Rethinking Architectural Passive Cooling Strategies in New Zealand's Non-residential Building Stock

Lesley METIBOGUN[a], George BAIRD[b]

[a] *School of Architecture, Victoria University of Wellington, New Zealand, lesley.metibogun@vuw.ac.nz*
[b] *School of Architecture, Victoria University of Wellington, New Zealand, george.baird@vuw.ac.nz*

ABSTRACT

Whereas traditional building designs successfully integrated passive cooling strategies, current non-residential buildings have become dependent on mechanical cooling to achieve thermal comfort. The aim of this study is to demonstrate that with appropriate design input passive methods of cooling can be successfully incorporated into non-residential buildings. Following a brief outline of how our dependence on mechanical cooling has spread over the full range of building types and climatic zones, the focus of this paper is on non-residential buildings in temperate climates where passive cooling should be feasible in principle. It was found that current design policies, regulations and guidelines and current building design practices militate against their use. Perceived association with prestige, inflexibility of design processes, rigid planning regulations and sustainability rating systems were identified as key factors forcing the need for mechanical cooling. Recommendations are made on how to further encourage development in this direction from the perspective of architectural design.

Keywords: *climatic responsive architecture, passive cooling, non-residential buildings*

1. INTRODUCTION

New Zealand's non-residential building stock was estimated at 41,154 with a total floor area of 39.9 million m^2 (Cory, 2016).The non-residential building stock is divided into five size ranges, namely; size S1, S2, S3, S4, and S5 with a minimum floor area of 5 m^2, 650 m^2, 1500 m^2, 3500 m^2, and 9000 m^2 respectively. It is interesting to note that the building size S4 and S5 are large and they are mostly multi-storey buildings with percentage of buildings at 4% and 1% respectively. Small buildings, S1, S2, and S3 amount to 80% of the stock. The non-residential building stock is classified into three building use types namely; commercial office, retail, and others. Cory (2016) found that air conditioning was present in large commercial buildings (mainly office buildings). Despite the development of sustainable building design strategies with the potential to avoid overheating risk, the unnecessary use of air conditioning is escalating in non-residential building stock. The use of air conditioning in the non-residential buildings has become a norm in New Zealand (NZ) due to poor architectural design (Budin & Leardini, 2015). It is also evident that some of the current design practices and guidelines militate against the implementation of architectural passive cooling strategies which could alleviate the potential for overheating (Byrd, 2012).

Lenoir et al. (2012, pp157) stressed that "thermal comfort can be achieved in public buildings without air conditioning". How has the human race survived for millions of years without air conditioning, but suddenly cannot live without it? Is it so difficult to design without air conditioning? The following paper includes a brief description of the trend towards dependence on mechanical cooling; the impact of the energy crises; the changing climate and sustainable building strategies; the relationship between current practices and the institutional drivers and the use of air conditioning; and studies on retrofitting non-residential building for passive cooling. This study aims to understand the trend towards the dependence on mechanical cooling and current design practices and regulations that have encouraged the spread of air conditioning specifically for temperate climates within the practical context of NZ non-residential building stock.

2. THE TREND TOWARDS DEPENDENCE ON MECHANICAL COOLING

Prior to the 1900s, non-residential buildings utilised passive design strategies, enabling solar penetration into the building in winter and shading to prevent it during the summertime (Arnold, 1999). Generally speaking, buildings were designed to adapt to the climate with minimal impact on the environment (Donn & Cresswell-Wells, 2014). Passive design strategies require little increase in building cost without any additional running cost. However, while passive design strategies have both economic and environmental benefits, they have perceived limitations. Between 1900 and 1920, there was a gap in research into passive design strategies (Gokarakonda & Kumar, 2016) leading to their gradual neglect with the result that overheating became more common in buildings. This led to a worldwide growth of alternative means to solve overheating problems in non-residential buildings. The conventional solution to overheating was the installation of air conditioning (Yu et al., 2009) and this resulted in a high market drive for air conditioners (Balaras et al., 2007).

