Beyond recovery: measuring ventilation strategies and their impact on energy.

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Abstract. Working with a medium scale, research-focused architectural practice this paper measures the efficacy of balanced pressure heat recovery ventilation systems (BPHR systems) in the existing housing stock as a strategy to mitigate thermal heat loss when incorporating ventilation strategies in New Zealand. Current research indicates that BPHR systems boast an efficiency upwards of 80%. The aim of this research is to determine at what point do BPHR systems meet current claims of efficiency. An examination of the existing New Zealand housing stock identifies that 66% of all dwellings do not meet thermal performance requirements. This has been attributed, in part, to the governance of legislation of minimum performance, which did not exist until 1978. This paper, first, identifies building simulation measures and assumptions to accurately simulate BPHR systems in controlled conditions, which is quality assured against the expected performance of a conventional code minimum residential building and a range of models that represent a spectrum of building leakage for pre-legislation buildings. This paper then examines passive ventilation strategies in each model to identify the energy balance of using BPHR systems and the potential for heating energy loss when implementing simpler ventilation strategies. This study identifies that the efficiency of BPHR systems significantly differ in the pre-legislation building simulations. In these models, the building leakage alone renders heat recovery negligible in comparison to simple passive design and occupant-controlled measures that achieve a similar result for the indoor air quality.

1. Introduction

Recent news reports have shed light on growing evidence that indoor air quality in New Zealand homes, schools and offices is an overlooked but potentially huge health threat that has prompted calls for new standards [1]. This potential health threat becomes more evident considering most urban dwellers spend around 90% of their time indoors [2]. Taptiklis et al. [3] identify when air quality is poor, the exposure to pollutants is prolonged, which means the occupant’s health can be adversely affected.

“The United States Environmental Protection Agency (USEPA) has identified indoor air quality as one of the top five environmental hazards for the Western world. While the USEPA has a mandate to research and disseminate knowledge on indoor air quality, the same level of activity hasn’t happened in New Zealand. It can be argued that New Zealand is lagging behind Europe and the USA on its indoor air quality research, public information and uptake programmes and policy.” [3]

Taptiklis et al. also identify New Zealand’s statistics of some very significant acute and chronic health issues with poor indoor air quality being the central theme in these. These significant statistics of the acute chronic health issues are listed in Table 1.

Leading manufacturers of modern ventilation strategies like Balanced Pressure Heat Recovery (BPHR) systems often speak of poor IAQ and its link to the aforementioned health issues, boasting an ability to supply adequate fresh air alleviating poor IAQ whilst recovering upwards of 80% of the heat energy from the outgoing air [4]. This paper evaluates the efficacy of BPHR systems in the New Zealand housing stock.
Table 1. Health issues at the centre of New Zealand’s poor IAQ in houses

| Statistics behind some of the worst health issues associated with poor IAQ in New Zealand |
|----------------------------------------------------------------------------------------|
| 1. The second highest rate of asthma – asthma affects one in four children and costs $4 million. |
| 2. The highest rate of hospitalisations from skin infections – this rate is double that of either Australia or USA and has doubled in the last decade. |
| 3. One of the worst rates of rheumatic fever, which can be the result of streptococcus throat infections; |
| 4. The highest rate of excess winter mortality in the Organisation for Economic Co-operation and Development (OECD). |
| 5. A very high rate of chronic obstructive pulmonary disease (COPD) with an onset at an average age of 55 years old for Māori and 65 years old for Pākehā. |
| 6. A high rate of fuel poverty, which is increasing as fuel prices are rising faster than incomes. |

2. Modern and conventional ventilation strategies.

2.1. Conventional passive ventilation strategies

The ventilation rate for housing is often described as the number of air changes achieved in an hour (ACH), in New Zealand, as elsewhere, an optimal healthy ventilation rate is 0.5 ACH [5]. Conventional passive ventilation strategies are the simplest way to bring fresh air into any given space and this is achieved by passive occupant-controlled ventilation measures, i.e. opening and closing windows. The biggest problem with passive ventilation measures is that this relies on occupants to understand and follow a ventilation schedule that appropriately ventilates space, not the aforementioned minimum fresh air but also to expel indoor pollutants and stale air. The user must have knowledge about ventilating space i.e. how long to ventilate and when to ventilate. Relying on the household to follow a prescribed passive ventilation strategy cannot guarantee proper ventilation because of human error and even human behaviour. Conventional active ventilation strategies present an opportunity to overcome these issues.

