paved plaza. Green shade sails protect workers from the sun, wind and light rain, and flowering seedlings can be used to add sensorial amenity in different seasons.

Figure 23: Outdoor Workspace under Sail-like Cover

*The photo modified by AI illustrates a paved plaza where a planted sail-like shade cloth has been used to create a vegetated pergola. The original photo extracted from SingularGreen's website and modified using AI to add the climbing plant (Google Gemini, 2025; SingularGreen, n.d.).*

Other structures that can provide support for vegetation to enhance EE and thermal comfort are awnings or eaves. Choosing the appropriate size and shape of these structures is critical to enable shading for doors and windows that are more exposed to sunlight in the summer, minimising heat transfer into the building envelope, while allowing sunlight in winter.

Determining the correct depth for these structures is crucial. As illustrated in Figure 8 The sun's trajectory angle changes throughout the year in proportion to the Earth's surface (Bustamante, 2009); therefore, calculating the depth that will block as much sun from a higher angle in summer, while allowing sunlight when the sun is at a lower angle in winter, will enable an optimal utilisation of sunlight (BRANZ, 2025). Another option is to grow a deciduous climber on the structure.

Figure 24 showcases examples of green eaves and awnings in residential settings where they are more often used. In Figure 25, photos generated with AI software illustrate how these can be scaled up for use in commercial and industrial buildings. Eaves and awnings can be installed in industrial premises to cover entrances and windows, in commercial premises to provide thermal comfort and amenity to customers walking in the area, and to shade smaller buildings that may have access to put plants on their terrace.

Figure 24: Green Eaves or Awnings Examples in Residential Settings

*(Fanning, n.d.)* *(Hefner, n.d.)* *(Kuulkers, n.d.)* *(Amazon UK, n.d.)*

*Photos illustrating green eaves or awnings found on the Internet, featuring various structural options for use above openings.*

Figure 25: Green Eaves or Awnings in Industrial and Commercial Settings

*The artificially generated photos illustrate potential retrofit options for adding eaves, awnings, and pergolas to existing structures in industrial and commercial settings. From left to right, the first and second photos show the entrance of a warehouse, the third a commercial centre, and the fourth a structure that connects two buildings (Google Gemini, 2025).*

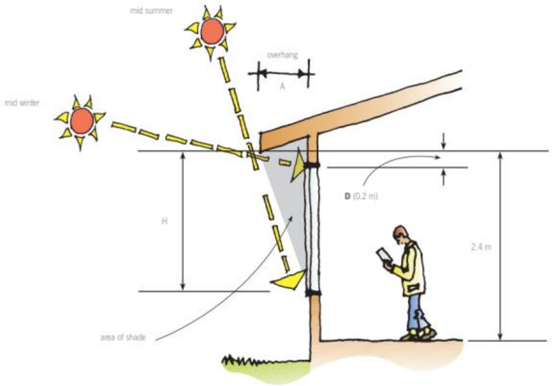
To calculate the appropriate overhang size for the trellis, BRANZ (2025) recommends using the equation $A = H \times F_{height}$, where A represents the overhang, H denotes the opening height, and $F_{height}$ is the factor based on the specific location within the country (refer to the $F_{height}$ chart in Figure 26). To find the shade head height for winter allowing sunlight through, the formula $D = H \times F_{shade}$ should be used, where D is the shade distance between the eave or trellis and the top of the window, H is the height of the window, and $F_{shade}$ is the relevant factor from the chart in Table 3.

Table 3: Eaves and Awnings Calculating Factors

| Location | $F_{height}$ | $F_{shade}$ |
|---|---|---|
| Auckland | 0.24 | 0.14 |
| Wellington | 0.32 | 0.15 |
| Christchurch | 0.35 | 0.15 |
| Dunedin | 0.39 | 0.16 |

*Chart with the calculating factors based on latitude for Aotearoa's main cities (BRANZ, 2025).*

Figure 26: Calculating Overhang Depth for Eaves and Awnings




*Graphical explanation of the overhang depth equations graph (BRANZ, 2025)*

These solutions can be implemented utilising the same native plant species described in Section 5.2.2, potentially providing sensory benefits through the flowers' colour and fragrance. Eaves and awnings may serve as significant structures for EE, facilitating the incorporation of vegetation in various shapes and forms, even in the absence of ground space. This characteristic enhances their versatility in augmenting WW by transforming sterile and artificial settings and enabling employees to enjoy outdoor exposure, even within less visually appealing industrial contexts.

For a summarised evaluation of this section's solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.3 Pergola, Awnings & Other Outdoor Structures.

### 5.2.4. Balconies

Other outdoor areas within commercial and industrial premises that can support vegetation include balconies. Although balconies are generally smaller in surface area compared to other outdoor spaces, some are sufficiently spacious to serve as viable locations for introducing vegetation. Balconies that are accessible to occupants often feature doors and openings in the building envelope, which can serve as both opportunities and vulnerabilities for EE. These openings play a significant role in managing energy transfer, primarily through the movement of heated or cooled air, thereby influencing the building's overall energy performance (Gonzalo & Vallentin, 2014; Raji et al., 2015). Moreover, balconies function as valuable outdoor environments that provide a safe and convenient space for employees to engage in activities such as making phone or video calls, conducting work meetings, having lunch, and attending work-related events, all without necessitating departure from the premises (Lottrup, 2012; Petersson Troije et al., 2024).

A study conducted in Albania examined the energy performance of buildings featuring balconies and utilising HVAC systems. This research compared balconies with permanent concrete planters that utilise computer modelling for various plant species against cleared balconies (Forzani et al., 2020). The shading effect of vegetation led to significant energy reductions in south-facing areas (which would be north-facing areas, in Aotearoa), with reductions reaching up to 53%, resulting in an average annual cooling reduction of 35.6%. For balconies with planted vegetation facing west, energy savings reached a peak of 47.5%, with a yearly average cooling reduction of 39.4%. It is important to note that these results may be overly optimistic for cities in Aotearoa, as the Albanian climate is, on average, warmer.

For north-facing balconies in Aotearoa, it is advisable to utilise small vase-shaped-crown trees or shrubs that extend higher than the window or opening, with a bole reaching approximately three-quarters of its height (Forzani et al., 2020). In line with the awnings and eaves discussed in 5.2.3, this design allows the green canopy to provide shade from the direct sun during the summer months without obstructing the balcony view, while still permitting sunlight to reach the openings in winter. For west-facing balconies, it is recommended to employ shorter vegetation that covers at least half of the opening (Forzani et al., 2020).

Raji et al. (2015) suggest that green balconies can significantly reduce a building's energy consumption by providing shade in the summer and protection from winds throughout the year. However, they caution that excessive vegetation and improper plant arrangements can increase energy demand in the winter due to shading. Furthermore, their research emphasises that while water retention offers an additional benefit, it also introduces complexities regarding the weight of plants and pots on the balcony, which must be carefully considered for safety reasons.

An option that has not been extensively documented in existing literature,  is the employment of mobile planters on balconies (Harshdeep, n.d.). Specifically, outdoor mobile planters or pots mounted on wheeled bases can facilitate the reconfiguration of balcony layouts in response to seasonal changes and allow planters to be relocated to mitigate potential damage during extreme weather conditions.

Figure 27: Balcony or Decking Area Working Space with Movable Planters

*This AI-generated photo depicts an outdoor balcony with planters that can be moved to suit different seasons for shading and wind protection (Google Gemini, 2025; Harshdeep, n.d.).*

Inspired by previously cited studies, Figure 27 illustrates an outdoor balcony equipped with mobile planters. Native Cabbage trees *(Cordyline australis)* were selected for their natural vase-shaped morphology and wind tolerance (Forzani et al., 2020). However, other native species may also be appropriate depending on site-specific wind exposure. For lower vegetation or hedge like appearance, species such as Kapuka (*Griselinia littoralis*), Taupata (*Coprosma repens*) or Mānuka *(Leptospermum scoparium)* can be used. These planters can serve more as a wind barrier, and to subdivide workspaces, allowing for privacy within the balcony and from neighbouring buildings. In addition, plants like Mānuka *(Leptospermum scoparium)*, Rengarenga *(Arthropodium cirratum)* and native flaxes such as Harakeke *(Phormium tenax) or* Wharariki *(Phormium cookianum)* will enhance the sensorial experience when flowering.

With the increasing adoption of glass curtain wall technology in commercial buildings, which is characterized by a predominantly glass façade with fixed windows that cannot be manually opened (Wu & Flemmer, 2020), many office structures are relying solely on balcony doors to facilitate natural ventilation. Furthermore, these buildings can benefit from year-round shading effects due to the greenhouse-like structure that often leads to overheating.

It is evident that balconies present significant potential, especially in urban settings, as they represent areas suitable for the inclusion of potted plants. Additionally, incorporating seasonal arrangements for balconies enhances the various wellness factors highlighted in the concept of biophilia, as discussed in Section 3.3.1. However, meticulous planning of the layout, careful selection of plants, and proper pruning are crucial to achieving positive results and preventing any adverse effects.

For a summarised evaluation of this section's solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.4 Balconies.

## 5.2.5. Living Roofs

Figure 28: Ōtākaro Orchard Blue-green Roof with Solar Panels

*Photo of solar panels integrated into a green-roof in Ōtāutahi (NUWAO, 2024). Designed by CDM.*

Roofs account for a significant amount of surface across all business premises in Aotearoa. From an energy perspective, many roofs are being used to install solar panels for solar energy generation. Nonetheless, the potential to use vegetation on roofs is significant, and the technology to retrofit these has improved in recent years. Case studies such as the Ōtākaro Orchard living roof in Ōtāutahi is evidence that these two solutions can co-exist in some cases, shown in Figure 28 (NUWAO, 2024). In this thesis, the term living roof allows to consider any way of adding vegetation on a roof, as the term green roof normally suggests roofs that are fully covered with a substrate where vegetation can grow.

Stormwater management is a key benefit of living roofs, but they offer many additional advantages. These include financial savings from enhanced thermal performance, where they act as insulation when dry and provide thermal mass when wet. Through evapotranspiration, living roofs also help cool the surrounding area. They enhance occupant well-being by improving thermal comfort, providing sound insulation, and filtering air pollutants, potentially increasing property values. From a broader urban perspective, living roofs mitigate the urban heat island effect (UHIE) and support biodiversity by creating habitats (Avery & Davies, 2019; Cunningham et al., 2017; Fassman-Beck & Simcock, 2013; Raji et al., 2015).

To evaluate whether a green roof is a viable solution for an existing building the first step is to assess the suitability of the roof based on its structural limitations, including the weight it can support. This assessment dictates the amount of soil, water, and plants that can be accommodated, as well as the roof's slope, which may influence the ability of the green roof layers to remain in place. Based on these structural considerations, two types of green roofs can be considered: extensive and intensive, depending on the type and depth of the substrate (the substrate will be the soil or an artificial component where plants will grow and hold on). Extensive green roofs are generally thinner (50 to 150mm deep), require less structural support, and are often the most straightforward option for retrofitting. Intensive roofs' substrates can be over 200mm and may hold grown trees (BRANZ, 2011; Fassman-Beck & Simcock, 2013; Raji et al., 2015). Note that, depending on the green roof, prior consent from the council may be required alongside an engineered structural assessment. Therefore, for this study, which focuses on retrofit potential, extensive green roofs will be the primary emphasis as they are easier to accommodate, more often on flat terrace roofs (Fassman-Beck & Simcock, 2013).

Extensive green roofs have been proposed as a more cost-effective option for both installation and maintenance, often not requiring irrigation systems unless the local summers are prolonged and dry. However, the reduced costs may also lead to diminished benefits in stormwater retention and energy efficiency, and many of these roofs are not suitable for foot traffic (Fassman-Beck & Simcock, 2013).

It is also worth noting that living roofs can be modular in design, allowing for installation in tray modules that act as building blocks. Another alternative is using containers or large pots to cover a terrace. These roofs can coexist with solar panels and be referred to as biosolar living roofs (Avery & Davies, 2019; Fassman-Beck & Simcock, 2013). These last considerations raise a crossover between VGS structures (Section 5.2.2), pergolas and eaves structures (Section 5.2.3) and balconies (Section 5.2.4). The solutions previously outlined can be applied to roofs or terraces to create a vegetated living roof, provided the structure can withstand the weight.

For example, commercial, office, and industrial buildings featuring a terrace roof designed for shading and protection against rain, as illustrated in the AI-generated image to the left in Figure 29, can benefit from extensive living roof solutions depicted in the image to the right. While this living roof is unlikely to be accessed by foot traffic, it plays a crucial role in stormwater management, helps lower temperatures on the roof and in its surroundings, and enhances the visual appeal for employees who have a view from their windows in an area where greenery is sparse. Furthermore, if the building's windows are operable, the cooler air from the vegetation can improve natural ventilation, and the flowers can provide both a visual and olfactory sensory experience.

Figure 29: Hypothetical Extensive Living Roof Application

*In these AI-generated photos, a regular office building with eaves and roofs outdoors can be seen to the left, which can be used for extensive living roof planting as shown in the right photo (Google Gemini, 2025).*

While some living roofs may appear vibrant and lush, they can necessitate considerable maintenance. To mitigate these costs, it is advisable to adopt a more natural aesthetic that evolves in harmony with the seasons. This may initially be uncomfortable, as it might not align with conventional beauty standards (Stanley, 2025). Consequently, it is important to acclimate to the sight of weeds and plants appearing dry in the summer, rather than striving for an idealised aesthetic (Fassman-Beck & Simcock, 2013). This approach can also foster a biophilic experience, allowing one to truly appreciate the changing seasons throughout the year, rather than holding unrealistic expectations for a flawless view.

