Indoor Air Quality and Health in New Zealand's traditional Homes

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ABSTRACT: Sustainable design consists of principles and practices of architecture that protect environmental quality and human health, reducing environmental impacts resulting from construction activities. Considering that in New Zealand approximately 15% of the adult population and 20% of children under the age of 15 are affected by asthma, the ongoing attempt to introduce sustainable principles in New Zealand's architecture appears questionable, as Indoor Air Quality (IAQ) and the related aspect of health have been poorly considered so far. A major step towards sustainability will be the retrofitting of the existing building stock, in order to meet new energy efficiency standards while providing a healthier indoor environment by reducing the risk of allergies and asthma.

Allergies in New Zealand have become a serious health problem with considerable social and economic impact. Especially the indoor environment of residential buildings plays a major role in the increasing numbers of allergies and airways infections. Many new and renovated homes have been designed and built with low quality insulation and heating systems, and a lack of adequate ventilation. Furthermore, the energy performance upgrade of the existing building stock, ongoing since 1978, has changed the buildings' physical behaviour, generating new and unexpected problems. Badly constructed houses are difficult and expensive to heat: the consequent inadequate thermal comfort in homes, associated with poor ventilation, leads to growth of moulds, with health consequences.

This paper examines the indoor air pollution in relation to construction details, insulation level, ventilation and humidity. It also addresses moisture damages caused by damp housing. The specific influence of poor IAQ on health in general and possible risks of developing allergies in particular is identified. The lack of information about IAQ in New Zealand's buildings is addressed by discussing preventative actions, advice how problems can be proactively avoided and practical recommendation for the refurbishment of specific building typologies. As in New Zealand practice there are currently no methods available to simulate the process of moisture transport within building components in relation to the indoor climate, a calculative assessment of thermal and hygric processes in the external wall assemble is introduced by using the simplified Glaser Method and the computer programme WUFI (Wärme und Feuchte instationär). That allows producing realistic calculations of the transient heat and moisture transport in building components under natural conditions.

Conference theme: Sustainability issues
Keywords: indoor air quality; health; damp housing; moisture control.

INTRODUCTION

Generally, sustainable design refers to principles and architecture practices that reduce environmental impacts of buildings, to protect environmental quality and human health. The recent effort to introduce sustainable principles and practices in New Zealand's architecture insufficiently addressed the indoor air quality (IAQ) and the associated health issues. Considering that approximately 15% of the adult population and 20% of children under the age of 15 are affected by asthma in New Zealand, it is necessary to review common practice and to gather more information on health effects in New Zealand homes (National Institute of Public Health 1999).

It is proven that badly constructed houses are difficult and expensive to heat and that inadequate thermal comfort in a home can lead to mould growths, with negative health effects for the occupants (Boardman 1991). The relation between inadequate heating, dampness problems, cold and mouldy houses and health problems have been highlighted in several national and international research studies (Bornehag 2004). The scope of this paper is to explore the effects of environmental exposures in terms of temperature, ventilation and dampness on health problems, such as allergies, airways infection and asthma. Considered recent international and national studies on this topic, proving that these health problems are becoming increasingly significant in New Zealand's context, this paper also provides practical recommendations for the refurbishment of particular building typologies that were built between the 1950s and the 1980s, in order to provide comfortable and healthy living conditions.

1. HEALTH EFFECTS RELATED TO INDOOR AIR QUALITY

1.1. A large burden to New Zealand's society

Looking back 30 years ago, allergies were a relatively uncommon disease. Today, allergies affect a large part of the population in industrialised countries and represent a large burden to society worldwide. The question is "what has changed in the environment that is driving this increase of allergies, as the time period has been too short for important genetic changes". The International Study of Asthma and Allergies in Childhood (ISAAC) (Asher 1998) and the European Community Respiratory Health Survey (ECHRS) (Burney, 1996) have mapped variations in the prevalence of asthma symptoms worldwide and indicated causative environmental factors. Their results prove that the increase of allergies has to be associated with changes in our environment, with Western EU countries having a prevalence that is up to ten times higher than the prevalence in Eastern EU countries (Bornehag 2004).

