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Why Are Naturally Ventilated Office Spaces Not Popular in New Zealand?

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Academic Editor: Umberto Berardi
Received: 28 February 2017; Accepted: 19 May 2017; Published: 26 May 2017

Abstract: In this paper, we investigated the reason(s) why natural ventilation is not as popular as air-conditioned or mixed-mode ventilation systems in Green-rated office buildings in New Zealand. To achieve this, we had three objectives. Firstly, we reviewed the Green Star criteria for thermal comfort in office buildings to ascertain which ventilation system the NZ Green Star rating tool promotes. Secondly, we ascertained the perception of occupants in office buildings regarding thermal comfort. This was followed by an interview with building experts regarding factors that affect the use of natural ventilation in New Zealand offices. The findings showed that the NZ Green Star thermal comfort criteria encourage the use of mechanical ventilation over natural ventilation which results in designers opting for air conditioning systems in office designs. We observed that occupants of naturally ventilated spaces were least satisfied with the thermal comfort of their offices when compared with occupants of mixed-mode and air-conditioned offices. This study fulfils the need to encourage the use of natural ventilation in office environments by designers and building owners. Further study on other aspects of the indoor environment quality that is related to naturally ventilated systems such as lighting and noise is required in a bid to ascertain its viability in office environments.

Keywords: natural ventilation; Green Star rating tool; thermal comfort; environmental sustainability

1. Introduction/Background

Buildings represent the largest capital investment made by any society [1]; as such, creating a conducive indoor environment is essential to the resilience of our buildings. This has helped building performance with respect to Green Architecture gain increasing attention in recent years. Also, the fact that people spend about 90% of their time indoors [2,3] has made the implications of the indoor environment very important to designers. The benefits of an appropriate indoor environment have been documented by research [4–7]. As such, organisations strive to create the appropriate indoor environments for workers. The dilemma lies with which indoor type of environment is most appropriate for a particular set of occupants; in this case, New Zealand office workers. To uphold the principles of environmental sustainability and keep up with the expectations of occupants, many studies have explored the indoor environment in a bid to identify what conditions best achieve both requirements—a Green building and comfort for occupants.

In terms of thermal comfort for occupants, studies have endeavored to identify which conditions occupants perceive as comfortable [8,9]. These conditions have become standards and guided architects and engineers over the years in specifying thermal comfort criteria for occupants. These standards specify the levels of a building's physical characteristics, such as temperature whereby it is assumed that occupants are satisfied and comfortable.

For naturally ventilated spaces, these standards have been found to be higher and to contain wider temperature ranges than those for air conditioned buildings. For instance, Brittle et al. [10] found that when occupants had access to openable windows, internal comfort temperature could be raised beyond 24 °C to a maximum of 28 °C. They also observed that yearly ventilation and cooling energy savings ranging between 21% and 39% could be achieved. Alessi et al. [11] observed that occupants had high acceptability of the thermal environment and were comfortable in a mixed-mode system of an air-conditioned National Australia Bank (NAB) in Melbourne. The research was based on the adaptive theory of thermal comfort. Honnekeri et al. [12] found that occupants in the naturally ventilated zone of a mixed-mode building were more satisfied in a warmer comfort temperature range (29–34 °C) than those in an air- conditioned zone (23–29 °C). They also found that the opportunity to adapt to the warmer environments in the NV zone by use of windows, fan, blinds and doors overrides the possible increase in thermal expectation from intermittent exposure to the AC zone. The investigations of Daghigh et al. [13] on thermal comfort levels in a naturally ventilated office showed that whereas the naturally ventilated office was objectively cold, the subjective survey showed that occupants found the conditions to be comfortable. This suggests a wider acceptable of temperature range.

As for Green buildings, it is implied that the design of a Green building aims to produce technologically, materially, ecologically and environmentally stable buildings [14]. As such, 'Greenness' is intrinsic in the very shape, envelope and style of the building. Attman [ibid] pointed out that the efficient use of energy in operating a building is a major determinant of a building's level of Greenness. This means that a building which does not use minimal energy throughout its lifespan may not be regarded as Green [15].

Combining both requirements of a building's performance results in an environment that is expected to be environmentally sustainable with a conducive indoor environmental quality (IEQ) for occupants' use. In a commercial setting, Green office spaces are purported to provide such environments. Research has shown that these office spaces offer the much needed IEQ that can improve the comfort and health of occupants [16,17]. In addition to this, they are claimed to contribute to environmental sustainability by minimising the impact of buildings on natural resources through energy efficiency [18].

Green rating tools are noted to encourage the design and construction of energy efficient buildings that also have economic and social benefits, of which occupant comfort is a significant factor. For example, Lee and Guerin [19] noted that Green certification aims to improve the quality of living and the productivity of the buildings' occupants while having an indirect but very specific impact on financial and social issues. These tools are designed to evaluate buildings by means of a selected standard of environmental performance [20]. In New Zealand, the Green Star rating tool is applied in commercial settings and stipulates, amongst other categories, the IEQ criteria for office environments. Green rating tools are expected to encourage systems that can achieve the stipulated standards of environmental performance in office spaces.

