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Medium-density dwellings in Auckland and the building regulations

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Abstract

National thermal standards have historically been set to minimise winter heating energy in detached houses. It is uncertain whether these standards are optimal for the increasing number of joined, medium-density dwellings when summer and winter conditions are considered. Using freely available software, annual heating energy use and summertime peak temperatures were calculated for a number of versions of detached and joined dwellings offering the same occupied volume and window areas. Initial results indicated that, as expected, the joined dwellings required less heating energy. The detached house exhibited a higher peak summertime temperature but a lower overall average daily temperature. Interventions such as changing insulation, glazing areas and ventilation were calculated to reduce summertime temperatures in the joined dwelling. Increasing ventilation provided the greatest improvement particularly during the sensitive sleeping hours. Changes to clauses H1 Energy Efficiency, G4 ventilation and G6 Airborne and Impact Sound are recommended if these early findings are confirmed in a more complex simulation.

Background

New Zealand has 1.84 million homes. Of these, 81.1% are separate houses and three quarters of these are single storey (Statistics New Zealand, 2017a). A quarter of this total (473,452 dwellings) are in Auckland. The proportion of separate houses in Auckland is slightly smaller, at 74.7%. The proportion in Auckland that are single storey is also smaller, less than two thirds, and this is reducing as new houses are built (Auckland Council, 2014).

The national insulation standards, first applied in 1978, then revised in 2000, 2004 and 2007 (Ministry of Culture and Heritage, 2016), targeted the dominant separate, single-storey typology. However, the Auckland Plan (Auckland Council 2016) indicates that this dominance is changing. Increasing pressures on land and affordability are unlikely to reverse the trend, further increasing the percentage of multi-storey, joined dwellings.

The movement toward medium-density dwellings aligns strongly with the first and second priorities noted in Chapter 11 of the Auckland Plan to "Increase Housing Supply to Meet Demand" and to "Increase Housing Choice to Meet Diverse Preferences and Needs" (Auckland Council, 2016).

Housing New Zealand (HNZC) are replacing stand-alone dwellings with two-to-four-storey medium-density housing and, as a consequence, large families are being relocated to this stock. Because Maori and Pasifika peoples are much more likely to live as extended families than other New Zealanders, as indicated in the 2013 Census (Statistics New Zealand, 2017c), the health, social and cultural impacts of medium-density housing are of particular concern. This is particularly so given that Māori and Pasifika families make up over 50% of social housing tenants, and that cultural obligations can lead to occupancy levels being under-reported (Ministry of Social Development, 2017).

Internal conditions

In the context of building, a volume enclosed by a cube results in the smallest surface area and is theoretically the most efficient when trying to minimise heat loss through the external envelope. The increasing percentage of joined, multi-storey dwellings shows that the new Auckland housing is moving towards this optimal shape.

Whilst the cube is optimal for preventing winter heat loss it could be sub-optimal in summer. Small surface areas might prevent unwanted heat gain through the envelope but do little to prevent solar gain through windows. In parallel, double glazing is little better than single glazing in the prevention of summer solar gain, despite reducing winter heat loss. Overheating of residential dwellings is a growing and significant challenge in northern hemisphere countries whose building typologies are dominated by the type toward which Auckland is trending. This move toward denser building types in Auckland may provide similar overheating challenges to those being experienced in the northern hemisphere.

The risks are twofold: the first is that energy saved during the winter is replaced by energy required to cool in summer, when our hydroelectricity lakes are at their lowest levels (Knight, 2009). The need to run equipment to actively cool homes may have unintended consequences on national energy consumption and the associated carbon emissions. Burroughs, Saville Smith and Pollard (2015) discovered that 58% of 160 heat-pump owners used their heat pump for cooling. The second risk is that if overheating prevails into the evenings the disruption to sleep patterns may be detrimental to occupants' health. Whilst opening windows may be seen as a simple, traditional solution, research has shown that occupants rarely 'tune' ventilation to suit thermal conditions (Herkel, Knapp, & Pfafferott, 2008). Once opened or closed, windows are left untouched for long periods. Concerns about security and external noise in increasingly densely populated areas, especially during sleeping hours, may further limit the effectiveness of this solution. Party walls can also reduce the opportunities for cross and through ventilation.

There is also significant evidence that, despite increasing insulation levels, examples of cold, damp and mouldy houses and their associated health affects still exist (Statistics New Zealand, 2017b). Overcrowding and the increasing airtightness achieved partly by higher thermally performing windows have been identified as possible aggravators. High rental and property prices in Auckland have exacerbated occupants' concerns with the high cost of warming rooms and warming cold, outside air used to ventilate spaces. It is therefore worth investigating whether the likely increase of medium- and high-density housing in Auckland, particularly for social housing tenants where overcrowding is more likely, warrants reconsideration of the current regulations relating to standards for internal comfort.