The modern air conditioning was invented by Carrier in 1920. It was primarily aimed at controlling internal temperature (Arnold, 1999). It was first applied to Abraham and Straus city departmental store in Brooklyn, New York, USA. However, the first entirely air conditioned building was the Millam High-rise Building in 1928. It was also installed for the senate and house chamber of the US Capitol, Washington, DC, in 1928 which eventually became the largest cooling system serving offices with a capacity totaling, 4800tr (16800KW). Air conditioning was installed in the UK in 1928 in Lloyd's Bank. As of 1961, only five buildings were installed with air conditioning in London; but by the 1990s, about 80% of newly constructed office buildings were air conditioned. Currently, virtually all new office buildings have air conditioning installed (Roaf, 2015).

The use of air conditioning altered architecture and paved way for buildings to be designed without consideration for the natural environment. It displaced the need for natural ventilation and permitted building designers to ignore solar protection in hot weather (Givoni, 1998a). Despite increased use of air conditioning in the building industry, there was no significant issue with energy cost as electricity was cheap. A consequence of this is buildings became dependent on an uninterrupted supply of electricity since, without air-conditioning, they cannot operate (Byrd & Leardini, 2011).

3. ENERGY CRISES, CHANGING CLIMATE, AND SUSTAINABLE BUILDING STRATEGIES

Following the energy crises of the 1970s, governments crafted legislation that would decrease their reliance on diminishing energy sources (International Energy Agency (IEA) 2007). In addition, the spread of air conditioning has led to power cuts (Herring & Roy 2007) and increased electricity prices (Balaras et al., 2007). For example, in Australia in 2011, for every $1500 spent on air-conditioning, $7000 had to be spent on improving the electrical infrastructure (Fanning, 2012). Almost 20% of electricity consumption in U.S. homes goes to air conditioning, as much as the entire continent of Africa uses for all purposes (Cox, 2012). Electricity generated from fossil energies such as coal, oil, and gas, or from uranium, will inevitably decline in time. But before the disappearance of these resources, galloping inflation, due mainly to the scarcity of these fuels, will make their purchase at reasonable prices impossible and results in air conditioning systems becoming too expensive to operate.

The Intergovernmental Panel on Climate Change (IPCC) projected that by 2100, there would be an increase in the average earth surface temperature of between 1.4 and 5.8°C (Hallegatte, 2009). Furthermore, the reality of climate change and its associated negative impact on the built environment (Guan, 2009) has made the need for adaptive measures obvious. Climate change is expected to further exacerbate the risk of overheating in buildings (Crawley, 2008). As a response, sustainable building initiatives were developed to enhance the environmental quality of buildings by reducing their negative impacts on the natural environment (Buckman et al., 2014). The first building suitability rating tool, the Building Research Establishment Environmental Assessment Method BREEAM was developed in the United Kingdom in 1990 and the New Zealand's version, Green Star was launched in 2007 (Prins, 2015). Budin & Leardini (2015) in a study of the performance of Green Star rated office buildings in New Zealand, reported that naturally ventilated buildings in New Zealand overheat while over 90% of Green Star certified buildings in the Auckland region are air conditioned. This seems completely contradictory to the concept of sustainable building. A sustainable building should be "self- sufficient" and must aim at optimising the use of natural ventilation, wind and daylight and avoiding too much summer heat penetration into the building, to save energy consumption and enhance occupants' comfort (Givoni, 1998b).

4. RELATIONSHIP BETWEEN CURRENT PRACTICES, INSTITUTIONAL DRIVERS AND THE USE OF AIR CONDITIONING

Most of the award winning NZ non-residential buildings, even certified Green Star buildings, are fully glazed (Byrd, 2012). A typical example is the School of Business at the University of Auckland. The building is fully glazed without any means of natural ventilation. Although it is aesthetically pleasing, these kinds of buildings easily get overheated during the summer time (Byrd, 2010). It can be argued that prestige-architecture drives overheating in NZ. Modern architecture should be innovative in a way to mitigate the growing climate change challenge and not compound it.

The Green Star NZ (2016) recommends a 2.5 % daylight factor as the minimum daylight for an office building. It also specifies that 400 lux of light is adequate for visual work. This may have influenced over glazing of office buildings in NZ. Byrd & Hildon (1979) estimated that to achieve a 2.5 % daylight factor in a room of 7 metres in depth; it would require the window aperture to be 80% of the wall area. Considering glazing bars, sills and building structure, this would effectively require the entire external wall to be glazed. Also, the temperature range given by Green Star NZ for an air conditioned building is narrow while that of a naturally ventilated building is wide. Architects find it convenient to design with air conditioning to achieve this. No wonder air conditioning has become the choice of all architects designing green buildings in NZ (Budin & Leardini, 2015).