2.2. Conventional active ventilation and modern strategies

An example of a conventional active ventilation strategy that can found in most New Zealand homes would be a common bathroom fan. There are three fundamental problems with ventilation strategies like bathroom fan extracts. First, a bathroom fan, simply extracts stale and humid air. With very little active control on air intake. Second, even this active ventilation strategy is considered an occupant-controlled system that, like passive ventilation strategies, requires occupants to know when to use it and also to open and close windows. Even if the household is upskilled to understand how to actively and passively ventilate space, the underlying issue of heat loss is ever-present. Modern active ventilation technologies such as Balance Pressure Heat Recovery (BPHR) systems have been proposed as the only alternative that addresses all of the aforementioned issues [6]. The validity of this claim comes into question when considering the various cases this would need to accommodate, especially considering that codes for building performance is relatively young in New Zealand and the world over.

3. Origins of building performance legislation in New Zealand and the global implications.

In 1978 a commencement order was issued bringing into effect the 1977 Building Performance Guarantee Corporation Act [6]. It took another 8 years to establish a coherent national building control regime, this led to the formation of the Building Industry Commission in 1986, which was set up to determine appropriate legal and regulatory provisions for building construction and maintenance across New Zealand [7]. As a result of a report produced by this commission, the 1991 Building Act was proposed and passed, which bought into effect the New Zealand Building Code in 1992. The New Zealand Building Code was one of the first performance-based building codes in the world. Unusually, it includes explicit performance criteria that all building elements must comply with [7].

3.1. The New Zealand housing stock today

The 2004 building code mandates that a building in New Zealand is intended to have a life of no less than 50 years [8]. There is some flexibility for this as clause 113 of the building Act [8] allows that consent can be sought to establish a specified intended life. As the building performance regulations in
New Zealand came into existence just over 40 years ago, some of the housing constructed immediately post-legislation is nearing its intended life. In fact, most of the housing stock in use today was actually built pre-1978 and is in fact between 90 and a 140 years old [9]. The fundamental problem is it is very likely that most of these dwellings do not meet current performance requirements.

3.2. Implications of the first performance-based building code in the world

There are some potentially significant global implications of this New Zealand situation. Although New Zealand’s Building Code was loosely derived from the Norwegian model [7] and was New Zealand’s first countrywide Building Code, New Zealand was one of the first countries in the world to legislate building performance regulations [7]. The potential disparity between legislated performance and actual performance may affect the majority of building stock in many other countries as well, especially considering New Zealand was an early adopter of regulating building performance. Any technologies that claim high efficiency heat recovery is likely to be as questionable for any buildings that are poorly insulated and do not meet current performance regulations, both in New Zealand and abroad.

4. Modelling a BPHR system in a New Zealand current housing stock

To consider the wide spectrum of performance in the current housing stock in New Zealand, understanding the evolution of the building code is a key aspect of the simulation strategy used in this study. In 2007 a Building Research Association of New Zealand (BRANZ) paper by Nigel Isaacs [10], examined the evolution of the minimum performance requirements of the components in the New Zealand house. Figure 1 shows the table Isaacs [10] created to demonstrate the changing requirements over approximately 60 years.

| YEAR | SOURCE/DATE | ROOF R-VALUE | WALL R-VALUE | FLOOR R-VALUE | GLAZING R-VALUE |
|------|-------------|--------------|--------------|--------------|----------------|
| 1950 |Watkins and Bercusman | 0.5 | 0.7 | 0.7 | -- |
| 1964 |Buildings | 0.8 | 0.7 | 0.7 | -- |
| 1977 |Warren County | 1.2 | 0.7 | 0.9 | -- |
| 1972 |Christchurch City | 1.0 | 1.0 | 1.1 | -- |
| 1972 |BRANZ | 1.6 | 1.1 | 0.9 | -- |
| 1975 |Government loan scheme minimum | 1.0 | 1.6 | -- | -- |
| 1975 |NZ Housing Corporation | 1.6 | 0.9 | 0.8 | -- |
| 1975 |NZS 4228:1977 | 2.0 | 2.0 | 0.9 | -- |
| 1990 | NZS 4228 (draft) | 2.0 | 2.0 | 1.0 | -- |
| 1990 | Ministry of Energy (recommended) | 3.2 | 2.0 | 1.5 | -- |
| 1990 | NZS 4228:1990 | 3.0 | 1.9 | 1.0 | -- |
| 1990 | NZS 4228:1990 | 1.0 | 1.5 | 0.9 | -- |
| 1990 | NZS 4228:1990 | 1.9 | 1.5 | 1.3 | -- |
| 2000 | NZS 4228:1990 | 1.5 | 1.5 | 1.3 | -- |
| 2003 | NZS 4228:2003 (draft) | 3.2 | 2.6 | 3.1 | 0.63 |
| 2004 | NZS 4228:2004 | 1.0 | 1.5 | 1.3 | 0.15 |
| 2007 | NZS 4228:2007 | 2.0 | 1.9 | 1.3 | 0.28 |

Figure 1. Evolution of the component R-value requirements [10]

The figures in bold are demonstrate the legislated mandatory requirements as these were implement by the New Zealand building code from 1978 onwards. To assess the efficacy of a BPHR system for the current New Zealand housing stock, which would be comprised on buildings of various age, a single town-house unit is simulated for three different time periods. These were:

- Pre-legislation period of 1964 – to account for the minimum building life of 50 years;
- First legislation period of performance in 1978 – first performance regulations;
- Current legislated performance from 2007 – to account for current and new build requirements.
- Passive house targets – to represent optimum building envelope performance.