From a WW perspective, living roofs offer numerous potential benefits comparable to the benefits of balconies described in Section 5.2.4, as these can facilitate outdoor work, break activities, and social hosting functions. An illustrative example of a local living roof within a professional environment is situated atop the Tonkin & Taylor office at the NZI Centre in Auckland. The photos in Figure 30 show how the roof was designed with seating areas intended for rest, as well as tables suitable for working or dining. The design remains adaptable, enabling modifications, and supports the hosting of work-related events while offering scenic views of the urban landscape. During a site visit, the ecologist who worked on the plant selection explained that they used only native plant species, with some indigenous to the Alpine regions of Aotearoa, selected for their resilience to wind exposure, considering the building's significant height.

Figure 30: Living Roof at the NZI Centre in Auckland

*These photos show the design of a living roof in Auckland, at the NZI centre. This was designed initially with the building as an intensive living roof. Photo taken by J.E. Cancina with permission from Tonkin & Taylor.*

The choice of plants is crucial for living roof to be sustainable, and will also highlight the need for maintenance. Native plants such as the New Zealand Daphne *(Pimelea prostrata)*, New Zealand Iris *(Libertia peregrinans)*, Pururea *(Acaena microphylla)* and Kowharawhara *(Astelia banksi)* are some options among other native grasses, flaxes and draught and wind tolerant plants (Fassman-Beck & Simcock, 2013).  Living roofs with exotic plants often use succulents of many kinds (Avery & Davies, 2019; BRANZ, 2011; Fassman-Beck & Simcock, 2013).

With the wide range of living roof technologies available today, these systems can take on various forms and can cover both small and large areas. Almost any rooftop has the potential to become a living roof by utilising planters or substrates. Depending on its intended use, structural requirements, and budget, living roofs can offer numerous benefits and may require minimal to extensive maintenance.

For a summarised evaluation of this section’s solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.5 Living Roofs.

### 5.2.6. Indoor Vegetation

Indoor vegetation has a range of benefits to the occupants in the building, with most studies focusing on wellbeing, including the visual amenity of plants and our connection to nature, and factors such as air quality and acoustic benefits explored in Section 3.3 (An et al., 2016; De Vries et al., 2023; Fjeld et al., 1998; Liu et al., 2022; Lottrup, 2012; Lygum et al., 2023; Pearson-Mims & Lohr, 2000; Robinson, 2018; Wolverton et al., 1984). Indoor plants can also contribute to reducing energy demand through shading and evapotranspiration. This section discusses how EE strategies that incorporate indoor vegetation can improve thermal comfort, contributing to improved work productivity and raising work productivity.

As previously mentioned in several sections (Sections 3.2.4, 3.5.4, and 5.3.4), a critical element to consider in current trends in building design is referred to as the glass building effect (Wu & Flemmer, 2020). These structures are easily identifiable due to their predominantly glass façades. According to Wu & Flemmer (2020), such buildings are primarily found in Auckland, which is less susceptible to earthquakes; notably, 87% of these buildings are single-glazed, and 90% are designed for office use. Some of the notable skyscrapers contributing to Auckland's skyline include the PWC Tower, Deloitte Building, and Phillip’s Fox Tower. One significant challenge associated with these buildings is the high HVAC costs for cooling, heating and ventilation. This is largely attributed to lower levels of insulation, which depend on the type of glass used, but more critically, it is due to the greenhouse effect created indoors. Various types of glazing exhibit different heat transmission rates, represented by their U-Values. For instance, clear glass has a U-value of 5.8 W/m²K, while double-glazed glass with argon, commonly known as low-e, has a U-value of 1.1 W/m²K. There are also glass types designed to reflect more light and heat, as well as filter UV rays; however, the extensive use of glass allows for 85% of interior light, along with a significant amount of heat, to penetrate (Wu & Flemmer, 2020).

The combination of glass and direct sunlight also contributes to increased glare levels, affecting the productivity of employees working with screens (Liu et al., 2022; Mangone et al., 2014), and raising psychological perception of heat by occupants (Wu & Flemmer, 2020). Research conducted in Auckland indicated that while staff appreciate the aesthetic appeal of these designs, they result in HVAC systems operating at moderate to high capacity, without considering natural ventilation (Wu & Flemmer, 2020).

For buildings featuring windows with high sun exposure, shading emerges as a critical consideration. As previously discussed in 3.5.1, external shading is generally more effective in protecting the building from direct sunlight. However, in many instances, such external solutions may be impractical or cost-prohibitive. An alternative approach involves using internal green blinds or planters that incorporate live plants to obstruct sunlight. An example of this can be seen in Aurecon's building located in Auckland, as illustrated in Figure 31.

Figure 31: An Example of Green Blinds

*The photo shows an example of green blinds at the Aurecon office in Auckland (Outside In, n.d.).*

Unfortunately, extensive research yielded no existing literature comparing the effectiveness of this approach with that of an engineered artificial blind. Adopting a first principles approach, given the thermal properties of leaves explained in 3.5.1, the use of vegetation for shading may perform better than manufactured blinds that still irradiate heat absorbed by the plastic and metal parts (Jayalakshmy & Philip, 2010). Moreover, heat on the leaves would increase evapotranspiration, which would increase the cooling effect on its surroundings (Liu et al., 2022), and cool its surroundings. Consequently, while this solution demonstrates beneficial potential for energy performance, among other positive aspects to be addressed later, it also highlights a gap in the literature that provides opportunities for further research.

Seidel (2021) interviewed a landscape architect who discussed the use of indoor plants to create a green blind, employing species that can thrive in direct sunlight, including the option of air plants. One of the ecologists interviewed within this research also endorsed the viability of this approach. She pointed out that she had an external 'green blind' which is effective for shading, and that the implementation of these indoors should be effective. She also highlighted that the plants used would require a certain level of humidity and water, which may be quite substantial during the summer months.

In Aotearoa's temperate climates, green blinds can be pruned in various ways to allow more sunlight during winter while encouraging growth in spring for shade in summer. Pots can be suspended from the ceiling, or climbing plants can be trained along trellises, as illustrated in Figure 32, or planter frames which can be made mobile, as depicted in Figure 33. This approach offers greater flexibility to adapt to different workplace arrangements and seasonal changes, as mobile plant walls can be used as blinds during the summer or when the sun shines through a specific window, and then moved away in winter to allow the heat to access the building.

Figure 32: Indoor VGS with Trellis

*The photo shows an example of indoor VGS using a wired trellis at Tonkin & Taylor's office in Auckland, photo by J.E. Cancina.*

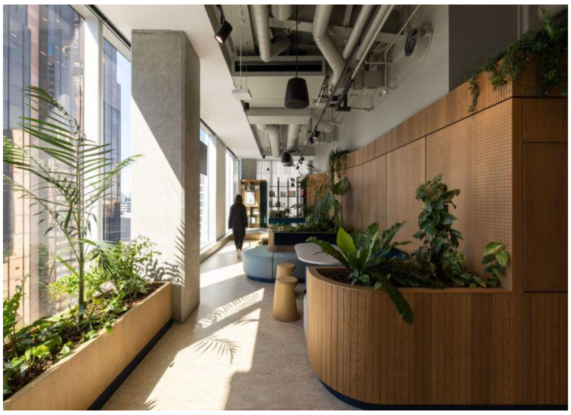
Figure 33: Indoor Vertical Mobile Planter

*The photo shows an example of an indoor vertical mobile planter. Original photo to the left, and AI-generated with a climbing plant to the right (Ambius, n.d.; Google Gemini, 2025).*

In addition to their versatile shading effects, mobile planters and green walls (Figure 33) facilitate the reconfiguration of office spaces into distinct subdivisions, thereby enhancing privacy across various areas and supporting diverse office functions.

Tall potted plants, such as Nīkau palms *(Rhopalostylis sapida)*, Cabbage *(Cordyline australis)* and Puka trees *(Meryta sinclairii)*, can be strategically employed in either fixed or mobile containers to provide shade within interior spaces, as illustrated in Figure 34, which depicts the Milford Asset Management office in Auckland. Certain plant species permit annual pruning prior to the colder season, thereby increasing sunlight penetration, and are allowed to regenerate during spring and summer to optimise shading effects. Additionally, research on evapotranspiration indicates that using only potted plants can improve thermal comfort by 19% to 25% and enhance the relative humidity levels negatively affected by HVAC systems. (Liu et al., 2022).

Figure 34: Indoor Fixed Planters Providing Indoor Shade



*The photo shows an example of fixed planter allowing plants to provide shade at Milford Asset Management office in Auckland (GreenAir, n.d.-b).*

Beyond the evident shading benefits in indoor settings, indoor plants play a significant role in reducing occupants' sick building syndrome (SBS), a topic introduced in Sections 3.5.2 & 3.5.4.

Empirical evidence supporting these assertions is derived from a study conducted within an office environment comprising 51 participants. The study employed a controlled design, assigning participants to two groups: one with offices containing indoor foliage and another without. Participants self-reported health symptoms via questionnaires administered across two cycles, each lasting three months, during the springs of 1995 and 1996 (Fjeld et al., 1998). The findings indicated that offices with plants exhibited a 23% reduction in neuropsychological symptoms—such as fatigue, headaches, and nausea—and a 24% decrease in mucous membrane symptoms, including eye and nasal irritation as well as coughing. These results suggest that integrating foliage plants into office settings may enhance occupant health by alleviating discomfort symptoms. Furthermore, the study implies that such environmental modifications may positively influence overall performance and productivity (Elliott, 2023; Fjeld et al., 1998; Lottrup et al., 2013; Petersson Troije et al., 2024).

A recent literature review corroborates the previously discussed benefits of vegetation (Raji et al., 2015). It suggests that vegetation can be integrated not only in designated office spaces but also in communal areas without access to natural ventilation, with indoor gardens proposed as a strategy to mitigate SBS. Additionally, indoor vertical walls can contribute to humidity regulation, air purification, and oxygenation. The research emphasises the importance of considering building age and compliance with relevant codes, as these factors can reveal opportunities for enhancing building capacity to implement NbS. For example, indoor vegetation has been shown to reduce volatile organic compounds in the air, which vary depending on construction materials, paints, and indoor furnishings—elements of buildings that have undergone significant changes to the building code (Raji et al., 2015).

In busy working environments, efficient and holistic designs that incorporate indoor vegetation improve privacy from a visual perspective. Office departments, activities, and break areas can be subdivided by locating plants of different sizes and foliage density to create corridors without obstruction (De Vries et al., 2023; Pearson-Mims & Lohr, 2000). This is especially advisable in open-plan spaces. Additionally, plants' acoustic properties help absorb some noise that would normally bounce off harder surfaces, making open-plan rooms more pleasant to work in (EMS Business Redefined, 2024; Pearson-Mims & Lohr, 2000; Raji et al., 2015).

Studies performed during, and pre- and post-COVID-19 pandemic also identify plants as an amenity that can help encourage employees to return to the office and better settle back after extended periods of working remotely from home (De Vries et al., 2023; Lygum et al., 2023).

The photos in Figure 35 illustrate the potential of vegetation to inform the design of diverse environments within office spaces across Aotearoa. The first image, from the MC Centre, depicts a one-on-one meeting area where greenery has been incorporated to enhance privacy and overall environmental quality. The central image from Gallagher Insurance demonstrates that planters positioned over cabinets and on walls serve to delineate departments and facilitate the creation of corridors. The final image displays a fixed planter wall, which helps subdivide the overall space without the need for traditional partitions that could obstruct airflow, natural light, or necessitate additional construction.

Figure 35: Office Designs using Indoor Plants in Aotearoa


*(Outside In, n.d.-b, Location MC Centre)*


*(GreenAir, n.d.-a, Location Gallagher Insurance)*


*(Ambius, n.d.-b, Title Vertical Green Wall)*

*These three photos from offices in Aotearoa illustrate how to utilise vegetation for the purposes of privacy, amenity, and effective design.*

The choice of plants for indoor environments can be challenging, as the plant, its pot size, and location can all impact its growth, either exceeding expectations or not growing enough. Several scholars advocate for including more native plants indoors to enhance the sense of belonging in Aotearoa (Ignatieva et al., 2008; Meurk et al., 2007; Stanley, 2025). Unfortunately, the interviews highlighted that exotics tend to be a common choice due to their ease of reproduction and maintenance. Interviewees also explained that there is a lack of data on how to utilise Aotearoa's natives more effectively indoors.

Some commonly used indoor native plants, mostly ferns, adapt better when they do not receive direct sunlight. For example, suitable for indoor use, among many others, these include the Pikopiko/Hen and chicken fern *(Asplenium bulbiferum)*, Makaka/Maidenhair *(Adiantum aethiopicum)*, Kiokio *(Parablechnum novae-zelandiae)*, and New Zealand cliff brake *(Pellaea rotundifolia)* (Auckland Botanic Gardens, n.d.-a; New Zealand Plant Conservation Network, n.d.-b). Other plants thrive under direct sunlight, for example Puka trees *(Meryta sinclairii) and* Cabbage Trees *(Cordyline australis).* While there is a data deficit, as suggested in Section 4.8, several ecologists interviewed suggest Kawakawa *(Piper excelsum)*, Pohuehue *(Muehlenbeckia complexa or australis)* (for the purpose of green walls) and Nīkau palms *(Rhopalostylis sapida)*.

For a summarised evaluation of this section's solutions effectiveness, cost-benefit, implementation difficulty and factors relevant to consider see Appendix 4.6 Indoor Vegetation.

## 5.3. Framework to Consider and Implement Nature-based Solutions within Work Premises

This section presents a systematic framework to guide businesses in the process of developing, implementing and monitoring the solutions suggested in Section 5.2. This framework, is based on ISO 14001 (International Organization for Standardization, 2015), Toitū's Enviromark Programme (Toitū Envirocare, n.d.) and the Plan-Do-Check-Act framework developed first by Walter Shewhart in the 1930s (Moen, 2020).