New Zealand has the second highest rate of asthma in the world. Data of hospital admissions in New Zealand show that asthma is the most common cause of admission for children to a hospital and its frequency has doubled during the last 30 years. Furthermore, Maori and Pacific people are disproportionately affected by asthma as well as people from lower socio-economic groups (NZBCSD B-2008). As international studies indicate a strong association between cold damp housing and allergies (Bornehag, 2004), researchers of the University of Otago investigated houses that are occupied by low income earners and demonstrated that New Zealand homes with proper insulation provide significant health gains to the occupants (Howden-Chapman 2007).

This is significant considering that 1.04 million homes in New Zealand, which equals 65% of the current housing stock, were built before insulation was required by the New Zealand Building Code (NZBC). Many of these buildings are now upgraded but the majority still does not provide a sufficient insulation level to meet the current NZBC. Furthermore, many homes which were built after insulation was required do not meet current insulation requirements either. Indeed, research has proven that about 375,000 New Zealand homes have inadequate ceiling insulation and over one million provide an inadequate underfloor insulation (NZBCSD A-2008).

According to the New Zealand Business Council for Sustainable Development (NZBCSD), a quarter of a million homes in New Zealand are currently too cold and damp, as well as poorly built which means that they can cause serious health problems. However, dampness is not just a problem affecting older homes. Also many new and renovated homes have been designed and built with low level of insulation and heating system, as well as a lack of adequate ventilation or double glazing. New Zealand is suffering from this massive housing problem that has to be faced and solved.

The World Health Organization (WHO) recommends that an indoor temperature should not be lower than 18°C for living areas and 16°C for bedrooms, as there is a dramatic improvement in health above these levels (NZBCSD A-2008). Research studies have also shown that the mortality rate in New Zealand is lower on days in which the average ambient temperature ranges between 15 to 25°C, compared to on days when the average ambient temperature becomes hotter or colder than this. Especially for very old and very young people the indoor air temperature should be about 20°C. The WHO also has proven that an indoor air temperature that is below 15°C can be a risk factor in increasing asthma severity and chronic obstructive pulmonary disease (COPD) (Howden-Chapman 2004). However, in winter time many New Zealand households are frequently an average 4°C below the recommended indoor air temperature of 18°C (Table 1). Furthermore, nearly 30% of them do not even meet the recommended minimum indoor air temperature of 18°C (NZBCSD B-2008). This problem will be intensified in New Zealand households by 2030 because 24% of the New Zealand population will be over the age of 60 by then thus requiring warmer homes.

Table 1: Mean temperatures: living room, bedroom and ambient

Type of Room	Mean Indoor Air Temperature (°C)				
	Morning	Day	Evening	Night	Average over entire day *
	7am - 9am	9am - 5 pm	5pm - 11pm	12am - 7am	
Living room	13.5	15.8	17.8	14.8	15.8
Bedroom	12.6	14.2	15.0	13.6	14.1
Ambient	7.8	12.0	9.4	7.6	
* The hour from 11pm to 12pm is not included due to software limitations					

Source: (Pollard 2006)

1.2. Damp Housing, Mould and House Dust Mites

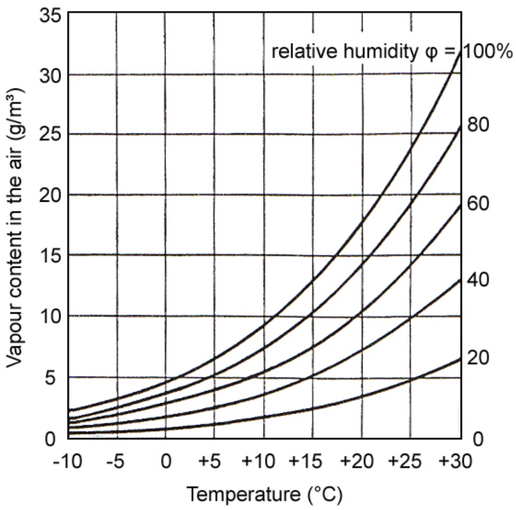
While building materials are typical sources of contaminants in homes, the major risk in New Zealand is associated with mould presence in the indoor environment, as mould is a key trigger for allergic reactions. At least 60 varieties of mould types are known which can cause serious health problems. The most prevalent type which is also the most aggressive disease trigger is Stachybotrys, commonly called "black mould". Compared to other mould types which prefer warmer temperatures, black mould grows well also at lower temperatures (between 2°C and 40°C) and is more common in colder and damper houses. As it needs the presence of liquid water to grow, it is found in abundance in buildings with leaks and condensation problems. New Zealand's un-insulated houses, with average relative humidity (RH) between 65% and 85% and possible condensation issues due to water vapour transfer from inside to outside, provide ideal conditions for black mould as it thrives especially when RH is above 70% (Zhang 2005).