The simulation strategy adopted for this analysis is discussed in greater detail in the following subsections.
4.1. Modeling geometry location and orientation of a single unit. 
The geometry of the blocks of the single unit examined in this study was split into ‘zones’ so different 
equipment loads and schedules of use could be applied to each zone. Zones were typically defined where 
walls separated walls. The roof cavity above the upper storey ceilings is modelled with a flat roof at 
average height of the original roof so that it still has the same volume. Shading elements were modelled 
and are shown in purple in Figure 2. The units are only modelled in one climate, Auckland, New 
Zealand. A TMY data file provided by NIWA New Zealand is used for the energy simulations [11]. All 
blocks of units are orientated with the longer building length oriented north towards the sun.

![Figure 2. End Unit of the case study town house simulated in EnergyPlus.](image)

4.2. Modeling materials, internal loads, schedules and heating systems and the BPHR systems. 
The construction of the building is exported from the BIM model as a schedule of quantities and added 
to the energy model inputs. The material inputs were taken from New Zealand Standard 4214:2006 
Methods of Determining the Total Thermal Resistance of Parts of Buildings. This may mean that the 
material data is not fully representative of actual as-built data but is a close approximation. The Internal 
loads and occupancy, electrical and lighting schedules are taken from the New Zealand Standard for 
thermal insulation – Housing and Small Buildings (NZS 4218:2009). Using this standard ensures 
consistency of energy models with other existing studies that have used this standard as a reference. 
These schedules use assumptions for a ‘typical’ family. Single speed direct exchange electric heat pumps 
are assigned to the conditioned zones bed, living and dining. These heat pumps are set to auto size and 
provide both heating and cooling based on the set points 18 to 25 degrees Celsius. The BPHR system is 
input with 80% efficiency [4]. The supply air fan speed is set to auto size for each conditioned zone 
running 24 hours a day for 7 days, supplying as much air as is needed to achieve a total of 0.5 air changes 
per hour (ACH).

5. Results: the wide variety of performance and heat recovery 
The simulation results plotted in Figure 3 identify the total kilowatt-hours of heat loss per annum when 
the building was modelled based on minimum construction standards for 1964, 1978 and 2007.

![Figure 3. Building heat loss with BPHR systems.](image)

Each simulation modelled a BPHR system that provides 0.5 ACH [10], with a heat recovery rate of 
80%. In order to understand the significance of these results, each simulation was conducted again with 
passive ventilation (opening windows). To match the BPHR models (and the minimum fresh air
requirement) these ‘natural ventilation only’ simulations were set to open windows to achieve 0.5 ACH as well. To be comparable, the results of both the BPHR and natural ventilation strategies are plotted in Figure 4. The first notable point in these results is that due to the significant building leakage in the 1964 construction model the window never opened as the minimum ACH required for fresh air was achieved due to the high infiltration of the building construction.

This inherently makes any BPHR system redundant in a building of this construction standard as the added heat losses through the BPHR system, even with 80% heat recovery, only adds fresh air into a building which already meets its fresh air requirements. The simulation result for the 1978 building, when a performance standard was first legislated in New Zealand, indicates that building leakage decreases to a point that some natural ventilation is needed to achieve 0.5 ACH. However, this is a negligible amount. In this 1978 example Figure 4 demonstrates the added heat loss of the BPHR system, even with heat recovery, is much greater than the heat losses of simply ventilating the internal environment naturally. Heat losses in this case would essentially be beyond recovery with a BPHR system. Conversely, the 2007, or current building code minimum, begins to indicate a more optimistic outlook. The current building code mandates a much more air tight building envelope than the 1964 and 1978 building examples. Based on the current code minimum a BPHR system is able to effectively provide 0.5 ACH with an annual heat loss of 239 kilowatt-hours in comparison to the 657 kilowatt-hours that would be lost through passive measure like opening windows.

A similar study by Dodoo et al. [12] examined the impact of ventilation heat recovery on the operation and primary energy use in residential buildings. This study identified varying performance and energy reductions based on the airtightness of the apartment buildings examined. These findings were analogous with three preceding studies conducted over the past four decades. The earliest study of this kind was by Hekmat et al. [13]. This study compared different residential ventilation strategies including heat recovery systems in different US climatic conditions. The following study by Jokisalo et al. [14] similarly simulated the performance of VHR systems in a typical Finnish apartment building using centralized or decentralized ventilation units. Finally a 2007 study by Sherman and Walker [15] analyzed the energy impact of different ventilation norms in typical US buildings. They found that energy performance of ventilation units is not significantly improved when VHR systems were installed. However, the fundamental limitation in all of these studies is that they all examined residential apartment buildings instead of stand-alone dwellings. Although airtightness of building envelopes are discussed these never speak to performance regulation, which was the unique focus of this study.