Natural ventilation is an element that is often associated with environmental sustainability or Green architecture. This is because it is energy efficient, relying mostly on wind and thermal buoyancy as driving forces to achieve thermal comfort. Despite numerous evidence that naturally ventilated spaces are environmentally sustainable [21,22] and provide thermal comfort [9,23], it is not a popularly used indoor environment control system in New Zealand office environments. Onyeizu [18] observed that the majority of Green Star-rated buildings in New Zealand are air conditioned. Lai and Yik [24] noted that buildings in modern cities are typically fully air conditioned. Russell and Inghm [25] pointed out that buildings within Auckland, New Zealand are likely to obtain air conditioning systems of some sort as the region is considered to be modern.

Hence, we asked the question: why is natural ventilation not a common indoor environmental control system in Green office environments?

To answer this question, this study set two objectives:

1. Ascertain which ventilation system the NZ Green building rating tool encourages most in office spaces.
2. Compare occupants' perception of thermal comfort in different ventilated office buildings (natural ventilation, mixed-mode and air conditioned).

The significance of this study is that it provides a background for further study of the implications of the use of natural ventilation to create resilient indoor environments for office buildings. This study is focused on thermal comfort because past studies have shown that it is the most influential environmental factor that affects the satisfaction of occupants regarding the indoor environmental quality of a building [26]. The success of this study will lend a hand towards the greater shift from dependence on mechanical systems to free running environmental control systems.

2. Method

The study question was investigated through a review of literature and a field survey of office workers. The benefit of using this method is that it increases the validity of the data obtained. As Webb et al. [27] wrote, once a proposition has been confirmed by two or more independent measurement processes, the uncertainty of its interpretation is greatly reduced. These research methods were employed to provide sufficient data from which findings were obtained fulfilling each objective of the study.

For Objective 1, a review of the NZ Green Star rating tool (v3.1) concerning the criteria for thermal comfort (IEQ-6) in Green office buildings was carried out. This was supported by a literature review of research-based theories on thermal comfort. Past studies that have tried to capture the concept of thermal comfort in office buildings were critiqued regarding their applicability in office design. Conflicting as well as complementary theories that have prevailed over time were examined and deductions were made. The NZ Green Star rating tool (v3.1) was selected for this critique as it is the only Green rating tool that certifies Green office buildings in New Zealand. The purpose of this is to ascertain which ventilation system the criteria encourage in Green office spaces.

For Objective 2, an online questionnaire was used to ascertain office workers' perceptions of thermal comfort in their office spaces. The use of this instrument is supported by Toftum [28] who pointed out that humans are the best available sensors, and they are highly subjective. Also, Leaman and Bordass [29] noted that in buildings, people are the best measuring instruments—they are just harder to calibrate. Conducting an online survey assisted in reaching a wider audience and avoiding researcher's bias [30]. The sample population was limited to occupants of office environments in Auckland City, New Zealand. Auckland City was chosen because it is the most populated city in the country and has the highest number of modern office buildings in the country. This city is the business hub of New Zealand. The purpose of this survey is to ascertain whether natural ventilation is a preferred ventilation system in office buildings.

The sequential nature of this study allowed for adequate investigation of employing natural ventilation as a sustainable feature in Green office buildings.

3. Results

3.1. NZ Greenstar IEQ Criteria and Natural Ventilation (Objective 1)

As earlier stated, this review is focused on the IEQ criteria for thermal comfort in the NZ Green Star rating tool (vs3.1). ASHRAE's [31] definition of thermal comfort is widely accepted. It defines thermal comfort as that condition of mind which expresses occupants' satisfaction with the thermal environment [31]. Hence, it is expected that the NZ Green Star IEQ criteria will specify conditions at which occupants are expected to be satisfied with the thermal environment. Also, as the NZ Green Star rating tool is designed to rate and communicate the sustainability of commercial buildings in New Zealand [32], it is assumed that measures which denote sustainability will be promoted in this rating tool.

According to Table 1 below, the NZ Green Star tool requires temperature standards that are based mainly on the Predicted Mean Vote (PMV) standards of comfort. It allocates more points as the range of temperatures is narrowed (three points for PMV levels between −0.5 and +0.5 for mechanically ventilated and mixed-mode buildings and −0.75 and +0.75 for naturally ventilated buildings) [33]. While this might seem reasonable, a dive into evidence-based research shows that these comfort standards may not be appropriate for naturally ventilated buildings.

Table 1. Overview of NZ Green Star (v3.1) office indoor environmental quality (IEQ) criteria for thermal comfort [33].

Ref. No.	Title	Aim of Credit	Credit Criteria Summary	Points Awarded
IEQ-6	Thermal Comfort	To encourage and recognise the use of thermal comfort assessments to guide design options.	Up to three points are awarded where it is demonstrated that assessments have been made of thermal comfort levels and used to evaluate appropriate servicing options. The following Predicted Mean Vote (PMV) levels, calculated in accordance with ISO 7730, (or equivalent using Draft ASHRAE Comfort Standard 55 and "Developing an Adaptive Model of Thermal Comfort and Preference—Final Report on ASHRAE RP884"), must be achieved during Standard Hours of Occupancy and using standard clothing, metabolic rate and air velocity values for 90% of the year.	For mechanically ventilated and mixed-mode buildings: One point = PMV levels are between −1 and +1 Two Points = PMV levels are between −0.75 and +0.75 and Three points = PMV levels are between −0.5 and +0.5. For naturally ventilated buildings: Two Points = PMV levels are between −1 and +1 and Three points = PMV levels are between −0.75 and +0.75.