Also related to RH is another very important allergen source and significant asthma trigger in indoor environments: house dust mites (HDM). HDM are microscopic, spiderlike insects of the arachnid family which feed on dead skin that sloughs from the human body. A grown up dust mite is approximately about 200 µm long and usually invisible to the bare human eye. Dust mites (Dermatophagoides Farinae) require a humid indoor environment with humidity levels ranging between 55% and 75% RH as well as an ideal indoor temperature ranging between 20° to 25°C because they have to absorb the water they require from the air in order to survive and, therefore, they need a humid indoor environment (National Institute of Public Health, 1999, p.20). The growth of HDM is, therefore, related to the season and to the location of the room within the building, as humidity levels vary depending on these factors. A limitation of dust mite infestation can be achieved through proper ventilation, opening windows and airing the bedding. HDM are perhaps the most common cause of perennial allergic rhinitis and occur mostly in buildings with moisture problems (National Institute of Public Health 1999). Nevertheless, research in this area can be difficult because the problem is to distinguish those effects that are caused by mould and HDM and those that are not. Another problem is that high levels of humidity in the indoor air leads to growth of mould but also increases the stickiness of the surfaces and reduces the dust levels in the indoor air. Therefore, research outcomes are often inconclusive (Rose 2005) and any specific threshold limit values for moulds to prevent hypersensitivity, irritant or toxic responses have not been established.

2. UNDERSTANDING THE PROBLEM OF DAMP HOUSING

2.1. The Problem of Damp Housing

New Zealand is known for its high outdoor humidity, with average relative outdoor humidity ranging between 80% in summer and 90% in winter time (Overview of New Zealand Climate 2008). The country is also known for its damp housing problems. Some authors mention that this fact probably reflects the problem of high indoor humidity levels, a relatively poor housing stock and a high prevalence of inadequate insulation, as well as inadequate heating systems. The outcome of a national telephone survey underlines such arguments as it indicates that visible mould in rooms was reported in 35% of all houses in New Zealand, especially in bathrooms (48%) and master bedrooms (47%) (Department of Public Health 2007). Moisture in buildings is definitely a risk factor which can cause problems in building structures and envelopes, but most importantly can cause health problems. In order to provide an acceptable IAQ, it is recommended maintaining a relative humidity (RH), between 40 to 60%, as a level below 40% or above 60% can offer ideal conditions for breeding micro-organisms causing serious health problems (Richarz 2007).



Source: (Frössel 2007)

Figure 1: The relationship between temperatures, vapour content and relative humidity.

If moisture can affect a building structure, it is also possible that a structure itself is the cause of a damp housing problem. As shown in figure 1, air temperatures, air vapour content and RH are interdependent, the RH being defined as the ratio of the partial pressure of water vapour in a parcel of air to the saturated vapour pressure of water vapour at a prescribed temperature. Therefore, in terms of moisture not only the source control is important, but also the insulating quality of the building envelope, consisting of roof, external walls and slab, plays a major rule, affecting indoor air temperature and consequently the RH (Reuters 2004). The fact is that a high indoor temperature reduces the moisture content of building materials and, therefore, can lower the risk of mould growth. Commonly, a RH measured at the surface of the materials, varying between 70 to 80% is an unacceptable level which is considered as critical as it supports an active mould growth and other decay microorganisms. With RH constantly at such critical level along with suitable nutrient medium, moisture, oxygen and temperature will provide the best conditions for spores to develop initial mould growth (Burkinshaw 2003).