### Step 1: Context, purpose and interested parties.

The first step is to identify the key reasons, or case, for the business to consider vegetation on its premises. This can be approached by developing a simple, high-level, yet robust SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, or by simply putting key thoughts into writing. Understanding the key reasons for this consideration will help guide implementation decisions.

In addition, it is important to consider interested parties that could benefit from or be affected by the addition of vegetation, such as staff, clients, the parent company, the board, neighbours, and the overall community, and how vegetation could influence these parties. Identifying the parties the solutions will affect will aid in assessing the significance of these solutions, and determining who to communicate with before, during, and after implementation, and with whom to consider for ongoing performance and management of these solutions.

### Step 2: Scope

Next, it is necessary to consider the premise design and structure, its geographical location, its orientation to the sun, outdoor planting availability, and indoor space. This will help guide the selection of solutions, considering the physical environment available. It is recommended to draw or map the site, highlighting outdoor and indoor spaces available, as well as mapping the sun trajectory against the building.

### Step 3: Mapping Activities

It is then recommended to map the activities that people do on behalf of the company and how these are distributed throughout the premises. This should include recreational activities and be performed by visitors or clients. By using the map in the Scope step, this crossover helps identify which activities occur and where they take place, highlighting areas that are currently underutilised and may have potential for development.

These three initial steps will help with approaching Meadows' systems recommendation, to *"Listen to the wisdom of the system"* (Meadows, 2009, p. 178). In other words, before rebuilding, replanting or contracting designers to undertake heavy modifications or projects, take the time to observe and acknowledge the current assets and opportunities you have within your current premises and how to work with the existing conditions.

### Step 4: Problem Identification

Identifying the key issues within the workplace is essential to consider the potential for vegetation to enhance EE and WW. Problems with implementation also need to be anticipated – such as watering regime, growth management, etc. This can be achieved through different pathways, which are not mutually exclusive, for example:

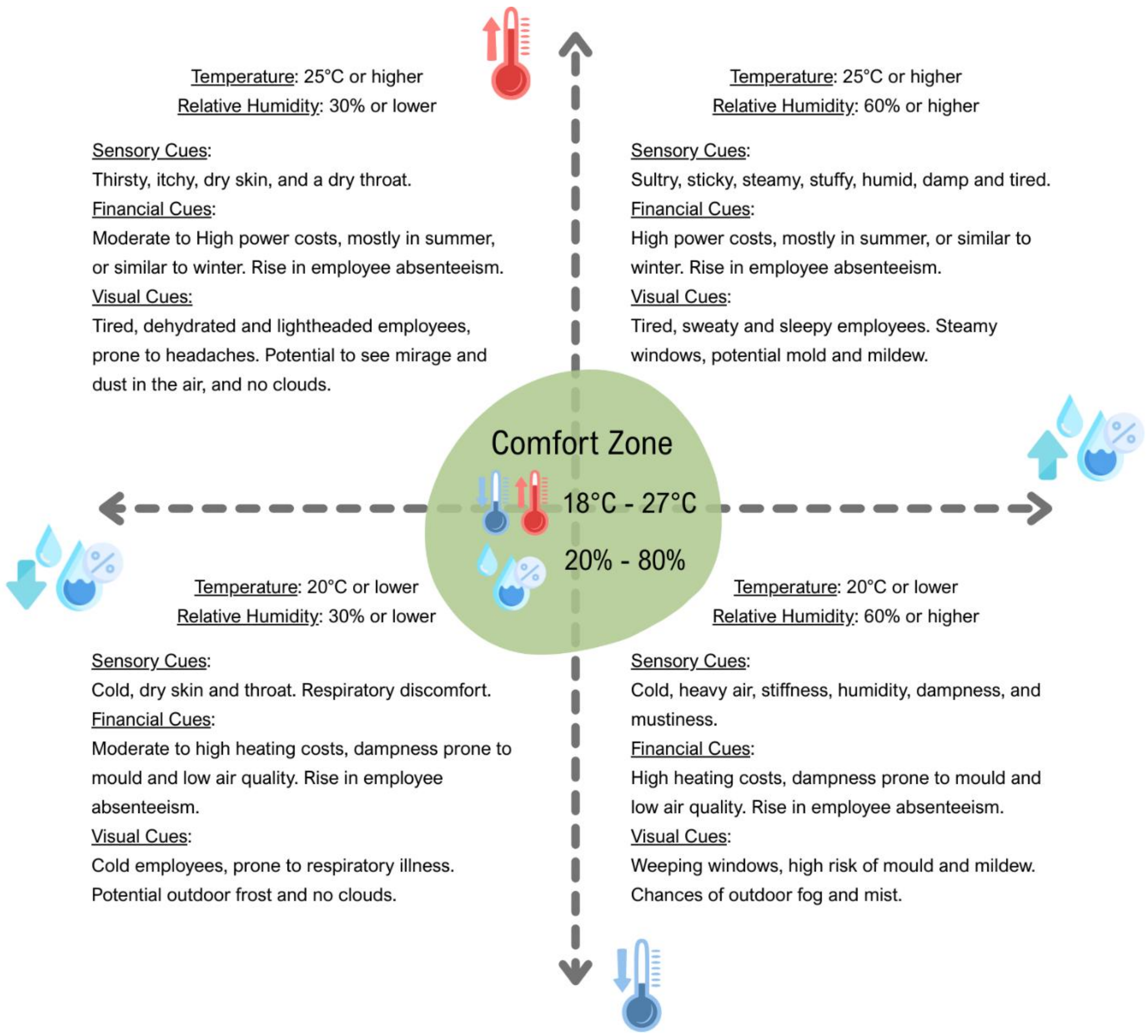
- Reviewing power bills to assess consumption throughout the year, and whether there is more consumption in winter, summer or if energy consumption is even throughout the year.
- Running an internal employee survey to hear their thoughts on thermal comfort, and symptoms related to SBS
- Assessing performance holistically with appropriate departments and verifying if there are key areas in the premise or teams that may not be performing as expected.
- Considering absenteeism and benchmarking it against national or industry standards.

As suggested by Meadows, *"The least obvious part of the system, its function or purpose, is often the most crucial determinant of the system's behaviour"* (Meadows, 2009, p. 178). Identifying the problems will ensure that the purpose of the solutions is realised.

Figure 36 presents a summary approach for identifying issues and cues when the working environment falls outside the comfort zone. The designated comfort zone ranges from 18°C to 27°C in temperature and 20% to 80% in relative humidity (Gonzalo & Vallentin, 2014; Mangone et al., 2014; Vadoudi, 2018). The graph is divided into four quadrants, each illustrating four potential case scenarios outside people's comfort zone that are too hot and humid, too hot and dry, too cold and humid, or too cold and dry. Each quadrant highlights, for each scenario, different cues that can help identify the issue. It is acknowledged that while temperature and humidity can be measured indoors, that is not the case for all workplaces. Additionally, comfort zone parameters are not clear-cut, and therefore, it is appropriate to consider these cues alongside temperature and humidity figures, if any are available.

Cues in each quadrant are divided into three types: sensory, financial and visual. Sensory cues are touch-based signals that can be perceived in the skin, throat, and even emotionally, such as itchiness, stickiness, and stuffiness. Financial cues can be seen in energy consumption trends, as reflected in power bills. It is worth noting that discomfort can also manifest as a financial cue when absenteeism levels rise, and this can be perceived across any quadrant. Visual cues are what a person perceives from observing the weather outside, sensory cues from others, and the premises themselves.

Figure 36: Guidance for Identifying the Problem




*The developed graph helps identify issues and cues when the premises environment is outside the comfort zone for employees. It divides the issues into four groups: outside the standard comfort zone, hot & humid, hot & dry, cold & humid, and cold & dry.*

### Step 5: Assessing Significance

The next step is to evaluate whether any of these issues are significant or material to the organisation by assessing each problem's positive and negative impacts holistically. It is recommended to *"Go for the good of the whole"* (Meadows, 2009, p. 178). This suggests taking a holistic approach that considers the wider benefits beyond the specific problem being solved and potential drawbacks. As discussed in Section 5.2, NbS can deliver a broad array of benefits and co-benefits. Before aiming to solve a particular issue, it is important to assess which of the many potential issues that are affecting thermal comfort are significant to address.

A holistic process can be undertaken by completing the two matrices in Table 4 for each of the problems identified in Step 4. The table is first divided into two: internal and external. Internal refers to impacts within the organisation, while external refers to impacts on the wider society. Fill in the internal and external chart with any positive or negative impact resulting from addressing that issue, and whether you think this positive or negative effect will have a low, moderate or high impact. Issues can also be divided among financial, operational, environmental, cultural-wellbeing and marketing-reputational. Some of these categories are likely to have overlapping impacts. Financial impacts refer to revenue or costs; operational impacts to efficiency; environmental impacts to the natural environment; cultural-wellbeing impacts to people's welfare; and marketing-reputational impacts referring to the organisation's brand.

Table 4: Internal and External Holistic Impact Assessment Matrices

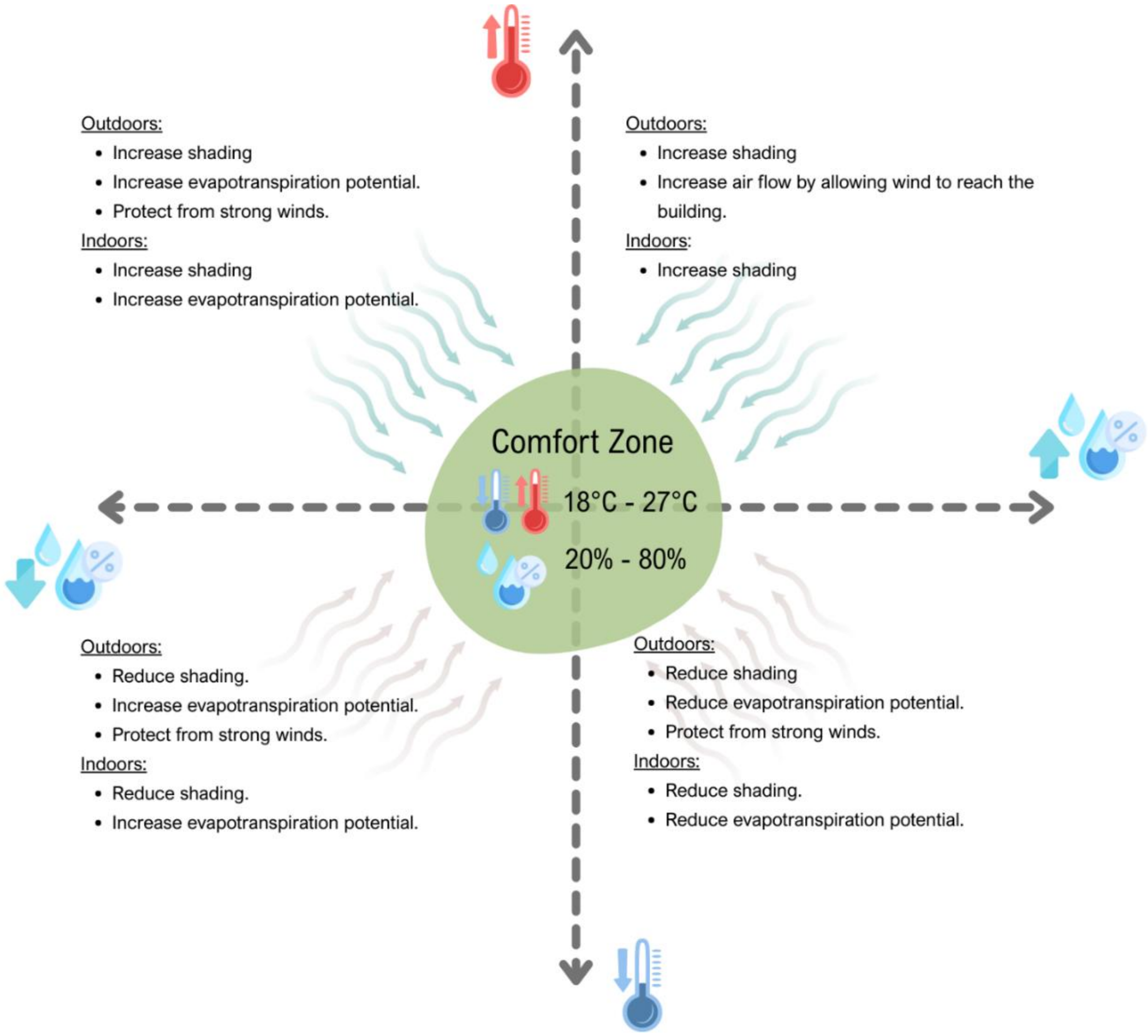
| | Internal Impact - Effects on the Business/Organisation | | | | | |
|---|---|---|---|---|---|---|
| | Negative | | | Positive | | |
| | High | Moderate | Low | Low | Moderate | High |
| Financial | | | | | | |
| Operational | | | | | | |
| Environmental | | | | | | |
| Cultural - Wellbeing | | | | | | |
| Marketing - Reputation | | | | | | |
| | External Impact - Effects on the overall City/Society | | | | | |
| | Negative | | | Positive | | |
| | High | Moderate | Low | Low | Moderate | High |
| Financial | | | | | | |
| Operational | | | | | | |
| Environmental | | | | | | |
| Cultural - Wellbeing | | | | | | |
| Marketing - Reputation | | | | | | |

*These two matrices aim to help consider positive and negative impacts from different perspectives within the organisation and outside of it.*

### Step 6: Considering Solutions

Once you have assessed significant problems in Step 5, which were previously identified in Step 4 using the diagram in Figure 36, cross-reference the previous results to consider and identify solutions. The diagram in Figure 37 uses the same four-quadrant graph style used in Figure 36, to help identify which vegetation factors are relevant to consider for selecting NbS from the ones developed in Section 5.2. Given the quadrant where issues and cues were identified in Figure 36, read the factors suggested in the same quadrant on Figure 37. Understanding the specific quadrant and its associated factors helps select appropriate solutions, as developed in Section 5.2, that align with the premises' capabilities and characteristics, ensuring effective management of environmental conditions.