The PMV method of measurement dates back to laboratory research by Fanger in 1967 that used a thermal balance model of the human body to derive an acceptable interior thermal environment for at least 80% of a building's occupants [34]. As a result of his findings, the mantra for thermal comfort became 'cold, dry, still indoor air' [8]. Even though this method (published as ASHRAE Standard 55, 2010) was originally intended to provide guidelines for centrally controlled HVAC [9], it formed the basis on which thermal comfort is evaluated in both naturally ventilated and mechanically air-conditioned buildings for a larger part of the 21st century. Although the recent amendment of the standard (ASHRAE Standard 55, 2013) acknowledges the Adaptive method for naturally ventilated buildings alongside the PMV model, the thermal comfort criteria of the NZ Green Star office tool seems to encourage the PMV method over the Adaptive method. As shown in Table 1, it is inferred that the Adaptive method follows the PMV approach and points are awarded based on PMV measurements.

Generally, the PMV model is a 'static' model, i.e., it advocates for a defined thermal point at which it presumes that a larger percentage of occupants will be thermally comfortable. However, there is strong research that challenges the idea that specific and constant levels of the thermal environment are an appropriate indicator of comfort, and it appears that adaptation to a wider range of conditions is not adequately considered [9,35], especially for naturally ventilated spaces. The adaptive comfort model was suggested as a more suitable comfort standard as it allows for warmer indoor temperatures [9]. The adaptive comfort model proposes adaptation to a wider range of thermal conditions. Whereas the adaptive comfort model struggles to be accepted as an efficient and popular model for thermal comfort in commercial buildings, the PMV model remains the fundamental standard for most thermal comfort measurements in NZ office buildings. The argument is that having a stable optimal indoor temperature is integral to occupant productivity [36,37].

The Adaptive model purports that energy saving can be achieved through adaptation [38]. It also claims that the PMV model is unable to articulate the underlying causal relationships that cause a shift in temperature and cannot account for the feedback that might initiate this shift or other behavioural responses [39]. On the other hand, the Adaptive model acknowledges that thermal perception in real-world settings is influenced by the complexities of past thermal history, non-thermal factors and thermal expectations [39]. de Dear and Brager [ibid] observed from field evidence that there was a clear distinction between the responses of occupants in a naturally ventilated building as opposed to an air-conditioned building.

The Applicability of PMV versus Adaptive Model in Green Rating Tools

The PMV model has been criticised as being unsuitable for naturally ventilated or mixed-mode buildings [38] since the 'voting' on PMV was carried out in air-conditioned offices. This is because it is often difficult to meet this narrow specification of thermal comfort without HVAC, even in relatively mild climatic zones such as New Zealand. As a consequence, designers tend to go for air-conditioned office buildings since compliance with thermal comfort criteria is relatively easy to achieve by air-conditioning [38]. The disadvantages of PMV as a measure of comfort are highlighted [22] within the context of the high energy penalty that is incurred when near isothermal conditions are maintained. The important results of field trials described by Arens et al. [21] indicate that spaces with tightly controlled temperatures do not provide higher acceptability/tolerance than spaces with less control. The authors conclude that "the theoretical basis of tight PMV/PPD building control is flawed" [21]. Adaptive models which recognise human tolerance of varying thermal conditions are suggested as more suitable metrics [37] (Figure 1). There is evidence that this model is in close agreement with the measured comfort vote of occupants and could better predict the thermal comfort of subjects [40]. Luo et al.'s [41] study on thermal comfort in mixed-mode buildings in sub-tropical climates found that the adaptive comfort model is a more flexible application and a valuable reference for the design and operation of such buildings.

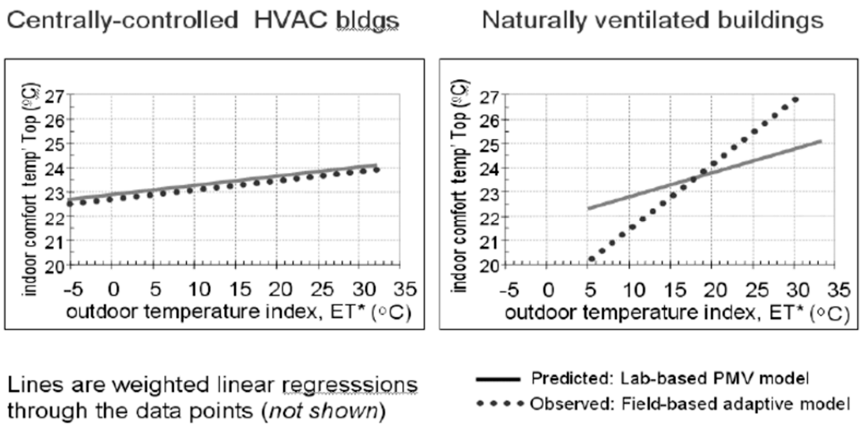

Figure 1. Observed and predicted comfort temperature between buildings with centrally-controlled HVAC and naturally ventilated buildings [37].

The limitations of the PMV metric for thermal comfort also include one implied by users: ignorance of the influence of cultural, social and contextual factors [9]. According to the authors, the physics governing a body's heat balance (the basis for PMV) is inadequate for fully explaining the relationship between perceived thermal comfort in naturally ventilated buildings and exterior climatic conditions. These factors have been found to play a significant role in the adaptive ability of occupants in any given thermal environment. This adaptive capacity in practice is the implementation of effective strategies to react to stresses to reduce the likelihood of harmful outcomes [42]. This includes involuntary (shivering, sweating) and voluntary (adding or removal extra clothing, fanning) actions through which an occupant exerts control and adapts to the environment. These activities are practical over wider ranges of thermal environments than those specified by the IEQ thermal criteria (PMV values) and are exercised in both mixed mode and naturally ventilated buildings. Nicol and Humphrey [43] observed that there is a range of things we can do to achieve thermal comfort. If a change causes discomfort, people react in ways that tend to restore comfort. Brager and de

Dear [9] noted that the total range of clothing worn by building occupants is much wider in naturally ventilated buildings.