6. Conclusions: beyond recovery

The aim of this research was to determine at what point BPHR systems are able to meet current claims of efficiency in New Zealand residential buildings. The majority of these dwellings are unlikely to meet current legislated performance requirements. This is because most were constructed prior to the 1978 legislation. A townhouse unit representative of medium density New Zealand housing was modelled with 1968, 1978 and current construction methods with both BPHR systems and natural ventilation only. These simulations demonstrated that the efficiency of BPHR systems significantly differ in the pre-
legislation building simulations representing 66% of the current housing stock. In these models, the building leakage alone rendered heat recovery negligible in comparison to simple passive design measures. However, when implemented in buildings that meet the current building code, BPHR systems are a suitable ventilation strategy that can mitigate heat loss through recovery. An area of further study would be to examine housing stocks in countries that were late adopters of performance regulation. Such an investigation may bring to light the potential global implications posited earlier in this paper.

References
[1] NZ herald article (2018), NZ’s hidden health threat: poor indoor air quality. Accessed on the 11th of April 2019, https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12146670

[2] Kostinen et al. (2008). The INDEX project: executive summary of a European Union project on indoor air pollutants. Allergy, 63(7), 810–9 Johnstone, I. M. (1994).The mortality of New Zealand housing stock. Architectural Science Review, 7, 181-188

[3] Taptiklis et al. (2017). Indoor Air Quality in New Zealand Homes and Schools. Accessed on 11th of April 2019, http://www.level.org.nz/energy/active-ventilation/

[4] Mitsubishi-electric ventilation specs, (2019). Whole Home Heat Recovery Ventilation. Accessed on 11th of April 2019, https://www.mitsubishielectric.co.nz/materials/ventilation/brochures/@LossnayVL220.pdf

[5] BRANZ (2019). Ventilation what and how it makes a more energy efficient home. Accessed on 11th of April 2019, http://www.level.org.nz/energy/active-ventilation/

[6] Building Performance Guarantee Corporation Commencement Order 1978, from the New Zealand Legal Information Institute database. Accessed on the 8th of April 2019, http://www.nzlii.org/nz/legis/num_reg/bpgcco1978555/

[7] Build 142, (2014). A Code to build by in Uniquely NZ. Accessed on 8th of April 2019 https://www.buildmagazine.org.nz/assets/Uploads/Build-142-49-Feature-Uniquely-NZ-A-Code-To-Build-By.pdf

[8] Building Act 2004, (2018). The 2018 reprint of the 2004 building act. Accessed on 8th of April 2019, https://www.building.govt.nz/building-code-compliance/how-the-building-code-works/building-act-2004/

[9] Johnstone, I. M. (1994). The mortality of New Zealand housing stock. Architectural Science Review, 7, 181-188.

[10] Isaacs. N, (2007). Thermal Insulation. Build 102. Accessed on 11th of April 2019, http://www.buildmagazine.org.nz/articles/show/thermal-insulation

[11] Liley, J. B., Hisako Shiona, James Sturman, David S Wratt (2008). Typical Meteorological Years for the New Zealand Home Energy Rating Scheme. Prepared for the Energy Efficiency and Conservation Authority. NIWA Client Report: LAU2008-01-JBL. Omakau, New Zealand: NIWA. http://www.level.org.nz/energy/active-ventilation/

[12] Dodoo, A., Gustavsson, L., & Sathre, R. (2011). Primary energy implications of ventilation heat recovery in residential buildings. Energy and Buildings, 43, 7, 1566-1572. https://www.sciencedirect.com/science/article/pii/S0378778811000636

[13] D. Hekmat, H.E. Feustel, M.P. Modera. (1986). Impacts of ventilation strategies on energy consumption and indoor air quality in single-family residences. Energy and Buildings, 9 (3), pp. 239-251. https://www.sciencedirect.com/science/article/pii/0378778886900241

[14] J. Jokisoolo, J. Kurnitska, M. Vuolle, A. Torkki. (2003). Performance of balanced ventilation with heat recovery in residential buildings in a cold climate. International Journal of Ventilation, 2 (3), pp. 223-235. https://www.tandfonline.com/doi/abs/10.1080/14733315.2003.11683667

[15] M.H. Sherman, I.S. Walker. (2007). Energy Impact of Residential Ventilation Norms in the United States. LBNL Paper LBNL-62341. Lawrence Berkeley National Laboratory, Berkeley