2.2. Calculation Methods of Thermal and Hygric Processes

Currently in New Zealand practice no calculation methods are used to simulate the process of moisture transport within building components in relation to the indoor climate conditions of a particular building. However overseas similar simulation tools are valid assets for common practice and could be easily adapted to New Zealand conditions. In particular two methods can be used to investigate thermal and hygric behaviour of specific building components: The Glaser-method as detailed in German standard DIN 4108 (German: Glaser-Verfahren) and the menu-driven computer program WUFI (Acronym of the German name 'Wärme und Feuchte instationär', meaning 'Transient Heat and Moisture').

Generally, the Glaser-method can be used to calculate temperature and moisture conditions within an existing wall assembly in order to verify if such detail can be considered as "safe". In Germany, the Glaser-method is usually used by civil engineers and architects to assess the moisture performance of building envelopes in order to obtain a building consent (Vydra 2007). In fact, the Glaser-method allows the assessment of the amount of interstitial condensation that is formed during winter and the amount of evaporable water in summer time. If the amount of condensation does not exceed specified limits calculated with the Glaser-method, and is also lower than the evaporable amount of water, the building assembly can be considered safe in terms of interstitial condensation problems. The method though does not produce a realistic simulation of heat and moisture conditions in a specific building component in relation to the weather conditions prevailing at its individual location. Furthermore, it investigates only the condensation by vapour transport in winter, but there are also other hygric processes to be taken into account, such as indoor air convection, precipitation and rising damp as well as the capillary moisture transport in a building component and its sorption capacity.

A simulation of realistic heat and moisture conditions involving also these hygric processes can be produced with WUFI Pro. This computer program has been developed to allow architects and engineers producing realistic and detailed simulations that present the behaviour of building components under natural conditions (Borsch-Laaks 2003). WUFI is based on the newest findings in terms of vapour diffusion and liquid transport in building materials and can be used to address concerns in terms of damp housing. However, the Glaser-method can be utilized as a simplified calculation method to determine the risk of interstitial condensation in existing wall components (Künzel 2000). Glaser-method and WUFI can assist New Zealand practitioners to provide a general assessment of the hygrothermal suitability of particular building components. Used as a means of verification, they highlighted the potential inadequacy and the risk associated with certain practices of renovation of the existing, while being an essential support to the definition of proper intervention techniques.