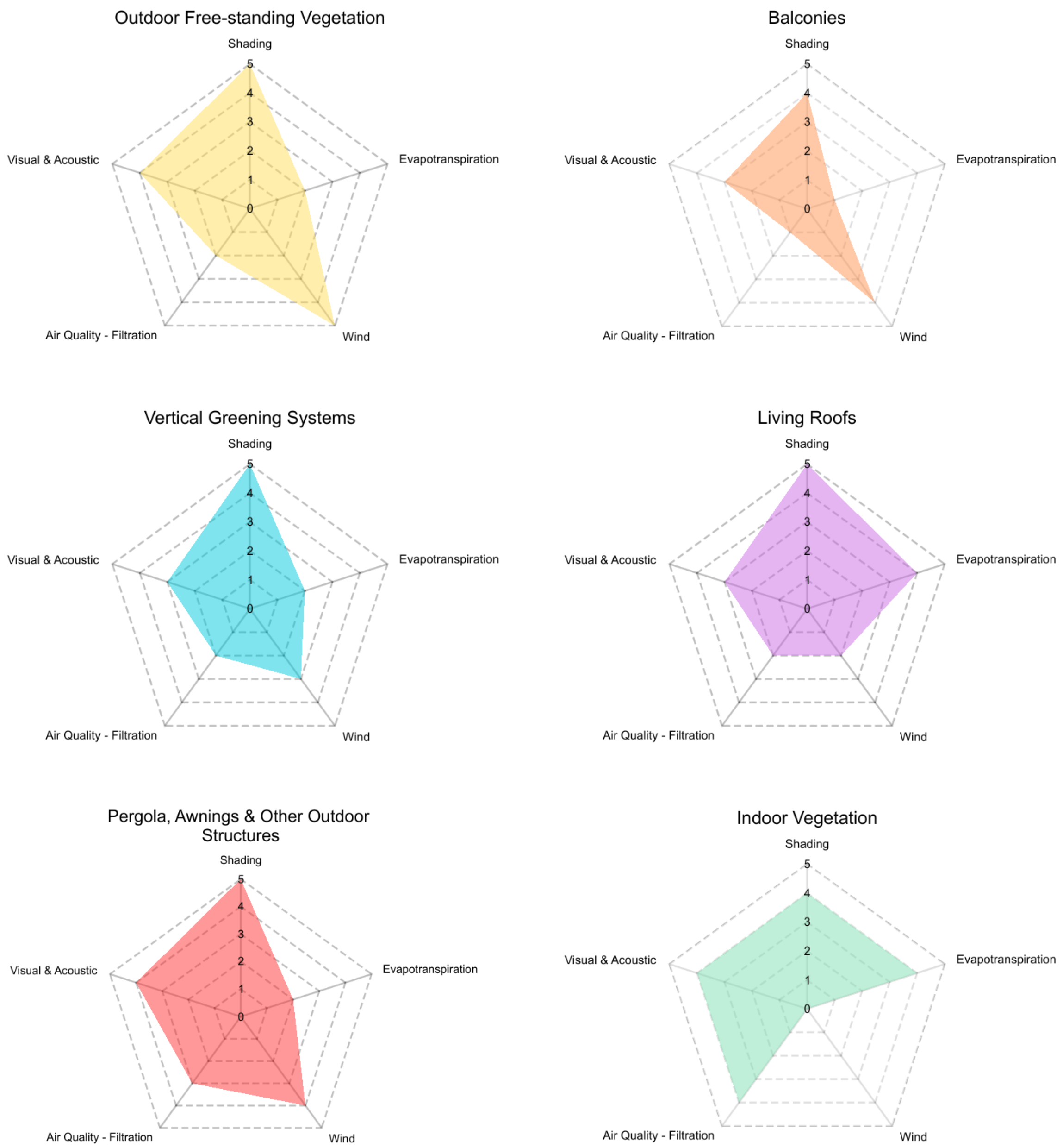
Figure 37: Considering Solutions – Guidance




*This graph helps identify the factors and solution groups that can be implemented given the problems identified when premises environment is outside the comfort zone for employees. It divides the factors or solution groups into four groups: outside the standard comfort zone, hot & humid, hot & dry, cold & humid, and cold & dry.*

The five vegetation opportunity factors developed in Section 3.5 should be considered for both indoor and outdoor solutions, if applicable. The six radar charts in Figure 38 illustrate and summarise the overall effectiveness of each NbS group, for each factor. The numbers assigned (1 to 5) are not a formal quantification of their effectiveness but qualitative, given the research outlined in Sections 3.5 and 5.2, and summarised further in Appendix 4. For this research, the valuation for effectiveness was represented as: 0 = none or N/A; 1 = Low; 2 = Low to Moderate; 3 = Moderate; 4 = Moderate to High; and 5 = High.

Figure 38: NbS Groups Effectiveness by Factor




*The six radar charts illustrate and summarise the overall effectiveness of each NbS group, given each factor. The qualitative valuation for effectiveness was represented as: 0 = none or N/A; 1 = Low; 2 = Low to Moderate; 3 = Moderate; 4 = Moderate to High; and 5 = High.*

It is recommended to use other external tools, many of which are available for free. An example is i-Tree Design (i-Tree, n.d.), which helps model the value of a particular tree given its placement against the building envelope, as well as modelling financial benefits from energy savings, carbon sequestration, and water management.

When evaluating different solutions and for ongoing management purposes, it is advisable to follow one of Meadows' system recommendations: *"Locate responsibility within the system"* (Meadows, 2009, p. 179). For these projects, this can mean understanding processes and parties within the business' control, such as properly using doors and windows, contracts with current landscaping services, and whether the property is owned or leased. Additionally, consider the parties or processes you can influence, like staff or occupants' behaviour. Lastly, recognise what you cannot control or influence, such as the weather. This thinking would cross over with Step 1 (Identifying Interested Parties) and Step 3 (Scope).

### Step 7: Implementing the NbS

Many of the solutions outlined in Section 5.2 can be easily implemented by anybody. However, consider whether contracting an indoor/outdoor landscaping company is beneficial, and/or whether a structure, such as a pergola, eave or awning needs to be built by a construction company.

Communicate the solutions' purpose and requirements to contractors to ensure these are built and implemented in line with the aligned goals. Otherwise, the solution can become aesthetically focused and lose the initial considerations and benefits pursued.

During implementation, consider whether you are adding to or creating a new environment. For instance, if you are adding vegetation outdoors, pre-assess existing plants to ensure they can coexist. If adding towards a native garden or forest patch, you may be able to identify existing native flora and fauna and add plants that will enhance or extend the area and deliver benefits and co-benefits to the existing biodiversity.

When identifying problems in Step 4, you may have encountered contrasting issues between seasons. It is likely that one of these issues was assessed as more significant than the other, but you may still be able to implement a solution that provides some flexibility across seasons. For instance, when addressing shading from vegetation facing north, you are likely to need sun for heating during winter and wind protection. If using planters or pots, some of these can be moved from one side of the building to the other, increasing its value proposition.

### Step 8: Performance Monitoring

Once a NbS has been implemented it is important to monitor its effectiveness. Monitoring will compare your expected results with measured observations. For instance, if you have implemented NbS indoors, you would expect to see some reductions in energy consumption on your bills and/or an increase in employee comfort. If benefits can’t be perceived, you are encouraged to consider whether the solution considered or implementation has failed to some degree, and fix or change as required.

Consider establishing a monitoring process to identify trends and overall NbS effectiveness. Monitoring can be performed at a suitable frequency by following the points outlined in Step 4:

- Reviewing power bills to assess consumption each month and changes in comparison to previous years.
- Running periodic internal employee surveys to identify positive or negative changes in thermal comfort and symptoms related to SBS.
- Comparing employees' absenteeism and/or performance against previous years.

### Step 9: Continuous Improvement

Just as monitoring is the key process in Step 8, reviewing is the key process in Step 9. The review process is typically less frequent than monitoring: every six months, once a year, or every three years, depending on the solution and its growth and development timeframe. During the review process, you are encouraged to question, "Is this good enough?", “Can we do better?” Depending on the solution(s), changes can be considered to increase their delivery value or effectiveness. For example:

- Pots and mobile walls can be moved and tested in different areas or designs.
- Unsuccessful plants can be replanted or changed if they do not provide the benefits pursued.
- Given the new design, occupants’ behaviour may change from the initial mapping, and these may need to be reconsidered.
- Occupant’s behaviour may vary across seasons, prompting the development of different designs that can be scheduled throughout the year.
- The long-term growth of trees may create new areas and environments with different potential.

Ensuring the performance and annual review of the design and benefits of these solutions by engaging with employees, visitors, and clients is crucial to maintaining their relevance and continued delivery of the benefits and values initially pursued.

## 5.4. Final Remarks from Chapter 5

Chapter 5 translated the findings of the literature review and expert interviews into a practical framework for implementing NbS within existing business premises. Six categories of NbS were identified based on shared design and implementation considerations. These were evaluated according to five key vegetation factors developed in Section 3.5. Collectively, these solutions demonstrate considerable potential to improve energy efficiency, thermal comfort, air quality, and workplace wellbeing while simultaneously delivering broader environmental co-benefits, including biodiversity enhancement and climate resilience. The chapter also highlighted the importance of adopting place-based approaches that consider local climate conditions and organisational needs while prioritising native vegetation, and with the potential to incorporate mātauranga Māori.

To support implementation, a systematic nine-step framework was developed to guide organisations through the identification, assessment, selection, implementation, and ongoing improvement of NbS. Together, these recommendations provide a practical pathway for businesses seeking to enhance both environmental performance and employee wellbeing through the strategic integration of nature.

# Chapter 6. Conclusion

Given the global shift toward replacing fossil fuels with renewable energy and the inadequate pace of the transition, it is imperative to make substantial efforts to enhance overall energy efficiency to sustain or improve existing standards of living and to better understand what true ‘standard of living’ actually entails. NbS can play a pivotal role in facilitating this transition. However, current approaches tend to concentrate on specific issues, particularly water management. In this context, a more holistic approach to integrating NbS is needed. This research explored two often-overlooked aspects of NbS: energy efficiency, and its impacts on workplace wellbeing and considered the potential for implementing NbS to promote EE and WW in existing industrial or commercial premises.

The first research objective was achieved by systematically reviewing the existing literature on NbS that can enhance EE in current business premises. Both the literature review and interviews revealed substantial potential to utilise vegetation, both inside and outside existing premises, to improve EE. Given Aotearoa’s distinctive climate, geography, and biodiversity, this research sought to translate solutions presented in international research solutions for the local context and adapt them to ensure effectiveness and efficiency. Chapter 5 drew upon both the literature and the 25 expert interviews to describe and discuss five categories of practical solutions that have been thoroughly considered, based on resources, location, and solution type. These categories include outdoor free-standing vegetation, vertical greening systems, pergolas, awnings, eaves and other outdoor structures, balconies, living roofs, and indoor vegetation. For each category, specific practical solutions were proposed and evaluated based on their impact and effectiveness on five key factors: shading, evapotranspiration, wind, filtration, and visual and acoustic effects. Both the literature and the experts interviewed emphasised the value of prioritising native species where possible to enhance the co-benefits of NbS, including supporting native fauna by creating endemic environments in which they can thrive.

The second research objective was to investigate the potential benefits of indoor and outdoor vegetation for improving workplace well-being. Here, thermal comfort functioned as a bridging concept highlighting a direct connection between energy efficiency and workplace wellbeing. The findings show a positive correlation between employee wellness and productivity, and their access to and contact with vegetation. Noteworthy research was found in the literature, and interviews with key experts deepened insights into some of the barriers to implementing NbS in the workplace. An unexpected barrier identified was the need for a change in mindset towards working outdoors, even when NbS are successfully implemented. The inclusion of WW throughout the thesis facilitates a more comprehensive and holistic approach for businesses, and thereby aligns with the principle of the "good of the whole" (Meadows, 2009, p. 178). This holistic perspective is intended to guide organisations' decision-making processes toward the optimised deployment of NbS within their operational environments and is convergent with mātauranga Māori.

All the practical solutions examined demonstrated considerable potential to enhance EE and WW when scaled and implemented appropriately for the context of specific business premises. To address the third objective, which prompted the development of a framework to identify, address and implement EE and WW NbS in business premises, a systematic step-by-step framework was developed (as outlined in section 5.3). This framework was conceived in accordance with international and national best-practice frameworks for implementing and managing environmental management systems. The framework aims to assist business owners and decision-makers in: identifying energy inefficiencies and WW issues; considering their premises' opportunities; conducting a structured assessment of the most suitable NbS to address these challenges effectively; and undertaking performance monitoring to ensure continuous improvement.

Both the literature review and interviews highlighted the fluidity of the concept of NbS, with a broad spectrum of potential solutions encompassed within the concept of NbS. Nonetheless, NbS literature focuses predominantly on water management, with some more recent references emphasising climate change, climate adaptation, and the resulting biodiversity benefits. The prevalent approach of addressing a single issue within a narrow scope was critically examined, leading to the conclusion that a comprehensive evaluation of NbS should incorporate co-benefits and trade-offs.