The adaptive model acknowledges that factors such as demographics, context and cognition interact with thermal perception through the process of adaptation [44]. Studies by de Dear and Brager [39] have shown that occupants in naturally ventilated buildings are tolerant to a wider range of temperatures as a result of behavioural and physiological adjustments. De Dear et al. [44] identified three categories of adaptation responsible for this—behavioural adjustment, physiological adaptation and psychological adaptation. The interplay of these categories creates an environmental control loop system of the Adaptive model such as the one illustrated in Figure 2.

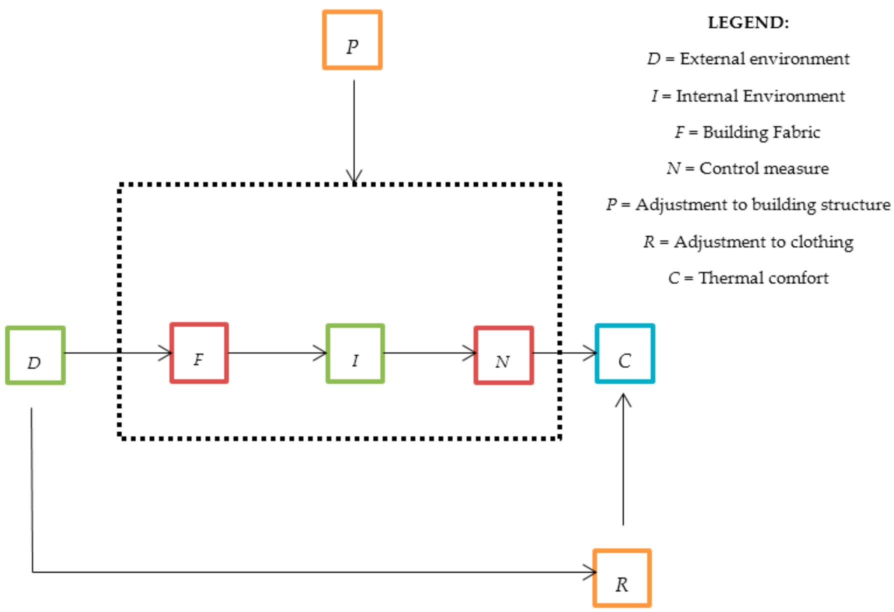

Figure 2. Interactive adaptive environmental control; adapted from [45].

To explain this figure, a set of external environmental disturbances (D) (such as the weather condition) impinges upon a person, interacting with the set of physical variables (such as temperature and humidity), which determines an occupant's level of thermal comfort. This interaction is often mediated with the introduction of a filter (F) (e.g., building structure) to enclose people and create an internal environment (I). In the internal environment, the interaction between (D) and (C) then occurs through a channel containing behavioural (e.g., adjusting clothes), physiological (e.g., acclimatisation) and psychological (e.g., altered perception of sensory information) control measures(N). These control measures affect the transmission from (D) to (C) and thus, the thermal sensation of the occupants. As this interaction is continuous and changes in magnitude and levels occur within a short period, adjustments are constantly made to control measures (F) and (N) represented by R (e.g., taking off or putting on extra clothing) and (P) (e.g., opening or shutting of windows and doors). The adjustments (R) and (P) are usually dependent on the external environment (D). These actions make up the adaptive control system.

The sole reliance on PMV standards of thermal comfort has been widely abandoned by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Chartered Institution of Building Services Engineers (CIBSE); the Adaptive model has been included to allow for a robust thermal comfort measurement. Yet, it is still applied in the New Zealand Green Star rating tool (Table 1). Using the PMV standards for indoor environmental control means that the design is largely dependent on artificial air conditioning systems such as HAVC. On the other hand, the adaptive model provides the opportunity for passive measures of air conditioning. The requirement for tightly controlled thermal environmental conditions in architecture that has a highly glazed and sealed envelope with ventilation and temperature control is achieved by air-conditioning. Once the decision is made to air-condition a building, the advantages of passive environmental control, such as thermal mass to smooth out diurnal changes in temperature, are negated. Furthermore, the need for solar protection is diminished as a larger air-conditioning plant to combat overheating is a cheaper initial option than the installation of effective solar shading.

New Zealand's National Institute for Water and Atmospheric research (NIWA) [46] predicts that most of New Zealand is estimated to exceed a mean 2 °C temperature rise by 2090 and that average temperatures may rise by 1 °C by 2040. The impact that this rise in temperature will have on buildings in warmer areas of the country (e.g., Auckland City) includes an insecure supply of electricity and greater cooling load [47]. Buildings that have not been designed to control peak temperature by passive means will require more energy for cooling systems that rely on electricity [47]. Commercial buildings are likely to have an even greater impact on energy demand since they remain in operation during diurnal temperatures [47]. As noted by Kwok and Rajkovich [42], it is important that we begin to future-proof our buildings with adaptive opportunities for passive, low energy buildings in response to the unprecedented climatic variability presented to us by climate change.