Current regulations

Building Code clause H1 Energy Efficiency (Ministry of Business, Innovation and Employment, 2017a) requires housing to achieve an adequate degree of energy efficiency to modify temperature, humidity, ventilation and in the provision of hot water. The provision of minimum insulation levels for houses is one method of compliance and this can be demonstrated in a number of ways. The simplest Acceptable Solution is to provide the minimum insulation levels scheduled in external surfaces, and by limiting the proportion of glazing in external surfaces. More flexible Verification Methods permit higher percentages of glazing to be compensated for by higher-than-minimum insulation levels in other parts of the external envelope. Even more flexibility involves use of the Building Performance Index (BPI). This single index balances the consumption of heating energy, supplied by a network, utility operator or a depletable energy resource against the coldness of the climate and the area of external surfaces. Quantification of the *supplied* heating energy enables this to be reduced by useful, free solar gain. Section H1.3.3 refers to the need to take into account heat gains from solar radiation, but the emphasis in the Acceptable Solutions and Verification Methods is on the efficient use of heating energy. As a result, guidelines are not set to limit the

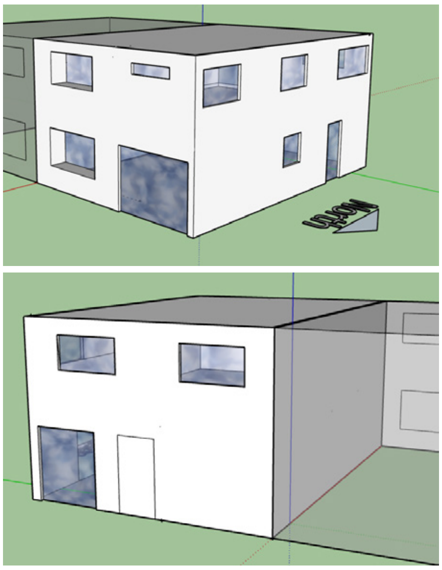

Figure 1. Generic medium-density, joined dwelling (Med D).

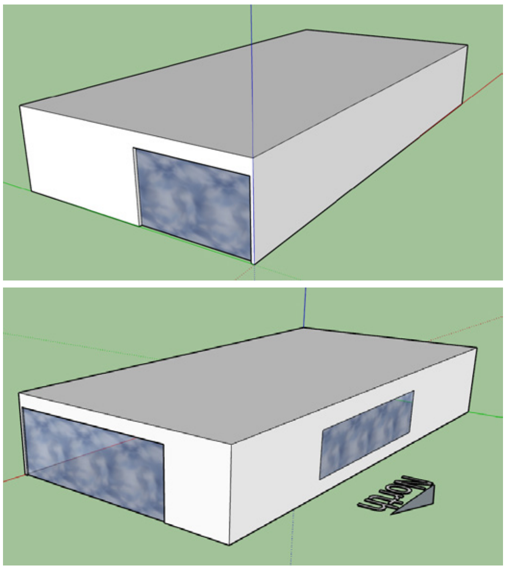

Figure 2. Traditional low-density equivalent dwelling (Low D).

energy consumed to cool a house. This same section requires consideration of the airtightness of the envelope, but Acceptable Solutions or Verification Methods focus on minimising heat loss, and therefore do not consider the impact of this in conditions requiring cooling.

Section G4 (MBIE, 2017b) addresses ventilation, and emphasises the need for air purity rather than any prevention of undesirable moisture conditions or overheating. The provision of minimal levels of ventilation through opening windows assumes that windows are left open but does not consider any resulting cooling effect when internal conditions might warrant it.

Section G6 (MBIE, 2017c) considers the sound transmission between abutting occupancies and is particularly relevant for joined dwellings, setting minimum standards for airborne and structure-borne sound transition through walls and floors.

Comparisons

The impacts of moving away from the traditional type of New Zealand house, on which standards were initially based, warrant investigation. The approach taken was to undertake calculations using simplified tools, so, depending on these results, more complex simulation may then be warranted. Initial investigations compared the traditional house to a sample medium-density, joined dwelling. Quantification of the annual heating energy and summertime peak temperatures were investigated for a number of versions of the houses and are shown in Table 5.

The starting point was a generic, two-storey medium-density house (Med D) joined to a second property, shown in Figure 1, and represents a number of new houses being constructed. BRANZ (2017a) predict that in five years' time

Building type	Volume m^3	Ground floor m^2	Total Floor m^2	Roof area m^2	External wall m^2				Window m^2				Total surface area
					N	S	E	W	N	S	E	W	
Med D % of external wall area	416	78.75	158	78.75	46.2	0	27.0	31.8	9.2 16%	0	12.7 32%	7.8 20%	348
Low D % of external wall area	416	158	158	158	36.9	46.2	11.1	15.9	9.2 20%	0	12.7 53%	7.8 33%	455
R value m^{2}K/W		Med D 1.8 Low D 1.5		2.9	1.9	1.9	1.9	1.9	2.6	N/A	2.6	2.6	

Table 1. Insulation and dimensional information of comparative buildings.