Given the research focused on solutions specifically for Aotearoa, the interviews highlighted that mātauranga Māori should be integrated into the research framework. An effort was made to research and include mātauranga Māori principles. These proved helpful in enabling a holistic assessment of the solutions by using Walker et al.’s (2021) Kaitiaki Atua framework, and the potential selection of different Atua to focus on the NbS discussed, while maintaining a robust, holistic approach.

Overall, this research seeks to contribute to addressing a gap in the literature about NbS, that is, the potential for NbS to contribute to enhancing energy efficiency and workplace wellbeing within existing business premises in Aotearoa. It demonstrates that nature-based solutions present a viable business proposition by reducing energy demand while increasing workplace wellbeing, thereby delivering operational, social, and environmental benefits. The implementation framework developed in Chapter 5 offers a structured process that guides organisations to develop practical and effective solutions to increase their energy performance while improving WW. By grounding this process in the five functional mechanisms of vegetation, and prioritising the use of native vegetation where possible, the framework enables businesses to identify interventions that optimise co-benefits and minimise trade-offs within existing premises. It was found that NbS not only support ecological enhancements but provide cost-effective strategies capable of strengthening building performance and contributing to broader sustainability outcomes.

## 6.1. Limitations & Future Directions

Considering the limitations of this research outlined in Chapter 2, some key topics have been identified as important for future consideration and research:

- A comprehensive consideration of mātauranga Māori through engagement with experts in the field would enable a broader and more holistic approach to developing and implementing NbS in Aotearoa. This would require community engagement with local Hapū and Iwi to reflect local connections with the whenua and whakapapa.
- Several barriers to the adoption of NbS were identified through the interviews, with ecological literacy being the most prominent. While this research supports informed decision-making from both scientific and business perspectives, there is a need for additional research to further understand and address the lack of ecological literacy in Aotearoa.
- While this research aims to be holistic, the scope of the thesis did not permit consideration of all the benefits, co-benefits, and trade-offs. Nonetheless, it focuses on two benefits that are more material to businesses and often overlooked. Developing a framework that could better and more comprehensively include other co-benefits and trade-offs could provide significant value.
- During the research it was recognised that quantifying the benefits and properly budgeting for them are key factors that would support implementation. Unfortunately, since quantification must be carried out for each solution based on the climate, building, and its surroundings, this could not be pursued. Additionally, some factors from global research only indicate trends and general directions but cannot be used to model all parameters precisely. Several tools were identified as having potential to assist, but these need further research to develop a comprehensive approach.

# References


Alexandri, E., & Jones, P. (2006, September 6). *Ponds, green roofs, pergolas and high albedo materials; which cooling technique for urban spaces?* PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva.

Amazon UK. (n.d.). *Wall-mounted garden arch for climbing plants half round rose arches wrought iron decorative arches arbour archway garden arch trellis for patios windows gardens porches* [Online post]. Pinterest. Retrieved https://au.pinterest.com/pin/AT1KNlWobJblFG-RU3aZ3SW9kOwiPID-bEs3wQUtjPLs6vLCRmGJi63Jeh8aPlxywx5amu7v1btpP0kiMnwJApk/

Ambius. (n.d.). *Mobile green wall* [Graphic]. Retrieved http://www.ambius.co.nz/plants/green-walls/green-wall-mobile

An, M., Colarelli, S. M., O'Brien, K., & Boyajian, M. E. (2016). Why we need more mature at work: Effects of natural elements and sunlight on employee mental health and work attitudes. *Plos One*, 11(5), e0155614. https://doi.org/10.1371/journal.pone.0155614

Auckland Botanic Gardens. (n.d.-a). *Plants for Auckland*. Retrieved https://www.aucklandbotanicgardens.co.nz/plants-for-auckland/www.aucklandbotanicgardens.co.nz/plants-for-auckland/

Auckland Botanic Gardens. (n.d.-b). *Sustainable water management*. Retrieved https://www.aucklandbotanicgardens.co.nz/about-us/our-policies/www.aucklandbotanicgardens.co.nz/about-us/our-policies/sustainable-water-management

Auckland Council. (2019). *Auckland's urban ngahere (forest) strategy*. https://www.aucklandcouncil.govt.nz/content/dam/ac/docs/plans/environmental-strategy/urban-ngahere-forest-strategy.pdf

Auckland Council. (2024). *Making space for water*. Environment. https://new.aucklandcouncil.govt.nz/en/environment/looking-after-aucklands-water/making-space-for-water.html

Avery, Z., & Davies, R. (2019). *Whangārei living roof guide* (Living Roof Guide v5.0). Whangarei District Council. https://www.wdc.govt.nz/Council/Council-documents/Standards-Guidelines-and-Rules/Living-Roof-Guide

Bakhshoodeh, R., Ocampo, C., & Oldham, C. (2022). Exploring the evapotranspirative cooling effect of a green façade. *Sustainable Cities and Society*, *81*, 103822. https://doi.org/10.1016/j.scs.2022.103822

Baró, F., Haase, D., Gómez-Baggethun, E., & Frantzeskaki, N. (2015). Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. *Ecological Indicators*, *55*, 146–158. https://doi.org/10.1016/j.ecolind.2015.03.013

Benyus, J. M. (2002). *Biomimicry: Innovation inspired by nature*. HarperCollins Publishers.

Berry, R., Livesley, S. J., & Aye, L. (2013). Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. *Building and Environment*, *69*, 91–100. https://doi.org/10.1016/j.buildenv.2013.07.009

BRANZ. (n.d.). *BRANZ map*. Retrieved https://experience.arcgis.com/experience/6e83b0bb19d14a0db411aebdc301cf49

BRANZ. (2011, April). Green roofs—An overview. *Bulletin*, (533). https://www.branz.co.nz/pubs/bulletins/bu533/

BRANZ. (2018, April). Managing wind effects around buildings. *Bulletin*, (620). https://www.branz.co.nz/pubs/bulletins/bu620/

BRANZ. (2024, May 5). *Climate zones*. https://www.branz.co.nz/sustainable-building/up-spec/climate-zones/

BRANZ. (2025). Controlling airborne contaminants. *Level*. http://www.level.org.nz/passive-design/controlling-indoor-air-quality/controlling-airborne-contaminants/

Brears, R. C. (2022). *Financing nature-based solutions: Exploring public, private, and blended finance models and case studies*. Palgrave Macmillan.

Brundtland, G. H. (1987). *Our common future: Report of the world commission on environment and development* (UN-Dokument A/42/427). http://www.un-documents.net/ocf-ov.htm

Building Performance. (2022). *H1 energy efficiency acceptable solution H1/AS2 energy efficiency for buildings greater than 300 m2* (978-1-99-001956–2; Version First Edition Amendment 1). Ministry of Business, Innovation and Employment. https://www.building.govt.nz/assets/Uploads/building-code-compliance/h1-energy-efficiency/asvm/h1-energy-efficiency-as2-1st-edition-amendment-1.pdf

Bustamante, W. (2009). *Guía de diseño para la eficiencia energética en la vivienda social*. Ministerio de Vivienda y Urbanismo (MINVU) & Programa Pais de Eficiencia Energética (PPEE). https://doi.org/10.13140/2.1.2184.3847

Cameron, R. W. F., Taylor, J., & Emmett, M. (2015). A hedera green façade – energy performance and saving under different maritime-temperate, winter weather conditions. *Building and Environment*, *92*, 111–121. https://doi.org/10.1016/j.buildenv.2015.04.011

Cassin, J. (2021). History and development of nature-based solutions: Concepts and practice. In *Nature-based Solutions and Water Security* (pp. 19–34). Elsevier. https://doi.org/10.1016/B978-0-12-819871-1.00018-X

Castro, A. J., Verburg, P. H., Martín-López, B., Garcia-Llorente, M., Cabello, J., Vaughn, C. C., & López, E. (2014). Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning*, *132*, 102–110. https://doi.org/10.1016/j.landurbplan.2014.08.009

Chen, W. Y., & Jim, C. Y. (2008). Assessment and valuation of the ecosystem services provided by urban forests. In M. M. Carreiro, Y.-C. Song, & J. Wu (Eds.), *Ecology, Planning, and Management of Urban Forests* (pp. 53–83). Springer New York. https://doi.org/10.1007/978-0-387-71425-7_5

Clegg, B. (2023). *Biomimetics: How lessons from nature can transform technology*. Icon Books Ltd.

Constanza, R., Cumberland, J., Daly, H., Goodland, R., & Norgaard, R. (1997). *An introduction to ecological economics*. CRC Press. https://doi.org/10.1201/9781420048353

Constanza, R., & Daly, H. E. (1992). Natural capital and sustainable development. *Conservation Biology*, *6*(1), 37–46. https://doi.org/10.1046/j.1523-1739.1992.610037.x

Cranfield University. (n.d.). *Conducting your literature review: Snowballing and grey literature*. Cranfield University Library Services. Retrieved https://library.cranfield.ac.uk/literature-review/grey-literature

Creswell, J. W., & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches* (Sixth edition). SAGE.

Cribb, M., Macpherson, E., & Borchgrevink, A. (2024). Beyond legal personhood for the Whanganui river: Collaboration and pluralism in implementing the te awa tupua act.

*The International Journal of Human Rights*, 1–24. https://doi.org/10.1080/13642987.2024.2314532

Cunningham, A., Colibaba, A., Hellberg, B., Roberts, G. S., Simcock, R., Speed, S. R., Vigar, N., & Woortman, W. (2017). *Stormwater management devices in the Auckland region*. Auckland Council.

Dahanayake, K. W. D. K. C., & Chow, C. L. (2017). Studying the potential of energy saving through vertical greenery systems: Using EnergyPlus simulation program. *Energy and Buildings*, *138*, 47–59. https://doi.org/10.1016/j.enbuild.2016.12.002

De Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

De Vries, S., Hermans, T., & Langers, F. (2023). Effects of indoor plants on office workers: A field study in multiple Dutch organizations. *Frontiers in Psychology*, *14*, 1196106. https://doi.org/10.3389/fpsyg.2023.1196106

Desmarais, R. (2024). Ecological literacy: Definition, early articulations, frameworks and empirical research. *Journal of Sustainability Education*, *29*. https://research.ebsco.com/c/4egzpd/viewer/html/pmqlhry2ev

DGB Group. (2023, September 12). Beyond carbon: The benefits of nature-based solutions for businesses. *DGB Group*. https://www.green.earth/blog/beyond-carbon-the-benefits-of-nature-based-solutions-for-businesses

Dhakal, A., Meghna Rajbhandari, Sophiya Shrestha, & Acharya, A. (2022). *Thermal behavior of concrete and its effect on urban heat island*. https://doi.org/10.13140/RG.2.2.15785.67683

Elder, H. (2020). *Aroha: Māori wisdom for a contented life lived in harmony with our planet*. Penguin Random House New Zealand.

Elliott, T. (2023, August 7). Designing for wellness: How biophilic elements can promote health in the workplace. *Europlan*. https://europlan.nz/blog/designing-for-wellness-how-biophilic-elements-can-promote-health-in-the-workplace/

Emetere, M. E. (2022). Typical environmental challenges. In *Numerical Methods in Environmental Data Analysis* (pp. 41–51). Elsevier. https://doi.org/10.1016/B978-0-12-818971-9.00004-1

EMS Business Redefined. (2024, June 26). The impact of corporate garden on employee well being. *LinkedIn*. https://www.linkedin.com/pulse/impact-corporate-garden-employee-well-being-trmvc/

Ettinger, A. (2024, July 19). *A fellowship for nature-based solutions to climate change*. The Nature Conservancy. https://www.nature.org/en-us/about-us/where-we-work/united-states/washington/stories-in-washington/nature-based-solutions-to-climate-change/

European Commission. (n.d.). *Nature-based solutions*. Research and Innovation. Retrieved https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en

European Commission: Directorate General for Research and Innovation. (2020). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: Final report of the horizon 2020 expert group on "nature based solutions and re naturing cities."* Publications Office. https://doi.org/10.2777/765301

Excell, L. E., & Jain, R. K. (2024). Examining the impact of energy efficiency retrofits and vegetation on energy performance of institutional buildings: An equity-driven analysis. *Applied Energy*, *357*, 121722. https://doi.org/10.1016/j.apenergy.2023.121722

Fanning, K. (n.d.). *Grapes* [Online post]. Pinterest. Retrieved https://au.pinterest.com/pin/6473993210195119/

Fassaden Grün. (n.d.). *Grapevine canopies, awnings ('galleries')*. Retrieved https://www.fassadengruen.de/en/grapevine-gallery.html

Fassman-Beck, E., & Simcock, R. (2013). *Living roof review and design recommendations for stormwater management*. Auckland Council.

Feng, H., & Hewage, K. (2014). Lifecycle assessment of living walls: Air purification and energy performance. *Journal of Cleaner Production*, *69*, 91–99. https://doi.org/10.1016/j.jclepro.2014.01.041

Fjeld, T., Veiersted, B., Sandvik, L., Riise, G., & Levy, F. (1998). The effect of indoor foliage plants on health and discomfort symptoms among office workers. *Indoor and Built Environment*, *7*(4), 204–209. https://doi.org/10.1177/1420326X9800700404

Food and Agriculture Organization of the United Nations. (2016). *Benefits of urban trees* [Graphic]. https://openknowledge.fao.org/server/api/core/bitstreams/aff703e7-13d2-4020-ba2f-ca44269a41b9/content

Forest & Bird. (2020). *Plant list: Common native species suitable for urban gardens in Auckland central*. https://www.forestandbird.org.nz/sites/default/files/2020-04/Native%20Plant%20List_0.pdf

Forest and Bird. (2024, July 10). *Nature-based solutions welcomed in new climate strategy – but short on detail*. https://www.forestandbird.org.nz/resources/nature-based-solutions-welcomed-new-climate-strategy-short-detail

Forzani, L., Mazzucchelli, E. S., & Rigone, P. (2020). Use of vegetation to increase building energy efficiency: Application to a real case study. *IOP Conference Series: Earth and Environmental Science*, *588*(3), 032083. https://doi.org/10.1088/1755-1315/588/3/032083

Givoni, B. (1992). Comfort, climate analysis and building design guidelines. *Energy and Buildings*, *18*(1), 11–23. https://doi.org/10.1016/0378-7788(92)90047-K

Golubiewski, N., Lawrence, G., Zhao, J., & Bishop, C. (2020). *Auckland's urban forest canopy cover: State and change* (Revised April 2021). Auckland Council = Te Kaunihera o Tāmaki Makaurau.