The points discussed indicate that the NZ Green Star thermal comfort criteria may not just be inappropriate but encourage artificial air conditioning systems in office buildings. This results in the need for buildings to resort to artificial means of cooling when they could rely on natural means. It also appears to contradict the idea of environmental sustainability. Onyeizu [18] noted the indoor environment control dilemma faced by designers in the design of Green buildings (Figure 3). The author stated that there is still the conflict of satisfying occupants' expectations of an indoor environment and being environmentally sustainable. This conflict is further highlighted by market trends and the ever-changing expectations of occupants.

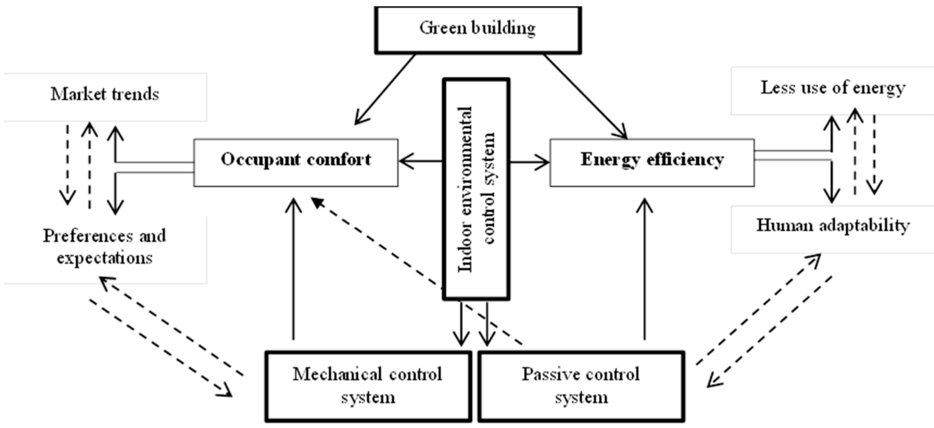

Figure 3. An illustration of indoor environment control dilemma in Green buildings. Energy-efficient, passive-control system on the right-hand side; monotonous mechanical control system on the left-hand side [18].

Over the last decade or more, research into IEQ has moved away from models that assume comfort to be an adequate measurement of conditions to an acceptance that diversity within, and adaptability to, the physical environment are more conducive to comfort and possibly productivity [34]. This is similar to a finding made by Healey and Webster-Mannison [48] in their survey on qualitative factors that influence thermal comfort: "the common theme among respondents was that as long as one was able to work at a satisfactory rate and without major distraction, there was no problem with the indoor conditions" (p. 173). Vischer [49] noted that a workspace cannot be designed to be a one-time, final and permanent ergonomic support for all office tasks, but rather it needs to be adaptable and 'negotiable' to be supportive to users. This is because people differ and respond differently to the same conditions [26].

3.2. Occupants' Perception of Thermal Comfort in Their Office Buildings (Objective 2)

This section discusses occupants' perception of thermal comfort in three different types of office spaces—Natural ventilation (NV), Mixed Mode (MM) and Air Conditioned (AC). While there are various factors associated with thermal comfort of which air temperature, humidity, air velocity, etc., are involved, this study concentrated on those that represent an impact on a person's thermal comfort [50]. These factors are namely:

a. Temperature extremity (too hot, too cold)
b. Temperature fluctuation (stable or varied)
c. Air flow rate
d. Control over temperature

These factors have been established by research to have an influence on a person's thermal comfort and thus performance, especially in office environments [51,52]. For instance, Bordass [53] found an effect of temperature extremity (too hot or too cold) and air fluctuation on occupants' comfort in office environments. Onyeizu and Byrd [54] observed that air quality and temperature were the most influential IEQ factors that affect the productivity of occupants. Agha-Hossein et al. [55] noted that psychological comfort involves feelings of ownership and the control over one's indoor working environment. Lee and Brand [56] found the perception of control over aspects of the physical environment mediated the relationship between perceived distractions and perceived job performance. Monfared and Sharples [57] noted that the expectations of occupants in buildings were based on lack of control over environmental conditions. These factors are also investigated in standardised post-occupancy evaluation surveys of buildings (e.g., Building in Use Survey (BUS)) to study the performance of buildings about occupants' comfort [58]. The BUS questionnaire is internationally applied, and its results used extensively in this area of research.

The sample population was randomly selected from office workers in Auckland City, New Zealand. A target was set for 300 responses out of which 216 responses were deemed adequate for statistical analysis. Background information on the respondents is presented in Table 2 below. As shown in the table, 38% of the respondents were in naturally ventilated office spaces (NV), 33% were in mixed-mode spaces (MM) while 29% were in air-conditioned spaces (AC). Most of the respondents were male (75%) and in the 45 and above age group (50%).

Table 2. Demographic information on survey participants.

Background	Percentage			
Gender	Female = 25%	Male = 75%		
Age	Under 25 = 10%	25–35 = 22%	36–45 = 18%	Above 45 = 50%
Ventilated space	NV = 38%	AC = 29%	MM = 33%	

The survey questions were designed as closed-ended to provide quantifiable responses towards an indication of occupants' preference.