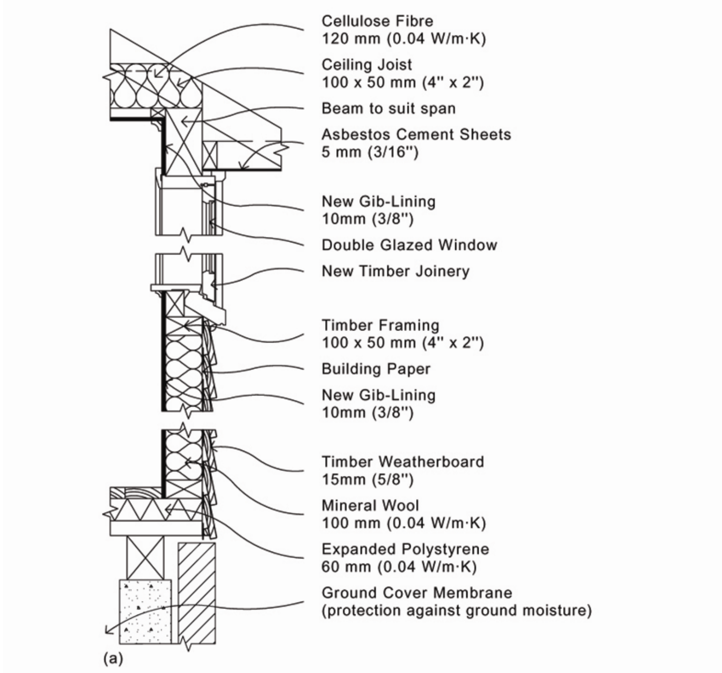
3. CASE-STUDY: LABOUR STATE HOUSE UPGRADE PACKAGE

In order to verify potential risks associated with common renovation practice in New Zealand, calculation and simulation methods were used to highlight possible issues of interstitial condensation and mould growth. Reference R-values were taken from the national standard on building energy efficiency. Since October 2008, the New Zealand Standard NZS 4218:2004 has required all new homes to meet new thermal insulation requirements formulated for different climate zones. Although not applicable to the existing building stock nor to retrofitting interventions, the new R-values of the updated standard can be used as a minimum target to achieve acceptable thermal comfort. Therefore, different house typologies were investigated to understand the main retrofit barriers, challenges and opportunities, starting from the analysis of common renovation practice in New Zealand, which, unfortunately, seems to suffer from a lack of information and often relies on common sense more than proven experience.

However, for the purpose of this paper, only procedures and results of the analysis regarding a Labour State House upgrade package in Auckland are discussed. In order to verify the efficacy of this retrofit solution, simulations were run using the Glaser method and the WUFI simulation to estimate the hygrothermal behaviour of external building components. Such calculations can show if the moisture content within a particular wall component increases permanently and allow to predict moisture damages (that will lead to hygienic problems and health risks due to mould growth), and loss in insulation performances. In the case study, the WUFI simulation showed that interstitial condensation occurs and the moisture content of the insulation layer remains always very high (relative humidity over 80%). It is also to be considered that this condition, besides the effects on health and the insulation, could lead to initial mould growth within the timber construction, with consequent structural damage.

3.1. The upgrade package

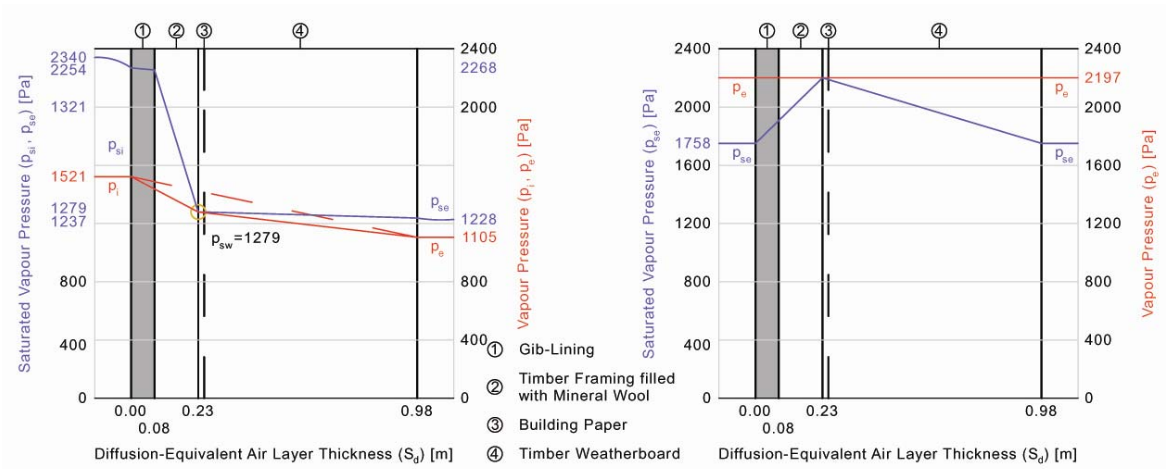
Generally, different insulation materials can be used to improve the thermal resistance of the existing building envelope of a labour state house (Figure 2). As the roof construction is usually accessible and ventilated, it is possible to retrofit the roof space with 120 mm of a good insulation layer (λ = 0.04 W/mK) to achieve an acceptable R-value of minimum 2.9 m^2K/W. In terms of the floor construction, the most common solution is installing 60 mm of expanded polystyrene (EPS) underneath the accessible and ventilated floor construction, which provide a minimum R-value of 1.3 m^2K/W. Regarding the external wall construction, it is common practice to fill in the existing frame cavities with thermal insulation material, generally glass fibre batts (λ = 0.04 W/mK), improving the wall thermal resistance to an acceptable R-value of minimum 1.9 m^2K/W. The absence of a ventilated gap between the weatherboards and the timber frame can improve the insulation ability of the external wall but also increase the risk of moisture build up. In order to prove that such retrofit solution is not acceptable and to provide a result that allows comparing both the Glaser-method and the WUFI software, this paper explores the hygro-thermal behaviour of such retrofitted wall using both tools.