González-García, A., Palomo, I., Codemo, A., Rodeghiero, M., Dubo, T., Vallet, A., & Lavorel, S. (2025). Co-benefits of nature-based solutions exceed the costs of implementation. *Cell Reports Sustainability*, *2*(3), 100336. https://doi.org/10.1016/j.crsus.2025.100336

Gonzalo, R., & Vallentin, R. (2014). *Passive house design: Planning and design of energy-efficient buildings*. Redaktion Detail, Institut für internationale Architektur-Dokumentation.

Google Gemini. (2025). *Hypothetical outdoor workspace* [Graphic]. https://gemini.google.com/

GreenAir. (n.d.-a). *Hotel Grand Chancellor* [Graphic]. Retrieved https://greenair.co.nz/project/green-wall-hotel-grand-chancellor/

GreenAir. (n.d.-b). *Milford Asset Management* [Graphic]. Retrieved https://greenair.co.nz/project/biophilic-design-at-milford-asset-management-greenair/

Haggerty, J., & Campbell, H. (2009, March 1). *Pre-Māori vegetation cover*. Te Ara Encyclopedia of New Zealand. https://teara.govt.nz/en/map/17880/pre-maori-vegetation-cover

Harshdeep. (n.d.). *Plant pots with wheels: Benefits, uses & top picks in India*. Retrieved https://harshdeepindia.com/plant-pots-with-wheels/

Hefner, W. (n.d.). *Awning trellis* [Online post]. Pinterest. Retrieved https://au.pinterest.com/pin/505388389410390955/

Heisler, G. (1986). Energy savings with trees. *Arboriculture & Urban Forestry*, *12*(5), 113–125. https://doi.org/10.48044/jauf.1986.026

Henley, J. (2015, October 26). World set to use more energy for cooling than heating. *The Guardian*. https://www.theguardian.com/environment/2015/oct/26/cold-economy-cop21-global-warming-carbon-emissions

Hulme, P. E. (2020). Plant invasions in New Zealand: Global lessons in prevention, eradication and control. *Biological Invasions*, *22*(5), 1539–1562. https://doi.org/10.1007/s10530-020-02224-6

Ignatieva, M., Meurk, C., van Roon, M., Simcock, R., & Stewart, G. (2008). *How to put nature into our neighbourhoods: Application of low impact urban design and development (LIUDD) principles, with a biodiversity focus, for New Zealand developers and homeowners*. Manaaki Whenua - Landcare Research New Zealand.

International Energy Agency. (n.d.). *The crisis and global responses*. Global Energy Crisis. Retrieved https://www.iea.org/topics/global-energy-crisis

International Labour Organization. (2009, June 15). *Workplace well-being*. https://www.ilo.org/resource/workplace-well-being

International Organization for Standardization. (2015). *Environmental management systems—Requirements with guidance for use*. ISO Standard 14001:2015. https://www.iso.org/standard/60857.html

International Union for Conservation of Nature and Natural Resources, World Business Council for Sustainable Development, & Earthwatch Europe (Eds.). (2002). *Business & biodiversity: The handbook for corporate action*. Earthwatch Europe : IUCN--the World Conservation Union : World Business Council for Sustainable Development.

Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. *Building and Environment*, *45*(1), 81–88. https://doi.org/10.1016/j.buildenv.2009.05.003

i-Tree. (n.d.). *What is i-Tree?* About. Retrieved https://www.itreetools.org/about

Jayalakshmy, M. S., & Philip, J. (2010). Thermophysical properties of plant leaves and their influence on the environment temperature. *International Journal of Thermophysics*, *31*(11–12), 2295–2304. https://doi.org/10.1007/s10765-010-0877-7

Jim, C. Y., & Chen, W. Y. (2009). Ecosystem services and valuation of urban forests in China. *Cities*, *26*(4), 187–194. https://doi.org/10.1016/j.cities.2009.03.003

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T., & Berman, M. G. (2015). Neighborhood greenspace and health in a large urban center. *Scientific Reports*, *5*(1), 11610. https://doi.org/10.1038/srep11610

Kizildere, T. (2017). *Pacey truck services* [Google Maps]. https://www.google.com/maps/place/Pacey+Truck+Services/@-36.9373262,174.8356711,3a,75y/data=!3m8!1e2!3m6!1sCIHM0ogKEICAgICk1MjBqQE!2e10!3e12!6shttps:%2F%2Flh3.googleusercontent.com%2Fgps-cs-s%2FAG0ilSxh3kMyc7o6YzdkhfaVqSywEnOMA3omQFflnHuHJHHhb17t0hiMsseQQQRQsE5RAFaopnZK717mplg9BqnPigbEocNpmYUi2mtB2akp7i_np3wCrz3qoU97R8_kt1RIZagL1wNF6Q%3Dw203-h135-k-no!7i1843!8i1229!4m9!3m8!1s0x6d0d4ec821b63afb:0xbedf7ec1ec00a943!8m2!3d-

36.9373262!4d174.8356711!10e5!14m1!1BCgIgAQ!16s%2Fg%2F1tlmnh_l?entry=ttu&g_ep=EgoyMDI1MTAyOS4xIKXMDSoASAFQAw%3D%3D

Konijnendijk, C. C. (2024). *Rethinking urban green spaces*. Edward Elgar Publishing Limited.

Kuhns, M. (1993). *Planting trees for energy conservation: The right tree in the right place*. Utah State University. https://extension.usu.edu/forestry/files/trees-cities-towns/tree-selection/planting-trees-for-energy-conservation.pdf

Kuhns, M. (2012). Windbreak benefits and design. *ResearchGate*. https://www.researchgate.net/publication/242403992_Windbreak_Benefits_and_Design

Kuulkers, R. (n.d.). *Door arch* [Online post]. Pinterest. Retrieved https://au.pinterest.com/pin/396598310908080328/

Land, Air, Water Aotearoa. (n.d.). *Land cover*. Explore Data. Retrieved https://www.lawa.org.nz/explore-data/land-cover/

Landscape for Life. (n.d.). *Increasing energy efficiency with vegetation—Landscape for life*. Retrieved https://landscapeforlife.colostate.edu/plants/increasing-energy-efficiency-with-plants/

Li, Q. (2018). *Shinrin-yoku: The art and science of forest bathing*. Penguin Life.

Liu, F., Yan, L., Meng, X., & Zhang, C. (2022). A review on indoor green plants employed to improve indoor environment. *Journal of Building Engineering*, *53*, 104542. https://doi.org/10.1016/j.jobe.2022.104542

Living Future. (2020, May 6). *Living building challenge*. https://living-future.org/lbc/

Livni, E. (2019, March 1). This is how distance from nature is affecting our health. *World Economic Forum*. https://www.weforum.org/stories/2019/03/psychoterratica-is-the-trauma-caused-by-distance-from-nature/

Lottrup, L. (2012). Workplace greenery: Use, preferences, and health benefits of green outdoor environments at workplaces. In *Workplace greenery* (Report No. 50/2012; Forest and Landscape Research). Forest & Landscape, University of Copenhagen.

Lottrup, L., Grahn, P., & Stigsdotter, U. K. (2013). Workplace greenery and perceived level of stress: Benefits of access to a green outdoor environment at the workplace. *Landscape and Urban Planning*, *110*, 5–11. https://doi.org/10.1016/j.landurbplan.2012.09.002

Louv, R. (2011). *The nature principle: Human restoration and the end of nature-deficit disorder* (1st ed). Algonquin Books of Chapel Hill.

Lygum, V. L., Dupret, K., Bentsen, P., Djernis, D., Grangaard, S., Ladegaard, Y., & Troije, C. P. (2023). Greenspace as workplace: Benefits, challenges and essentialities in the physical environment. *International Journal of Environmental Research and Public Health*, *20*(17), 6689. https://doi.org/10.3390/ijerph20176689

Macara, G. (2018). *The climate and weather of New Zealand* (ISSN 1173-0382; 74). NIWA. The climate and weather of New Zealand

Mangone, G., Kurvers, S. R., & Luscuere, P. G. (2014). Constructing thermal comfort: Investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment. *Building and Environment*, *81*, 410–426. https://doi.org/10.1016/j.buildenv.2014.07.019

McPherson, E. G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., & Rowntree, R. (1997). Quantifying urban forest structure, function, and value: The Chicago urban forest climate project. *Urban Ecosystems*, *1*(1), 49–61. https://doi.org/10.1023/A:1014350822458

Meadows, D. H. (2009). *Thinking in systems: A primer*. Earthscan.

Meattle, K. (Director). (2009, February). *How to grow fresh air* [Video recording]. https://www.ted.com/talks/kamal_meattle_how_to_grow_fresh_air

Meurk, C. (2022). *Tree canopy cover benefits affected by urban intensification: Biodiversity and related issues*. https://oceaniacommons.net/artifacts/3695216/tree-canopy-cover-benefits-affected-by-urban-intensification/4501180/

Meurk, C., Blaschke, P., & Simcock, R. (2013). Ecosystem services in New Zealand cities. In *Ecosystem services in New Zealand: Conditions and trends* (574(931), pp. 254–273). Manaaki Whenua Press.

Meurk, C., Stancu, C., & Smith, A. (2007, February 21). Biodiversity in crisis: A crucial role for business. *Talking and Walking Sustainability*. 2nd International Conference on Sustainability Engineering and Science, Auckland. https://www.thesustainabilitysociety.org.nz/conference/2007/papers/MEURK-Sustainable%20Biodiversity%20For%20Business-AS.pdf

Ministry of Business, Innovation & Employment. (2017). *Unlocking our energy productivity and renewable potential: New Zealand energy efficiency and conservation strategy 2017-2022*. Ministry of Business, Innovation & Employment.

Ministry of Business, Innovation & Employment. (2025a). *Energy in New Zealand 25* (ISSN 2324-5913). https://www.mbie.govt.nz/assets/energy_in_new_zealand_2025.pdf

Ministry of Business, Innovation & Employment. (2025b, August 21). *New Zealand's renewable energy supply reaches record high*. News. https://www.mbie.govt.nz/about/news/new-zealands-renewable-energy-supply-reaches-record-high

Misni, A. (2018). The effects of landscaping on the residential cooling energy. *IOP Conference Series: Earth and Environmental Science*, *117*, 012022. https://doi.org/10.1088/1755-1315/117/1/012022

Moen, R. (2020). *Foundation and History of the PDSA Cycle*. https://deming.org/wp-content/uploads/2020/06/PDSA_History_Ron_Moen.pdf

Morgenroth, J. (2022). *Urban forest canopy cover*. Christchurch City Council and Wellington City Council. https://hdl.handle.net/10092/103852

Morgenroth, J., Chapman, T., Davies, H., & Melville, W. (2020). New Zealand's urban forests—Monitoring & managing for improved ecosystem services. *Tree Matters*, (Winter), 12–13.

Morris, H. (2013). Tree pruning: A modern approach. *International Dendrology Society*, 209–229.

New Zealand Plant Conservation Network. (n.d.-a). *Deciduous plants in New Zealand*. Deciduous Plants. Retrieved https://www.nzpcn.org.nz/flora/vascular/flowering-plants/deciduous-plants/

New Zealand Plant Conservation Network. (n.d.-b). *Flora search results*. Retrieved https://www.nzpcn.org.nz/flora/species/

Newton, K., Rodrigues, F., George, K., & Gibson, E. (2022). *The green divide: How wealth buys shade in a warming world*. Stuff. https://interactives.stuff.co.nz/2022/03/urban-heat-island-tree-cover/

Nola. (n.d.). *Products*. Retrieved https://nola.se/en/products

NUWAO. (2024). *Ōtākaro orchard blue-green roof with solar panels*. https://nuwao.org.nz/nbs-guide/otakaro-orchard-blue-green-roof-with-solar-panels/

NZGBC. (n.d.). *Introduction to GreenStar*. Green Star. Retrieved https://nzgbc.org.nz/introduction-to-green-star

Old, A., & Jones, N. (2024). *Options to improve ventilation* (Briefing N. H2024036633). Manatū Hauora Minister of Health.

Outside In. (n.d.). *Aurecon* [Graphic]. Retrieved https://www.outsidein.net.nz/projects/aurecon

Patterson, M., & Cole, A. (2013). Total economic value of New Zealand's land-based ecosystems and their services. *Ecosystem Services in New Zealand: Conditions and Trends*, 496–510.

Pearson-Mims, C. H., & Lohr, V. I. (2000). Reported impacts of interior plantscaping in office environments in the United States. *HortTechnology*, *10*(1), 82–86. https://doi.org/10.21273/HORTTECH.10.1.82

Pérez, G., Coma, J., Chàfer, M., & Cabeza, L. F. (2022). Seasonal influence of leaf area index (LAI) on the energy performance of a green facade. *Building and Environment*, *207*, 108497. https://doi.org/10.1016/j.buildenv.2021.108497

Perini, K., & Rosasco, P. (2013). Cost–benefit analysis for green façades and living wall systems. *Building and Environment*, *70*, 110–121. https://doi.org/10.1016/j.buildenv.2013.08.012

Peterson, N. (2016, October 24). Cold climate benefits from trees. *Deeproot*. https://www.deeproot.com/blog/blog-entries/tree-benefits-for-every-season-even-winter/

Petersson Troije, C., Lisberg Jensen, E., Redmalm, D., & Wiklund Gustin, L. (2024). Unlocking the transformative potential of outdoor office work—A constructivist grounded theory study. *Challenges*, *15*(2), 25. https://doi.org/10.3390/challe15020025

Petersson Troije, C., Lisberg Jensen, E., Stenfors, C., Bodin Danielsson, C., Hoff, E., Mårtensson, F., & Toivanen, S. (2021). Outdoor office work – an interactive research project showing the way out. *Frontiers in Psychology*, *12*, 636091. https://doi.org/10.3389/fpsyg.2021.636091

Petschek, P., & Gass, S. (2011). *Constructing shadows: Tents, pergolas, cables, plants*. London Birkhũser.