3.2.1. Sick Leave Taken per Year

The first section investigated the number of sick days that respondents take off work in a year. The aim was to establish the effect of the work environment on occupants' health. From Figure 4 below, we can see that occupants of AC spaces took more sick days than those in MM and NV spaces. While no occupant (0%) took sick days for 8–10 days in NV and MM spaces, 3% of AC occupants did. More AC occupants (41%) took sick days up to 3–5 days off than occupants in MM (29%) and NV spaces (20%). NV occupants (79%) took the least sick days off work per annum (0–2 days).

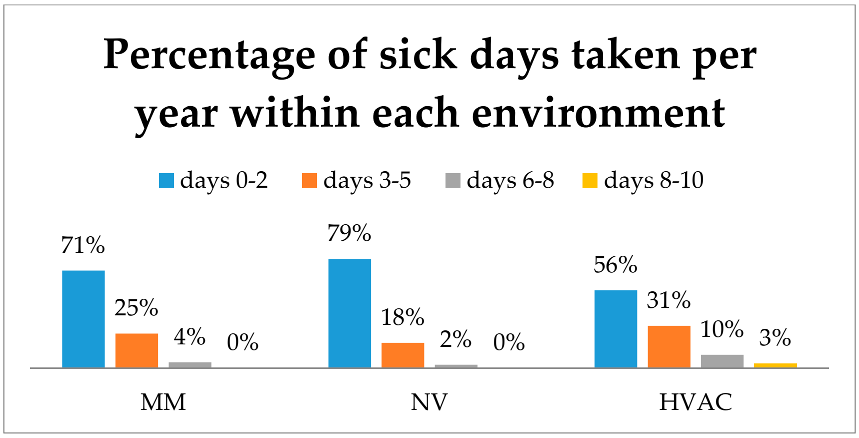

Figure 4. Percentage result of sick days taken off work by office workers per year.

3.2.2. Thermal Comfort Satisfaction

The next question enquired about the satisfaction level of workers with the thermal environment in their office spaces. The results from Figure 5 below indicate that a significant proportion of occupants regarded each space as Average or Good (37–45%). MM spaces received the highest votes for Very Good (17%), and no occupant of NV spaces thought that their work environment was Very Poor (0%).

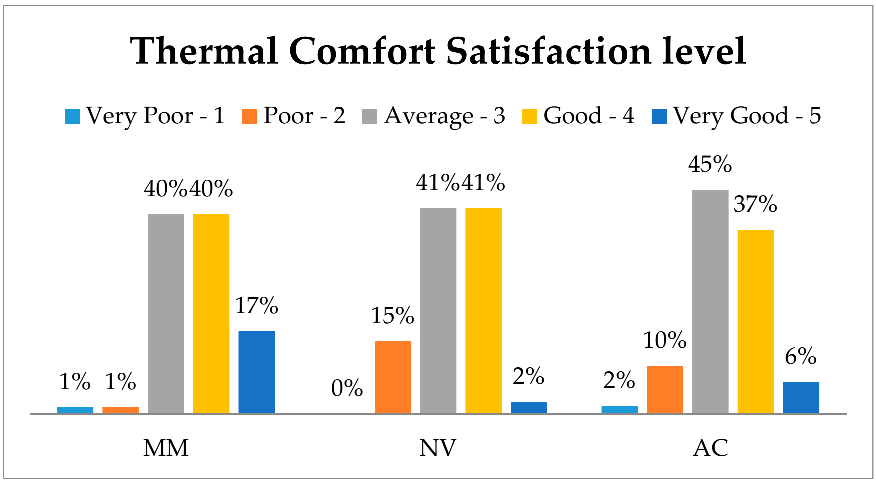

Figure 5. Percentage satisfaction rating on thermal comfort in office spaces.

3.3. *Descriptive Analysis*

The descriptive analysis was carried out with SPSS v23. The aim was to carry out more rigorous statistical analysis of the data collected to infer the perception of occupants on their thermal comfort. The mean differences of thermal comfort satisfaction levels within the different office spaces (MM, NV and AC) were compared using one-way ANOVA. This was done to establish the mean rating (MR) of the respondents' rating for each question [59] answered.

3.3.1. Satisfaction Rating for Thermal Comfort

The results were considered statistically significant when $p < 0.05$ (95% confidence level). The test showed that there was a statistically significant difference between the office spaces ($F(2,213) = 4.885$, $p = 0.008$). Table 3 shows that satisfaction means for the three office types are within the mean interval. This result indicates that occupants of all the three office types were satisfied with the thermal comfort in their office spaces. Comparing means, MM occupants were most satisfied with their thermal comfort (M = 3.69; SD = 0.816). This is followed by AC occupants (M = 3.37; SD = 0.815). NV occupants were least satisfied with their thermal comfort (M = 3.32; SD = 0.816).

Table 3. Mean satisfaction rating for thermal comfort in the three office types.

	N	Mean (MR)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Rank
					Lower Bound	Upper Bound	
Natural Ventilation	82	3.3171	0.75159	0.08300	3.1519	3.4822	3rd
Mixed Mode	72	3.6944	0.81602	0.09617	3.5027	3.8862	1st
Air Conditioned	62	3.3710	0.81450	0.10344	3.1641	3.5778	2nd
Total	216	3.4583	0.80587	0.05483	3.3503	3.5664	

3.3.2. Impact of Thermal Comfort Factors on Worker Performance

The next survey question investigated the four thermal comfort factors to identify which factor most impacted on worker performance. Firstly, a reliability test was conducted using the Cronbach Alpha (α) to ascertain that the thermal comfort factors were reliable subscales. An acceptable value of 0.8 was regarded as an internal consistency. As shown in Table 4, the thermal comfort variables were found to be highly reliable (α = 0.808) as deleting any of the factors will reduce the test value.