Source: (de Groot 2009)

Figure 2: Retrofit Solution of a Labour State House.

The Glaser calculation is used to assess the discussed upgrade solution but with an improved indoor air temperature of 20°C which has a direct influence on the internal vapour pressure. Regarding the retrofitted wall, the Glaser method proves that the retrofit solution changes the physical behaviour of the construction. The graphs below show that interstitial condensation occurs as the vapour pressure (p) is higher than the saturated vapour pressure (p_s) in the building component for a period of time (Figure 3). In order to verify results obtained with the Glaser method, the same retrofitting solution was simulated using WUFI. Suitable for different climate conditions the WUFI software can be used to prove whether the Glaser-method can be recommended as a general tool to determine the risk of interstitial condensation in New Zealand homes.

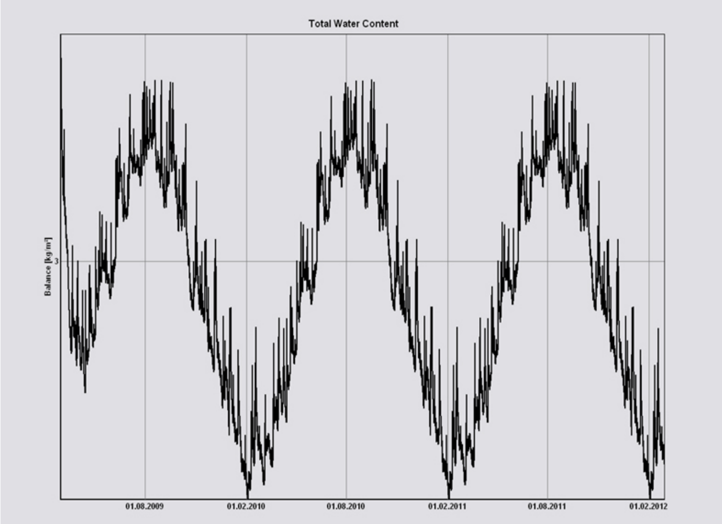


Source: (de Groot 2009)

Figure 3: (Left) Saturated vapour pressure is reached / (Right) Interstitial condensation is present.

The outcome of the WUFI Simulation shows that the total water content within the wall component is approximately about 2.2 kg/m² during summer and 3.7 kg/m² during winter time due to seasonal climatic changes and remains constant over the years. This proves that the component is able to reach its dynamic steady state (Figure 4). Compared with the outcome of the Glaser calculation it also proves that the total content of water within the insulation layer reaches a higher level which may also be caused by other hygrothermal processes, such as capillary moisture transport in the building material or its sorption capacity. Furthermore, the amount of 3.7 kg/m² of water is above the specified limit of 3.6 kg/m² (3,585.60 g/m²) stated by the Glaser calculation, indicating that moisture problems within the wall component will occur. However, the numerical value of the total content of water within the wall assemble is irrelevant because it does not indicate the water content within each layer material. The numerical value defines only the sum of water in all layers which depends on the thickness of the construction and the applied building materials.