The NZ Property Council encourages air conditioning by awarding quality grading 'A', 'B', and 'C' to non-residential building based on the amount of air conditioning installed. The more air conditioning, the higher the grading with resulting higher rental value. This is consistent with Smith's (1999) claim that air conditioned office buildings are regarded as being of a high quality and attract a price premium. Why should architects bother designing for natural ventilation when the building will have a low rental value? "The New Zealand Institute of architects (NZIA) is also known to give awards, which should be based on performance, to buildings that self-evidently do not perform". They gave a 'sustainability' award in 2010 to a fully glazed office building without solar protection on the notion that the "significant environmental feature concerning its energy performance was that the building had been double-glazed; a mandatory requirement for a building that is fully glazed" (Byrd, 2016). If a building can be air conditioned, why bother with solar shading or good orientation? Is that a good thing for sustainable architecture?

Non-residential buildings have developed in many unsustainable directions over the years (Roaf et al., 2009) and while proffering expedient solutions, the unnecessary use of air conditioning has been a major contributor (Walker et al., 2014). While it is apparent that air conditioning offers a solution to overheating by controlling internal

temperature, the resulting health, environmental and economic challenges caused by this technology are worth rethinking. A working architectural cooling strategy to reduce the use of air conditioning in temperate climates where passive cooling should be feasible for long periods of mild outside temperature is needed. The next section reviews strategies that could achieve this aim.

5. RETROFITTING NON-RESIDENTIAL BUILDINGS FOR PASSIVE COOLING

75% of the floor area of the existing stock will soon require retrofit upgrading (Cory 2016). Since 2011, there are several on-going seismic retrofits of the non-residential building in NZ due to recent earthquake. Thompson (2015) suggests improving natural ventilation in buildings while seismic retrofit is on-going. Apart from energy saving potential, Camilleri et al. (2001) stated that there is an opportunity for reduction in greenhouse gas (GGH) emission.

The ways in which buildings are designed, constructed, upgraded, and occupied require a real change and these are known as 'adaptation strategies' (Barbhuiya et al., 2013). There are many ways by which the construction industry and researchers can make buildings more energy efficient and reduce their green-house gas emissions in relation to climate change. These are referred to as "mitigation strategies" (Camilleri et al., 2001). Adaptation and mitigation strategies are complementary measures that can assist to effectively reduce overheating. Barbhuiya et al., (2013) propose a passive design approach aiming at minimising carbon emissions and improving occupants' comfort. They suggested reducing internal heat gain, improving window performance, proper building orientation, and wall insulation.

In a NZ study, Camilleri et al., 2001 suggested adaptation and mitigation strategies but expressed the view that "placing restrictions on window areas or prescribing shading or window treatment, might well be rejected by the design and construction sectors as being too restrictive and prescriptive, as they currently enjoy an almost unlimited reign in the form and aesthetics of their buildings. At the extremes, anything from a windowless box, to a building with roof and walls made entirely of glass can (with sufficient care) be made to comply with the NZ Building Code" (Camilleri et al., 2001 pp 448). Similarly, a recent study conducted by Cory (2016) on the possibility of retrofitting the entire New Zealand non-residential building stock to be Net Zero Energy, recommended passive strategies, energy efficient and renewable strategies. His study demonstrates these retrofit solutions would be effective in reducing energy consumption and buildings would hardly require air conditioning under current climate conditions. The next section highlights the methodology employed in a recent case study.

6. RETROFITING A PREVIOUSLY AIR CONDITIONED BUILDING FOR PASSIVE COOLLING – A RECENT CASE STUDY

The main methods for this case study were on-site physical observation and interviews with occupants. The aim was to investigate the design process employed and also to verify how the building actually performs in practice through occupants' experience. Photography was used as a means for data collection (Groat & Wang, 2002). The data from the occupants' experience were then analysed using discourse analysis. Discourse analysis is the study of social life, understood through analysis of

language in its widest sense (including face-to-face talk, non-verbal interaction, images, symbols, and documents (Potter & Wetherell, 1987).