Table 4. Reliability test for thermal comfort factors.

Reliability Test (Cronbach Alpha = 0.808)	Cronbach Alpha If Item Deleted
Temperature Extreme	728
Temperature Fluctuation Rate	742
Air Flow Change Rate	801
Temperature Control	753

Table 5 shows the result of the mean ratings of the impact of each factor on worker performance. All of the factors are shown to be statistically significant to performance since their means fall within the mean interval. Comparing means, Temperature Extreme was shown to have the most significant impact on worker performance across all the office spaces (Total mean = 2.4954; SD = 0.818). This is followed by Temperature Control (TM = 2.3796; SD = 0.854) and Air Flow Change Rate (TM = 2.2546 SD = 0.876). The least influential factor to performance is Temperature Fluctuation (TM = 2.2361; SD = 0.762).

On a case by case level, Temperature Extreme was ranked first across all the spaces followed by temperature control (second). While Air Flow Change Rate was ranked third by NV and MM occupants, it was ranked the least (fourth) factors by AC occupants. Temperature Fluctuation was ranked the least significant for NV and MM occupants but ranked third by AC occupants.

Table 5. Mean impact rating for thermal comfort factors on worker performance in the three office spaces.

		N	Mean (MR)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Rank
						Lower Bound	Upper Bound	
Temperature Extreme	Natural Ventilation	82	2.2683	0.70358	0.07770	2.1137	2.4229	1st
	Mixed Mode	72	2.6528	0.85843	0.10117	2.4511	2.8545	1st
	Air Conditioned	62	2.6129	0.85612	0.10873	2.3955	2.8303	1st
	Total	216	2.4954	0.81838	0.05568	2.3856	2.6051	

Table 5. *Cont.*

		N	Mean (MR)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Rank
						Lower Bound	Upper Bound	
Temperature Fluctuation Rate	Natural Ventilation	82	2.0610	0.65447	0.07227	1.9172	2.2048	4th
	Mixed Mode	72	2.2500	0.80053	0.09434	2.0619	2.4381	4th
	Air Conditioned	62	2.4516	0.80322	0.10201	2.2476	2.6556	3rd
	Total	216	2.2361	0.76237	0.05187	2.1339	2.3384	
Air Flow Change Rate	Natural Ventilation	82	2.1829	0.78768	0.08699	2.0099	2.3560	3rd
	Mixed Mode	72	2.3472	0.87468	0.10308	2.1417	2.5528	3rd
	Air Conditioned	62	2.2419	0.98656	0.12529	1.9914	2.4925	4th
	Total	216	2.2546	0.87603	0.05961	2.1371	2.3721	
Temperature Control	Natural Ventilation	82	2.2073	0.74928	0.08274	2.0427	2.3720	2nd
	Mixed Mode	72	2.4861	0.91917	0.10833	2.2701	2.7021	2nd
	Air Conditioned	62	2.4839	0.88228	0.11205	2.2598	2.7079	2nd
	Total	216	2.3796	0.85418	0.05812	2.2651	2.4942	

4. Discussion

The results of this study demonstrate a series of intriguing findings between the two instruments used.

Firstly, the literature review carried out showed that the NZ Green Star IEQ criteria for thermal comfort encourage air conditioning systems over natural ventilation. This is because while the points awarded for an air conditioning system are the same as those awarded for natural ventilation, the ease with which these points can be obtained by merely installing HVAC equipment creates an imbalance. This observation is not limited to NZ Green star tool as Roaf et al. [60] noted that the LEED rating tool does not support passive design strategies and is devised to promote the use of a mechanical system, which in turn heightens energy use. As such, designers may no longer be interested in the actual articulation of building design principles to achieve appropriate IEQ, but are thus more concerned with how to achieve a Green certification without much effort. A Green rating tool that is aimed at upholding the principles of sustainability should give preference to measures that will achieve this, of which natural ventilation is an example.

In fact, balancing the need to create a comfortable IEQ for occupant comfort with ensuring energy efficiency seems to be the dilemma of 21st-century Green office buildings. Cole [61] pointed out that much of the contemporary Green design involves an overly literal transfer of technical strategies from fundamentally different climatic and cultural contexts without any serious consideration of either their validity locally or their acceptance and engagement by the building occupants. As a result, the sustainability and ecological responsibilities of Green designs are downplayed as more importance is placed on providing the specified working environment. Research has shown that the energy performance of Green-certified buildings often does not achieve the expected result of energy efficient buildings. For example, during the design to renovate an Auckland office building to 5 Star Green rating, its estimated energy consumption of 170 kW/sqm/yr before renovation [62] increased to an energy consumption (recorded during occupancy) of 249 kW/sqm/yr—an increase of 45%. Bordass [53] pointed out that carbon dioxide emissions from supposedly Green buildings are commonly two or even three times as much as predicted. An occupancy survey of a Green-certified building in Auckland showed a 10.5% increase in satisfaction after renovation attributed to the Green IEQ of the building; while the actual energy consumption recorded a 46% increase in the estimated consumption [61]. Cole [63] pointed out that buildings designed with excellent Green performance standards can be severely compromised because the specifications and technical performance fail to adequately account for the users' needs, expectations and behaviour.