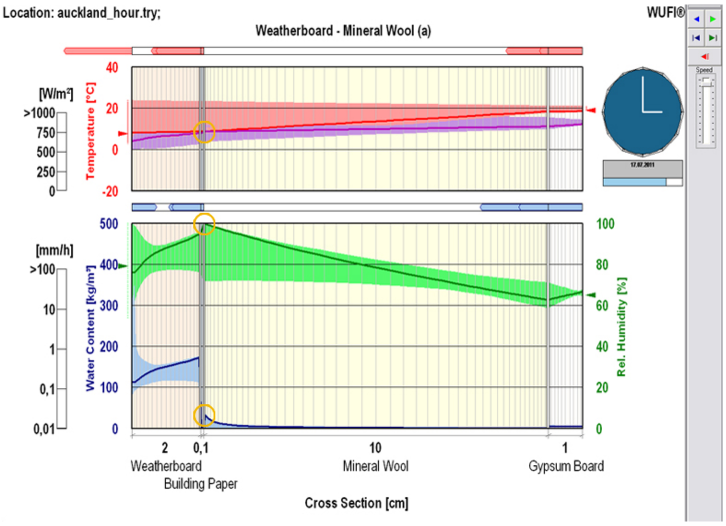
Therefore, the total content of water over a long-term is the basis for any assessment but it only proves if a wall construction is able to reach its dynamic steady state (Zirkelbach 2009).



Source: (de Groot 2009)

Figure 4: The total water content is approximately about 2.2 kg/m² in summer and 3.7 kg/m² in winter.

Significant instead is the WUFI animation which clearly shows interstitial condensation in the insulation layer. Referring to figure 5, the data shows that the RH (%) reaches 100% (top of the scale) during the calculation period of three years and, therefore, interstitial condensation occurs. Based on results of the WUFI simulation, it is not recommended filling the existing frame cavities with mineral insulation batts without additional construction changes as this will cause a moisture content during winter that is not acceptable.

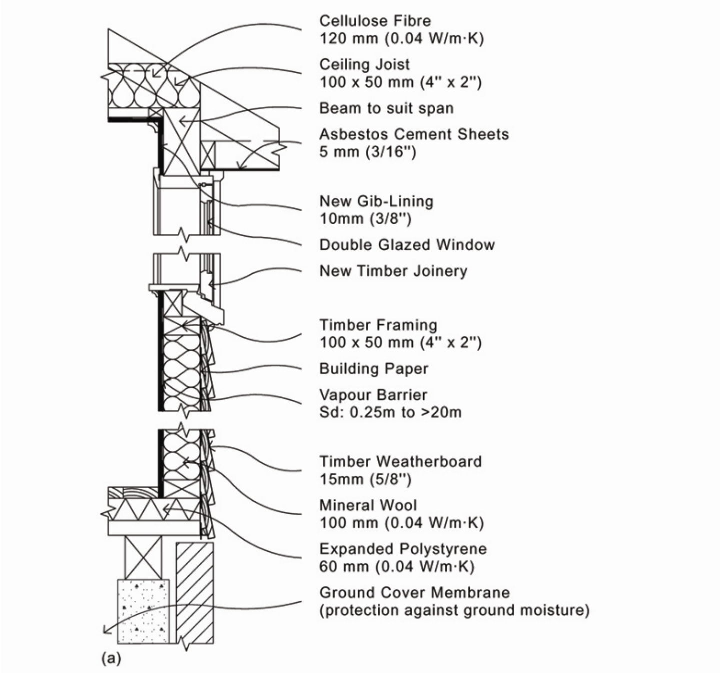


Source: (de Groot 2009)

Figure 5: 100% RH is reached during the calculation period leading to liquid water within the wall.

In order to avoid the problem, two different options can help: The first option would include a minimum 20 mm ventilated air cavity between the weatherboards and the building paper to control the content of water within the external wall component. The second and preferred option is the combination of a vapour check and a new layer of building paper between the insulation layer and the weatherboards. The vapour check must be installed between the new internal gib lining and the insulation to create an airtight layer. It acts as a vapour control layer that covers the insulation layer and impedes the transfer of warm and moisture laden air from the internal living space into the wall component by means of convection.