Potyondy, P. J. (2013). *Influence of urban tree canopy on single-family residential structure energy consumption at the community scale in Hutchinson, Minnesota* [University of Minnesota]. https://hdl.handle.net/11299/160283

Pure Advantage, & Tāne's Tree Trust. (2023, November). Recloaking Papatūānuku. *Pure Advantage*. https://pureadvantage.org/recloaking-papatuanuku/

Raji, B., Tenpierik, M. J., & Van Den Dobbelsteen, A. (2015). The impact of greening systems on building energy performance: A literature review. *Renewable and Sustainable Energy Reviews*, *45*, 610–623. https://doi.org/10.1016/j.rser.2015.02.011

Raworth, K. (2022). *Doughnut economics: Seven ways to think like a 21st-century economist*. Penguin Books.

Respyre. (n.d.). *Home*. Retrieved https://www.gorespyre.com/

Robinson, Breed, Camargo, Redvers, & Breed. (2022). *Biodiversity and human health: A scoping review and case studies on underrepresented linkages*. BIOLOGY. https://doi.org/10.20944/preprints202210.0275.v1

Robinson, M. (Director). (2018, May). *Why every desk needs a personal plant* [Video recording]. https://www.ted.com/talks/mike_robinson_why_every_desk_needs_a_personal_plant

Root in Nature. (2024, March 6). *5 proven benefits of nature's impact in the workspace—Root in nature*. https://rootinnature.ca/5-proven-benefits-of-natures-impact-in-the-workspace/

Sarre, A. (2018). *Unasylva: Forests and sustainable cities* (Vol. 69). Food and Agriculture Organization of the the United Nations.

Scherer, M. J. (2014). *Cortinas verdes na arquitetura: Desempenho no controle solar e na eficiência energética de edificações*. https://lume.ufrgs.br/handle/10183/109023

ScienceDirect. (n.d.). *Special issues and article collections*. Retrieved https://www.sciencedirect.com/journal/system/special-issues

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120

Seidel, P. (2021, March 15). Des plantes en guise de rideau. *Galaxus*. https://www.galaxus.ch/fr/page/des-plantes-en-guise-de-rideau-19159

SingularGreen. (n.d.). *Green shades leafskin technology*. Retrieved https://www.singulargreen.com/green-shades-toldos-vegetales/

Souter-Brown, G., Hinckson, E., & Duncan, S. (2021). Effects of a sensory garden on workplace wellbeing: A randomised control trial. *Landscape and Urban Planning*, *207*, 103997. https://doi.org/10.1016/j.landurbplan.2020.103997

Standards New Zealand. (2011, February 14). *NZS 3604:2011*. https://www.standards.govt.nz/shop/nzs-36042011

Stanley, M. (2025, June 2). *The importance of plants in connecting people and wildlife* [Lecture]. Banks Memorial. https://www.youtube.com/watch?v=jpfO526nEF4

Stec, W. J., Van Paassen, A. H. C., & Maziarz, A. (2005). Modelling the double skin façade with plants. *Energy and Buildings*, *37*(5), 419–427. https://doi.org/10.1016/j.enbuild.2004.08.008

Sustainability Victoria. (2020). *Energy smart housing manual*. https://www.sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/building-or-renovating/build-for-energy-efficiency/energy-smart-housing-manual

Tan, H., Hao, X., Long, P., Xing, Q., Lin, Y., & Hu, J. (2020). Building envelope integrated green plants for energy saving. *Energy Exploration & Exploitation*, *38*(1), 222–234. https://doi.org/10.1177/0144598719875529

Te Ara Encyclopedia of New Zealand. (2020, February 25). *Geography and geology*. https://teara.govt.nz/en/natural-environment/page-1

The Culture Factor Group Oy. (2023, October 16). *Country comparison tool*. The Culture Factor. https://www.theculturefactor.com/country-comparison-tool

Toitū Envirocare. (n.d.). *Enviromark certifications*. Retrieved https://www.toitu.co.nz/solutions/enviromark-certifications/

UN Department of Economic and Social Affairs. (2025). *Goal 7: Affordable and clean energy*. Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All. https://unstats.un.org/sdgs/report/2025/Goal-07/

UNEP-WCMC. (2025, May). *Why nature is integral to sustainable development*. News. https://production-wordpress.unep-wcmc.org/why-nature-is-integral-to-sustainable-development/

U.S. Department of Energy. (n.d.). *Energy-efficient landscaping*. Retrieved https://www.energy.gov/energysaver/energy-efficient-landscaping

Vadoudi, K. (2018). Development of psychrometric diagram for the energy efficiency of air handling units. *International Journal of Ventilation*, *3*(5), 491–500. ResearchGate.

van Wicklen, G. (2023). *Sick building syndrome is recognized*. EBSCO. https://www.ebsco.com

Walker, D. P., Ataria, J. M., Hughey, K. F. D., Park, P. T., & Katene, J. P. (2021). Environmental and spatial planning with ngā Atua kaitiaki: A mātauranga Māori framework. *New Zealand Geographer*, *77*(2), 90–100. https://doi.org/10.1111/nzg.12300

Waterfield, P. (2011). *The energy efficient home: A complete guide*. Crowood.

White, M. P., Hartig, T., Martin, L., Pahl, S., Van Den Berg, A. E., Wells, N. M., Costongs, C., Dzhambov, Angel. M., Elliott, L. R., Godfrey, A., Hartl, A., Konijnendijk, C., Litt, J. S., Lovell, R., Lymeus, F., O'Driscoll, C., Pichler, C., Pouso, S., Razani, N., … Van Den Bosch, M. (2023). Nature-based biopsychosocial resilience: An integrative theoretical framework for research on nature and health. *Environment International*, *181*, 108234. https://doi.org/10.1016/j.envint.2023.108234

WHO & ILO. (2022). *Mental health at work: Policy brief* (1st ed). World Health Organization.

Wohlleben, P. (2021). *The heartbeat of trees: Embracing our ancient bond with forests and nature* (J. Billinghurst, Trans.). Greystone Books.

Wohlleben, P., Flannery, T. F., Simard, S., & Billinghurst, J. (2016). *The hidden life of trees: What they feel, how they communicate*. David Suzuki Institute ; Greystone Books Ltd.

Wolverton, B. C., Mcdonald, R. C., & Watkins, E. A. (1984). Foliage plants for removing indoor air pollutants from energy-efficient homes. *Economic Botany*, *38*(2), 224–228. https://doi.org/10.1007/BF02858837

Wu, Y., & Flemmer, C. (2020). Glass curtain wall technology and sustainability in commercial buildings in Auckland, New Zealand. *International Journal of Built Environment and Sustainability*, *7*(2), 57–65. https://doi.org/10.11113/ijbes.v7.n2.495

Yates, A. M. (2019). *Whanake mai te mauri ora: Think piece – an expanded wellbeing framework and urban science data tool for integrated wellbeing governance*. Building Better Homes, Towns and Cities: Mauri ora and urban wellbeing. http://buildingbetter.nz/resources/publications.html

Zhang, B., Xie, G., Gao, J., & Yang, Y. (2014). The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction: A case study in Beijing, China. *Building and Environment*, *76*, 37–43. https://doi.org/10.1016/j.buildenv.2014.03.003

Zhong, W., Schröder, T., & Bekkering, J. (2022). Biophilic design in architecture and its contributions to health, well-being, and sustainability: A critical review. *Frontiers of Architectural Research*, *11*(1), 114–141. https://doi.org/10.1016/j.foar.2021.07.006

# Appendices

## Appendix 1 Information Sheet & Consent Form

My name is Eze Cancina and I am currently undertaking my Master of Environmental Management at Massey University. I would like to invite you to participate in my masters research project exploring the use of nature-based solutions in existing premises in Aotearoa New Zealand, with the aim to provide a practical framework for New Zealand businesses.

In this study, I will explore outdoor and indoor nature-based solutions that can be applied to businesses' existing premises, and their potential impacts on the environment, businesses and their employees. I would like to ask you about your work and experience on how greenery impacts the workplace environment, whether you apply any specific nature-based solution in your work or workplace, and any feedback you have received on nature-based solutions or related approaches.

This thesis is being supervised by Dr Karen Hytten and Dr Colin Meurk.

**Your rights as a participant**

We guarantee full confidentiality and anonymity to all participants in this study. Your contact details and interview transcript will be kept in a secure environment only accessible to the primary investigators. No participants will be identified in any way without prior consent. Participation in this research is completely voluntary. If you decide to participate, you have the right to:

- Ask any questions about the research at any time
- Decline to answer any question
- Decline to be recorded or to ask for the recorder to be switched off during the interview
- Be provided with a summary of the research findings when the study is concluded
- Withdraw from the study

Please do not hesitate to contact me at any time if you have any questions about the project.

Eze Cancina
[redacted]
+64 [redacted]

*This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research. If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.*

CONSENT FORM

I have read and understood the Information Sheet and I understand that I may ask further questions or withdraw from the study at any time.

☐ I agree to participate in this study under the conditions set out in the Information Sheet.

☐ I agree to the interview being recorded.

☐ I agree / ☐ I don't agree - to my organisation or project being explicitly named in research outputs.

Date: Full Name: Signature:

## Appendix 2 Interview Questions

Internal Data Collection

- Interview ID Recorded
- Date
- Industry Sector & Role Type

Introduction and NbS Concept

- Could you start by telling me a bit about your work relating to NbS, greenery and nature?
- In which country have you focused your work?
- In your own words, are you familiar with the concept of NbS? And how would you define it? Please provide examples.

Interviewer Section – Deeper Explanation of Research

*'Redefine' NbS for the purpose of the research, and further introduce the topic.*

Further questions on the topic specific to the research

- Have you ever considered the use of plants to increase energy performance in buildings as NbS? Yes/No/Other and elaborate.
- Have you ever considered NbS to be applicable indoors? Yes/No/Other and elaborate.
- Have you ever considered the use of plants to boost wellbeing at the workplace as a NbS? Yes/No/Other and elaborate.

Policy & Frameworks

- Based on your local and international knowledge and experience. Are you aware of any policy, framework or scheme that would consider quantifying, certifying or encouraging the NbS we are considering in this research?

Construction Sector

- Does your work include retrofits and/or new buildings? (Rough % split?)
- Do your customers proactively request to include nature-based solutions or greenery in their premises? Which are the most popular requests? Are these mostly for new or existing premises?
- Do you include nature-based solutions in your designs proactively (i.e. even if not requested by the customer)? Which ones do you do more often?
- Do you think GreenStar Performance rating encourages the implementation of NbS in existing buildings? Any comments on this framework?

Research Sector

- What is your focus of study around NbS? And why did you choose it?

- Do you consider NbS a new field of study?
- In research, what is the trend around the concept of NbS? Do you think there are any gaps?
- Which are the main difficulties you have faced when trying to promote your NbS research to be used in the private sector?

Benefits & Applications

- Based on your knowledge and experience, which are the ecosystem services (practical benefits) that greenery can provide?
- Please, elaborate further on the key benefits you mentioned
- "I read out loud a list of benefits and then asked: Were you aware of most of these other services that plants can provide? Any of you would like to highlight?

List of benefits: Shading-Cooling, Energy Efficiency, Evapotranspiration/Cooling, Promote Wellbeing, Air Filtering, Noise Reduction, Increases employees' productivity, Provide Comfort, Wind Protection, Water Management, Supports Biodiversity, Climate Change, Indoor Moist Management, and Privacy Indoors.

Obstacles & Barriers

- From your experience, which are the main barriers for businesses to implement some of the NbS we discussed in their offices and/or manufacturing/warehousing facilities?
- Have you experienced regulatory barriers to implement NbS?
- Have you heard of the concept of ecological literacy? If so, how would you define it? Do you think knowledge/ecological literacy is a barrier for implementing NbS?
- Do you have any example/s of a time when you faced any barrier when trying to implement, or sell, a NbS, and how did you overcome it?

Strengths & Opportunities

- Which NbS do you think would be easier for you to promote? Why?
- Which NbS do you think would be easier for you to implement? Why?

Biodiversity

- Please consider the questions below from a biodiversity perspective.
- How do you perceive the use of exotic plants indoors?
- How do you perceive the use of exotic plants outdoors?
- What are your thoughts with regards to businesses' active support in biodiversity enhancement?

Appendix 3 Climate zones by territorial authority.