An intriguing question which, although quite obvious, has eluded Green rating systems is how sustainable 100% air-conditioning could be. Since most Green-certified office buildings are fully air conditioned, the reliability of the Green rating tool in ensuring the energy efficiency of buildings during their operation and the total life cycle of these buildings is in doubt. This also implies that a building can achieve Green building status without reducing its energy use and subsequent carbon impact on the environment. The only difference between such buildings and their non-Green certified counterparts is the Green label achieved through the certification process.

The ability of naturally ventilated buildings to bridge the gap between environmental sustainability and occupant comfort is not that simple. Moujalled et al. [40] suggests that complex interactions need to be considered if energy consumption in sustainable buildings is to be reduced. Various aspects of thermal relativity need to be considered. The major aspects include the climatic suitability of the region, occupant acceptability and/or adaptability to varying temperatures and the internal loading on the building. The climatic conditions in the study area (Auckland City) can be said to be suitable for naturally ventilated buildings. It is located in a temperate region with a historical average outdoor temperature of between 11 °C and 28 °C [64]. This makes it appropriate for naturally ventilated office spaces since the outdoor temperature range is not extreme. The challenge, however, will be designing new or adapting existing buildings to reduce their energy consumption [47]. This requires an understanding of techniques of using ambient energy to reduce the demand on imported energy and is affected by other design constraints. Building code standards concerning energy consumption of buildings in New Zealand are some of the lowest in the OECD [47]. One reason for this is the relatively cheap price of electricity. However, as electricity prices increase and the security of an uninterrupted supply decreases, the energy consumed by buildings will take on a greater significance [47].

Regarding occupant acceptability, the survey of occupants' perception of thermal comfort showed that NV occupants were satisfied with thermal comfort in their offices (Section 3.3.1), even though this satisfaction is not favourable when compared with those in MM and AC occupants (Table 3). A plausible reason for this is explained by Roaf et al. [60] and Brager and de Dear [9] who noted that occupants of AC buildings become finely tuned to the very narrow range of IEQ; as such, they might not be comfortable in natural indoor environment conditions without time to re-acclimatise. After all, studies have shown high satisfaction of occupants in naturally ventilated office spaces [18,63]. According to Roaf [65], people now typically accept working patterns that are remote from the natural world; they have become accustomed to more sedentary lifestyles, and have come to expect buildings to automatically regulate indoor temperatures. Roaf [ibid] commented that in post-1960s buildings, designers often appear to be intent on following fashion and adhering to stereotypes—for example 'minimalism' or 'modernity'—to the extent that they produce buildings which are hard, sterile and inhuman.

The results of factors of thermal comfort that affected worker performance tested showed that extreme levels of temperature and lack of control over temperature were the most significant factors identified across the three office types. This finding intensifies the importance of these factors in office spaces. The inability of a person to function in an environment that is either too hot or too cold cannot be overstated as such environments are still prevalent in office spaces [18], especially in AC spaces [29]. While Roaf [65] points out that people have come to expect buildings to automatically regulate indoor temperatures, the importance of control over temperature in the office spaces is highlighted in this study and is supported by past studies [44,66]. Leaman and Bordass [67] noted that people who have greater control over their indoor environment are more tolerant of wider ranges of temperature. One way of achieving greater occupant comfort with a passive control system is by giving the occupants more control over the IEQ in their local environment [18]. Lee and Brand [57] noted that a sense of control over physical environment factors had a mediating influence between work attitudes and work outcomes.

5. Conclusions

This paper examined the reasons why natural ventilation is not a popular ventilation system in New Zealand Green office buildings. The reasons were deduced through a review of the NZ Green

Star IEQ criteria for thermal comfort and survey of occupants' perception of thermal comfort in their office spaces. It was found that the NZ Green Star IEQ criteria for thermal comfort do not encourage naturally ventilated office buildings. The perception of office workers regarding thermal comfort showed that that NV spaces were not preferred over MM and AC spaces. It was also found that temperature extremity and control over temperature are the thermal comfort factors perceived to have the most impact on worker performance in New Zealand Office environments. Perhaps if the NZ Green Star IEQ criteria for thermal comfort can be amended to promote the adaptive model that encourages natural ventilation, more designers could be interested in adopting this model. Whereas the perception of office workers was slightly less in favour of naturally ventilated spaces, the adaptability of human nature indicates the possibility of a change in preference once occupants become accustomed to the environment. Thus, we may be able to achieve naturally ventilated Green spaces that are thermally comfortable to occupants.

As stated in this paper, achieving a thermally comfortable, naturally ventilated Green space will ultimately depend on various factors. From a design aspect, it requires a combination of sound technical knowledge and manipulation of indoor and outdoor temperature, as well as occupants' leniency on wider thermal variations. A common argument is the likely productivity decrease often associated with natural ventilation. However, the productivity implication of naturally ventilated office spaces is still under debate [18] and should not be an excuse for energy inefficient buildings.

This study is part of research on naturally ventilated office environments in New Zealand. This study has focused on thermal comfort. There is need to study other aspects of the IEQ that are related to naturally ventilated systems such as lighting and noise. This will provide more information on the viability of employing this system in office environments.

Author Contributions: Eziaku Onyeizu Rasheed and Hugh Byrd conceived and designed the methodology for the study; Blair Money carried out the questionnaire survey; Eziaku Onyeizu Rasheed analysed the data; Jasper Mbachu and Temitope Egbelakin contributed analysis tools; Eziaku Onyeizu Rasheed wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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