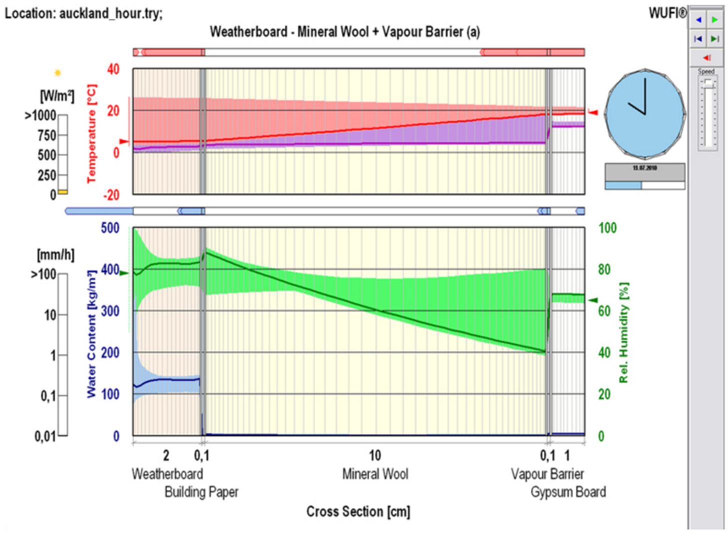
Convection usually results in undesirable heat losses and high levels of moisture that can occur within the insulation layer. Therefore, the vapour check should not be interrupted (Figure 6) (Richarz 2007). Without the need of a ventilated air cavity, this solution does not require changes to the original thickness of the external walls which would also affect the interior planning e.g. doors and window frames. However, further testing is recommended to investigate the full extent of effectiveness and success of this approach.



Source: (de Groot 2009)

Figure 6: Alternative Retrofit Solution of a Labour State House.

With the new solution, the analysis of the individual layers with WUFI shows that the moisture content within each building material is acceptable and does not exceed limits that support mould growth or impact on the building materials damaging the existing structure (Figure 7). In combination with new double glazed windows and timber joinery, it is also recommended to install a mechanical ventilation system to control indoor humidity and air pollutant levels. In combination with a new airtight layer, thermal insulation and tightly sealed windows it would definitely improve the IAQ (Richarz 2007).



Source: (de Groot 2009)

Figure 7: RH is not reached during the calculation period of three years.

The comparison between the Glaser-method and the WUFI programme shows that it is necessary to explore more than just the risk of interstitial condensation within a building component. The WUFI program allows determining the problem of moisture within a wall more detailed than the Glaser-method, but it also needs much more information in terms of material properties. The fact that most of New Zealand manufacturers and building material suppliers currently do not provide this information makes it questionable if WUFI can be used properly. Therefore, the Glaser-method could represent an alternative to easily provide a general assessment of the hygrothermal suitability of a wall component. Nevertheless, the WUFI program should be introduced if possible to understand the complexity of the hygrothermal processes within a building component.

CONCLUSION

The number of risk factors for mould and high indoor pollutant levels can be reduced by a range of adequate retrofit solutions, but unfortunately there is a lack of information on the quality and success of such solutions in New Zealand. Possible "changes" in terms of building physics produced by insulation improvements in retrofitted building components are not always considered by building suppliers and designers. The current practice of retrofitting of different house typologies built between the 1950s and 1980s, shows that installing additional insulation in the wall cavity improves the R-value on the one hand but shifts the dew point within the wall component on the other. Without a ventilated air cavity or a vapour control layer, this will eventually lead to interstitial condensation and moisture problems. Despite the relevance of this topic, vapour movement and building airtightness is still not of concern in the NZBC. The new requirements in terms of insulation of the building envelope will lead to warmer homes but increase the risk of mould growth within the wall components.

As a possible solution to determine the risk of interstitial condensation within retrofitted external walls, this research paper introduces the Glaser-method as a general tool as well as the WUFI software as a realistic simulation tool of hygric processes in particular retrofitted building components. The Glaser-method can be used to provide a general assessment of the hygrothermal suitability of building components. However, in order to consider the entire hygric behaviour of particular retrofitted building components at their individual location, the WUFI software is recommended. It can be used to calculate and to check the transient heat and moisture transport within a retrofitted wall component to achieve best possible comfort conditions in retrofitted homes. In conclusion, the greatest challenges still lie in the understanding the building physicality as the result of a comprehensive strategy involving insulation, ventilation rate, airtightness and humidity control.

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