*Source:* Building Performance (2022, p. 23)

| North Island/Te Ika-a-Māui | |
|---|---|
| **Territorial authority** | **Climate zone** |
| Far North District | 1 |
| Whangarei District | 1 |
| Kaipara District | 1 |
| Auckland | 1 |
| Thames-Coromandel district | 1 |
| Hauraki District | 2 |
| Waikato District | 2 |
| Matamata-Piako District | 2 |
| Hamilton City | 2 |
| Waipa District | 2 |
| Ōtorohanga District | 2 |
| South Waikato District | 2 |
| Waitomo District | 2 |
| Taupo District | 4 |
| Western Bay of Plenty District | 1 |
| Tauranga City | 1 |
| Rotorua District | 4 |
| Whakatane District | 1 |
| Kawerau District | 1 |
| Ōpōtiki District | 1 |
| Gisborne District | 2 |
| Wairoa District | 2 |
| Hastings District | 2 |
| Napier City | 2 |
| Central Hawke's Bay District | 2 |
| New Plymouth District | 2 |
| Stratford District | 2 |
| South Taranaki District | 2 |
| Ruapehu District | 4 |
| Whanganui District | 2 |
| Rangitikei District (north of 39°50'S (-39.83)) | 4 |
| Rangitikei District (south of 39°50'S (-39.83)) | 3 |
| Manawatu District | 3 |
| Palmerston North City | 3 |
| Tararua District | 4 |
| Horowhenua District | 3 |
| Kapiti Coast District | 3 |
| Porirua City | 3 |
| Upper Hutt City | 4 |
| Lower Hutt City | 3 |
| Wellington City | 3 |
| Masterton District | 4 |
| Carterton District | 4 |
| South Wairarapa District | 4 |

| South Island/Te Waipounamu | |
|---|---|
| **Territorial authority** | **Climate zone** |
| Tasman District | 3 |
| Nelson City | 3 |
| Marlborough District | 3 |
| Kaikoura District | 3 |
| Buller District | 4 |
| Grey District | 4 |
| Westland District | 4 |
| Hurunui District | 5 |
| Waimakariri District | 5 |
| Christchurch City | 5 |
| Selwyn District | 5 |
| Ashburton District | 5 |
| Timaru District | 5 |
| Mackenzie District | 6 |
| Waimate District | 5 |
| Chatham Islands | 3 |
| Waitaki District (true left of the Otekaieke river) | 6 |
| Waitaki District (true right of the Otekaieke river) | 5 |
| Central Otago District | 6 |
| Queenstown-Lakes District | 6 |
| Dunedin City | 5 |
| Clutha District | 5 |
| Southland District | 6 |
| Gore District | 6 |
| Invercargill City | 6 |

## Appendix 4 NbS Summary of its Effectiveness Opportunity Factor

*Summary of findings from the NbS groups in Section 5.2, and its effectiveness considering the opportunity factors developed in Section 3.5.*

### Appendix 4.1 Outdoor Free-standing Vegetation

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | High | Low to Moderate | High | Low to Moderate | Moderate to High |
| Cost-Benefit | High | Low to Moderate | Moderate to High | Moderate | Moderate to High |
| Implementation Difficulty | Low | N/A | Low to Moderate | N/A | Low |

| Factors ↓ | Considerations |
|---|---|
| Shading | Deciduous vs. Evergreen Trees: Choose wisely based on seasonal needs.<br>Distance from the Building: Proper placement can enhance effectiveness.<br>Tree Height: This should consider the angle of seasonal sunlight.<br>Native vs Exotic Species:<br>• Native Plants: Typically require less maintenance in the long term and provide broader co-benefits to native Biodiversity.<br>• Exotic Deciduous Trees: These could be selected to allow sunlight in during the winter months. Prioritise Native Deciduous.<br>Overall Design:<br>• Create Sun Traps for Winter: This can enhance warmth.<br>• Provide Shade to Reduce Glare: This improves indoor light quality.<br>• Shade for Thermal Comfort in Outdoor Workspaces: Ensures a pleasant working environment. |
| Evapotranspiration | A level of effectiveness can be perceived in areas with dense vegetation.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Wind | • Assess prevailing winds in the region and categorise them by strength and temperature. Then consider the local topography and surrounding urban landscape.<br>• Consider guiding warm winds from the north to reach the building to boost ventilation, unless these are extremely strong.<br>• Consider deflecting and dampening cold winds from the south instead of damming them.<br>• Prioritise the use of endemic plants that will adapt easily to the area to reduce maintenance.<br>• Use a mix of short, medium, and tall vegetation to better absorb wind.<br>• Ensure your wind and shading vegetation are compatible. |
| Air Quality - Filtration | A level of effectiveness can be perceived in areas with dense vegetation.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Visual & Acoustic | Vegetation has the potential to create a microclimate around the building premises if designed appropriately to block less visually appealing surroundings and reduce noise from nearby roads, while creating pleasant sounds with the movement of the wind. |

## Appendix 4.2 Vertical Greening Systems

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | High | Low to Moderate | Moderate | Low to Moderate | Moderate |
| Cost-Benefit | Moderate | Low to Moderate | Low | Low to Moderate | Moderate |
| Implementation Difficulty | Moderate to High | N/A | Moderate | N/A | Moderate to High |

| Factors ↓ | Considerations |
|---|---|
| Shading | A highly effective solution for summer, but it may have negative effects in winter.<br>Cost-effectiveness depends greatly on the orientation and system used.<br>Consider shade versatility by:<br>• Choosing deciduous vs evergreen plants.<br>• The possibility of having window access for pruning and maintenance.<br>• Ensuring to select the wall/s or areas more exposed to the sun.<br>• Avoid overshading natural light access to the building, which could lead to indoor darkness. |
| Evapotranspiration | It can be an overall effective and cost-efficient way to lower outdoor microclimatic temperatures if combined with outdoor self-standing vegetation or other VGS.<br>Consider easy access for watering the system to prevent water stress from stopping the evapotranspiration process.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Wind | Effective as an insulation layer, reducing temperature loss. This depends on the system used and its orientation in relation to prevailing winds.<br>Costs vary significantly, with crawling plants as green façades being the most affordable option.<br>In windy, strong areas, consider using climbing plants that are attached directly to the wall or systems designed to resist the wind. |
| Air Quality - Filtration | It can be an effective solution in the absence of an outdoor planting area, as the surface VGS can cover a significant area.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Visual & Acoustic | A visual amenity that can improve any surface by covering it. Creeping plants can easily adapt to many surfaces, blocking undesired views or providing privacy.<br>Its insulation potential also helps reduce sound bouncing or the echo effect. |

## Appendix 4.3 Pergola, Awnings & Other Outdoor Structures

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | High | Low to Moderate | Moderate to High | Moderate | Moderate to High |
| Cost-Benefit | Moderate to High | Low to Moderate | Low to Moderate | Low to Moderate | Moderate to High |
| Implementation Difficulty | Moderate to High | N/A | High | N/A | Moderate |

| Factors ↓ | Considerations |
|---|---|
| Shading | These solutions are versatile, with creeping plants able to take the shape of any structure; therefore, these are highly effective for shading.<br>Depending on the structure chosen and its design, these solutions are generally affordable, enabling shading potential with a small amount of soil available or using planters.<br>Consider shade versatility by:<br>• Choosing deciduous vs evergreen plants.<br>• Ensuring the right size and depth of awnings/eaves for the building opening.<br>• Evaluate wind currents, as these can endanger the structure.<br>• If in planters, it is recommended that the canopy also shades the planter to reduce the potential of dehydration. |
| Evapotranspiration | Moderate effectiveness depending on the microclimate and wind currents at the site.<br>A cost-effective solution that allows greenery to be established in already paved areas, or without access to planting ground.<br>If using planters, consider their size to be generous to allow for sufficient water to prevent water stress from stopping the evapotranspiration process.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Wind | This solution is not recommended for use as a wind shelter, as its horizontal disposition would not effectively block the wind. Nonetheless, VGS can be set on the sides, allowing creeping plants to also become green walls that protect the pergola from prevailing winds.<br>Consider using wind-tolerant creeping plants and robust structures for windy areas. |
| Air Quality - Filtration | Moderate effectiveness, as these solutions can cover a large area and be dense, depending on the structure.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Visual & Acoustic | A visual amenity that can improve any surface by covering it. Creeping plants can easily adapt to many surfaces, blocking undesired views or providing privacy.<br>Plants' insulation potential helps reduce sound bouncing or the echo effect, while air movement above and under the structure helps generate pleasant sounds. |

## Appendix 4.4 Balconies

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | Moderate to High | Low | Moderate to High | Low | Moderate |
| Cost-Benefit | Moderate | Low | Moderate | Low | Moderate |
| Implementation Difficulty | Moderate to High | N/A | Moderate | N/A | Low to Moderate |

| Factors ↓ | Considerations |
|---|---|
| Shading | A practical solution for summer if well-designed.<br>Overall, it's an affordable option since planters and equipment can last several years.<br>Its cost-effectiveness may also depend on the size of the balcony.<br>Think about shade versatility to suit different seasons:<br>• Make sure the layout can be adjusted to let in the sun during winter.<br>• Consider pruning some trees and hedges that might block sunlight in winter.<br>• Select plants that withstand sun and possible winds.<br>• To lower maintenance, opt for lightweight, mobile pots, such as those with wheels, so the setup can be changed for different seasons or weather events. |
| Evapotranspiration | Given the height and size of balconies, as well as the significance of airflow, the evapotranspiration potential is likely to be low at a site level.<br>Evapotranspiration may cool the air before it enters the building, depending on factors like airflow, coverage percentage, and overall layout.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Wind | Solutions can significantly reduce wind speed, helping occupants feel more comfortable on balconies and decreasing air exchange through covered doors and windows.<br>Consider choosing plants that can endure sun and possible winds.<br>Consider using sturdy mobile planters to support the plants during windy conditions, while enabling them to be moved in case of extreme weather events. |
| Air Quality - Filtration | Given the height and size of balconies, as well as the significance of airflow, the air filtration potential is likely to be low at a site level.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Visual & Acoustic | Vegetation in balconies can be an effective visual cover, providing privacy between buildings and within the balcony. It also provides visual access to nature through the building's windows, which have no direct visual access to nature outdoors.<br>Acoustic benefits can be insignificant, given the limited vegetation coverage of balconies compared to the overall building walls in an urban area. |

Appendix 4.5 Living Roofs

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | High | Moderate to High | Low to Moderate | Low to Moderate | Moderate |
| Cost-Benefit | Moderate | Moderate | Low | Low to Moderate | Low to Moderate |
| Implementation Difficulty | High | N/A | High | N/A | High |

| Factors ↓ | Considerations |
|---|---|
| Shading | It is highly effective because vegetation can grow across the entire area.<br>If cooling demand is high, this solution can be a cost-effective choice over the medium to long term.<br>Design considerations:<br>• Think about planting native plants that are tolerant to drought, sun, and possibly wind.<br>• Assess the possibility of retrofitting when the roof structure and slope allow.<br>• Explore extensive, shallow, and modular living roof options for easier maintenance.<br>• Check if the roof has walking access. |
| Evapotranspiration | Given plants and the soil, or substrate, can release water through evapotranspiration, its potential is significant.<br>Consider allowing evapotranspiration cooling effects to access indoors by opening windows or doors.<br>Consider whether an irrigation system may be necessary to support plant survival during summer seasons, and to allow for sufficient water to prevent water stress from halting the evapotranspiration process. |
| Wind | Its effectiveness heavily depends on the vegetation used. Extensive living roofs are unlikely to provide effective wind protection, but they may help reduce wind speed across their coverage or for windows with direct access to the living roof. |
| Air Quality - Filtration | Given the height and size of balconies, as well as the significance of airflow, the air filtration potential is likely to be low at a site level.<br>Effective effects can be perceived at a city level and for the benefit of society if widely implemented. |
| Visual & Acoustic | Vegetation in living roofs can be an effective visual access to nature through the building's windows, which have no direct visual access to nature outdoors.<br>The plants and soil/substrate’s insulation potential helps reduce the transmission of sound through the engineered structure, and the bouncing or echo effect. |

Appendix 4.6 Indoor Vegetation

| | Shading | Evapotranspiration | Wind | Air Quality - Filtration | Visual & Acoustic |
|---|---|---|---|---|---|
| Effectiveness | Moderate to High | Moderate to High | N/A | Moderate to High | Moderate to High |
| Cost-Benefit | Moderate to High | High | N/A | Moderate to High | High |
| Implementation Difficulty | Low to Moderate | N/A | N/A | N/A | Low |

| Factors ↓ | Considerations |
|---|---|
| Shading | Plants can be quite effective at providing overall shading indoors, but their effectiveness depends on how they are distributed and where they are placed.<br>Design considerations:<br>• Map indoor areas with high sun exposure for placing plants appropriately.<br>• Choose plant varieties that tolerate sun and can be grown in pots indoors.<br>• Avoid overshading natural light access to the building, as it could cause darkness and lead to excessive use of indoor artificial lighting.<br>• Consider using mobile planters or walls to adjust shading for different seasons. |
| Evapotranspiration | Indoor vegetation can have significant positive effects on cooling and maintaining comfortable humidity levels.<br>Consider watering frequency changes between seasons:<br>• HVACs remove moisture from the air when cooling. Allow for sufficient water to prevent water stress from halting the evapotranspiration process in summer.<br>• HVACs require more energy to heat moist environments in winter; therefore, consider not over-watering during the season. |
| Wind | Since wind is an external factor, this does not apply. However, considerable airflow between indoors and outdoors can have either positive or negative effects. Proper placement of plants to either allow or block airflow around openings can help achieve some positive outcomes. |
| Air Quality - Filtration | Indoor vegetation can significantly improve air quality and filtration. Consider the recommendations in the evapotranspiration section. |
| Visual & Acoustic | Indoor vegetation can be highly effective in providing indoor privacy in open spaces and offices.<br>Indoor vegetation can sometimes be the only viable strategy for certain premises. It is generally affordable, but the cost will depend on expectations, plant choices, and the solutions selected.<br>Plants help reduce the sound bouncing or echo effect.<br>Design considerations:<br>• Mix different plants that can thrive with or without direct sunlight.<br>• Use varied pot sizes and arrangements to craft different spaces.<br>• Consider using mobile pots or walls to enhance versatility across seasons and to suit different office layouts and work functions. |