6.1 Building description

The 12-storey Aorangi House on 85 Molesworth Street, Wellington central business district was built in 1970 with a net lettable area of about 5,000 m2. The building gradually became largely unoccupied due to ventilation, cooling, and heating problems. In terms of aesthetic, the building was no longer appealing, the environmental control systems was substandard as per performance. Structurally, it was unsafe for business activities as it was a risk to life and required a total refurbishment.

6.2 Integrated design approach

A team of architects and engineers was engaged by the building owner to work in collaboration in an integrated design process with the goal of developing a seismic upgrade of the existing building structure; critically tackle the problem of thermal discomfort by developing an improved thermal control strategy; explore the possibility of retrofitting the entire building to be naturally ventilated. After a series of coordination meetings between the design team members and the building owner, a passive design and seismic design upgrade, and other active technologies were developed. The following section describes how the passive design features were integrated into the existing building.

Figure 1: The East view showing the openable windows and overhangs used as solar shading

6.3 Passive design features

To allow for improved thermal modulation, the ceiling was left open but painted and about 40% acoustic panels laid on it. The aim was to better admit daylight into the building. The core areas were the only place covered with a suspended acoustic

ceiling. The building is largely naturally ventilated and cooled. This is made possible by utilizing both low and high-level window openings. These provide proper ventilation during winter. There is also night ventilation which assists in cooling the building during summer. Air conditioning was installed to assist in cooling should the internal temperature exceed 25°C especially during the summertime, but is rarely used. Glazing covers 33% of the total building wall area. External shading louvers were designed specifically for the north, east and west facades (see Figure 1). The concrete structure provides thermal mass which compliments passive heating and mitigates overheating in summer. An external insulation (German-engineered sto-system) was applied to the external façade and covered with a 3-coat plaster.

6.4 Feedback from occupants

It was found that the building internal temperatures have been comfortable. On those few occasions when it exceeded 25°C during the 2015/ 2016 summer the air conditioning switched on automatically (Baird et al., 2011).

7. CONCLUSION AND RECOMMENDATION

Reducing the non-essential use of air conditioning by developing a passive cooling technology means non-residential buildings will become more energy efficient. This implies a significantly reduced demand for national electricity. This will also complement government's target to make the nation carbon neutral and meet the international target of a 20% carbon reduction by 2020. It is apparent that the NZ non-residential building stock is now at the risk of overheating. Further study that seeks to understand the current overheating risk and cooling requirement in a wide range of non-residential buildings in NZ's climatic condition and offer an effective solution to inform design decisions is essential. How these decisions should be implemented in government initiated policies and regulations to develop a more sustainable non-residential building stock and reduce the use of air conditioning in it, is highly recommended. As the challenges are not just peculiar to NZ, the potential application of the developed solutions should be investigated and evaluated for other temperate climates.

REFERENCES

[1] Baird, G., Marriage, G., Masters, B. & Dykes, C., 2015. Aorangi house, Wellington - performance in practice of a refurbished office building. The Institution of Professional Engineers New Zealand, IPENZ Transactions, 1-10.

[2] Balaras, C.A., Grossmanb, G., Henningc, H., Ferreirad, C. A., Podessere, E., Wangd, L. & Wiemken, E., 2007. Solar air conditioning in Europe-an overview. Renewable and Sustainable Energy Reviews, 11(2), 299–314.

[3] Barbhuiya, S., Barbhuiya, S. & Nikraz, H., 2013. Adaptation to the future climate: A low carbon building design challenge. Procedia Engineering, 51(NUiCONE 2012), 194–199.

[4] Buckman, A. H., Mayfield, M. & Beck, S., 2014. What is a Smart Building? Smart and Sustainable Built Environment, 3(2), 92–109.

[5] Budin, H. & Leardini, P.M., 2015. 'Actual performance of naturally ventilated and air-conditioned Green Star certified office buildings in New Zealand' paper presented at the 49th International Conference of the Architectural Science Association, Melborne,Australia 1-4 December.

[6] Byrd, H., 2016. Cooling NZ : institutional drivers behind the growth in air-conditioning. paper presented at the 46th International Conference of the Architectural Science Association, Queensland, November 2012.

[7] Byrd, H., 2012. Post-occupancy evaluation of green buildings: the measured impact of over-glazing. Architectural Science Review, 55(3), 206–212.

[8] Byrd, H. & Leardini, P., 2011. Green buildings: Issues for New Zealand. Procedia Engineering, 21(February), 481–488.

[9] Byrd, H. & Hildon, A.,1979. Daylighting: appraisal at the early design stages. Lighting Research and Technology Vol. 11.No.2.

[10] Camilleri, M., Jaques, R. & Isaacs, N., 2001. Impacts of climate change on building performance in New Zealand. Building Research & Information, 29(6), 440–450.

[11] Cory, S., 2016. An Exploration of the Feasibility of Converting the New Zealand Commercial Building Stock to be Net Zero Energy. Thesis (PhD). Victoria University of Wellington.

[12] Cox, S., (2013). "Losing Our Cool: Uncomfortable Truths About Our Air-Conditioned World (and Finding New Ways to Get Through the Summer)". The New Press. 1595586024, 9781595586025

[13] Crawley, D.B., 2008. Estimating the impacts of climate change and urbanization on building performance. Journal of Building Performance Simulation, 1(2), 91–115.

[14] Fanning, E., 2012. The Hidden Cost of Infinite Energy. The Global Mail Retrieved from http://www.theglobalmail.org/feature/the-hidden-cost-of-infinite-energy-part-1/19/

[15] Givoni, B., 1998a. Climate considerations in building and urban design. Building, 241–300.

[16] Givoni, B., 1998b. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. Energy and Buildings, 28(1), 25–32.
[17] Groat, L. & Wang D. 2002 Architectural Research Method. John Wiley and Sons: New York.
[18] Gokarakonda, S. & Kumar, A., 2016. Passive Architectural Design Index applied to vernacular and passive buildings. International Journal of Environmental Studies, 73(4), 563–572.
[19] Guan, L., 2009. Global Warming : Impact on Building Design and Performance. Encyclopedia of Energy Engineering and Technology, 774–779.
[20] Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Global Environmental Change, 19(2), 240–247.
[21] Herring, H. & Roy, R., 2007. Technological innovation, energy efficient design and the rebound effect. Technovation, 27(4), 194–203.
[22] IEA (International Energy Agency), 2007. Renewables for heating and cooling. Technology, 1–210.
[23] Lenoir, A., Baird, G. & Garde, F., 2012. Post-occupancy evaluation and experimental feedback of a net zero-energy building in a tropical climate. Architectural Science Review, 55(3), 156–168.
[24] Potter J. & Wetherell M. 1987. Discourse and Social Psychology: Beyond Attitudes and Behaviour. London: Sage
[25] Prins, H., 2015. Adapting to Constraints – a Study of Green Star New Zealand ' s Effects on Decision Making Using Classic Grounded Theory . Thesis (MSc). Victoria University of Wellington.
[26] Roaf, S., Crichton, D. & Nicol, F., 2009. Adapting Buildings and Cities for Climate Change - A 21st Century Survival Guide Second Edition.
[27] Roaf, S., Nicol, F. & Rijal, H., 2015. Designing for comfort at high temperatures. Architectural Science Review, 58(August), 35–38.
[28] Smith, K. S., 1999, 'Social aspects of climate change and office building' Centre for research evaluation and social assessment (CRESA). Wellington.
[29] Thompson, J., Donn, M. & Baird, G., 2016. 'Utilising Calibration to Quality Assure CFD Models for Predicting Thermal Comfort in Naturally Ventilated Buildings Designed for High Occupancies', paper presented at 9th Windsor Conference, Windsor, UK, 7-10 April.
[30] Walker, G., Shove, E. & Brown, S., 2014. How does air conditioning become "needed"? A case study of routes, rationales and dynamics. Energy Research and Social Science, 4(C), 1–9.
[31] Yua, B.F., Hua, Z.B., Liua, M., Yangb, H.L. Kongb, Q.X. & Liub, Y.H., 2009. Review of research on air-conditioning systems and indoor air quality control for human health. International Journal of Refrigeration, 32(1), 3–20.