76% of all new medium-density builds will be horizontally attached. They also identify that "the most affordable units for medium income households are likely to be flats and terraced houses … constructed mainly from light timber framing" (para. 15). The southern face, identified as the party wall, is not considered external and has no windows.

A simplified single-storey detached house providing the same total floor area, volume and window area was developed, and is shown in Figure 2 (Low D). This reflects a more traditional, detached New Zealand house. To focus the comparison on the broad built form, Figure 2 has exactly the same window areas in each wall as the joined house. It does have an exposed southern face, but for this comparison glazing was omitted to minimise differences to the Med D option. The floor areas of both buildings are small compared to current standards, but have been chosen to ensure comparison with the smaller, more traditional dwelling is valid. These areas are in line with examples of new dwellings currently being constructed.

The insulation (R) values in Table 1 are the minimums set down in the Acceptable Solution, with the exception of floors which are higher, reflecting minimal practical construction details. The Med D is constructed with a concrete floor, following current practice, and is assumed to be partially uncarpeted; whereas Low D is constructed with a suspended timber floor, following past practice, and is also partially carpeted. For the same floor area and volume, the medium-density layout shows a lower surface area than the traditional layout, indicating a more thermally efficient shape.

For calculations of heating energy and internal temperatures, assumptions had to be made about operating conditions, requiring the input of climatic data including external wind conditions and internal heat generation from lights, number of occupants and appliances. These were applied consistently to both base buildings and all interventions.

The annual heating energy was calculated using the ALF tool (BRANZ, 2017b) using the same internal and external conditions for both dwellings. The tool takes into account the varying climate, solar gains and thermal properties to predict the heating energy required per year to maintain winter comfort conditions, measured in kilowatt-hours. It does not consider internal summertime temperatures. Conditions chosen were to heat the building to 20°C for 24 hours per day. This aligns with the conditions used to calculate the Building Performance Index (BPI), one of the verification methods for clause H1. The latest version of H1 states that the BPI is not a suitable mechanism for medium-density houses and is therefore not calculated. Calculations were also completed with a comfort level of 20°C, based on the assumption that the house was heated from 7.00am to 9.00am and 5.00pm to 11.00pm to reflect more typical heating conditions.

The Passive Design Assistant (PSA) calculation tool (ARUP, 2012) was used to predict summertime temperatures that may be experienced internally, based on the same thermal properties and relevant external environmental parameters of an Auckland climate. This software, initially designed for construction in UK conditions, had its input data calibrated against known thermal envelope data from a typical New Zealand house and New Zealand climatic conditions. Figure 3 indicates the comparison of actual data from a monitored house and the predicted results from the PDA tool. The tool uses the Admittance Method (The Chartered Institute of Building Services Engineers, 2006) to predict internal temperatures based on a cyclic input of air temperature, local solar gains and internal gains from occupants' lighting and equipment. The monitored house was unoccupied and had no internal gains. These gains were set to zero in the PDA tool. The PDA tool predicts a very similar internal maximum temperature and similar profile overall compared to the actual measurements. The weather data in the PDA tool is slightly warmer than that actually measured but this calibration indicates that the PDA tool will provide results close to those anticipated for typical construction details and climatic conditions in New Zealand and sufficiently close for this exploratory exercise. The infiltration parameter required adjustment to improve the match between calculated and monitored results. Normal settings would be based on a single air change per hour. The PDA model required this to be increased to two air changes to improve the match. This infiltration rate was used in the calculations for the Low D and Med D buildings used in this investigation.

Initial results

Table 2 shows that, because of the more thermally optimal shape, the energy to keep Med D comfortable is 3469 kWh, lower than that of Low D at 5490 kWh. At 25c/kWh, maintaining the Med D temperature at 20°C for 24 hours a day for one year would cost the owner $505 less that the owner of Low D. In reality, few people heat for this whole period and the difference between Med D and Low D for heating only in the morning and evening for one year would be $171.

Heating only for the shorter morning and evening periods reduces the difference between the building types. The energy needed to warm up the concrete slab in Med D with an intermittent heating pattern contributes to the reduced difference. If internal heating was achieved with heat pumps, the cost difference would be further reduced due the efficiency of the equipment.

In summertime the overall profile in Figure 3 indicates two peak periods, around midday and 8.00pm, with a drop in between. This is due to high solar gains in the morning and early evening associated with the higher percentages of glazing, and low sun angles on east and west faces allowing sunshine to

Figure 3. Comparison of actual and calculated internal temperatures to calibrate PDA inputs.

Building type	Annual heating energy KW/h/year 20°C 24 hours	Annual heating energy KW/h/year 20°C Morning & evening	Maximum summer temp °C	Average summertime daily peak °C	Average space temperature over summertime/day
Med D	3469	3010	37.56	36.33	30.3
Low D	5490	3695	38.66	37.05	28.9

Table 2. Initial results.

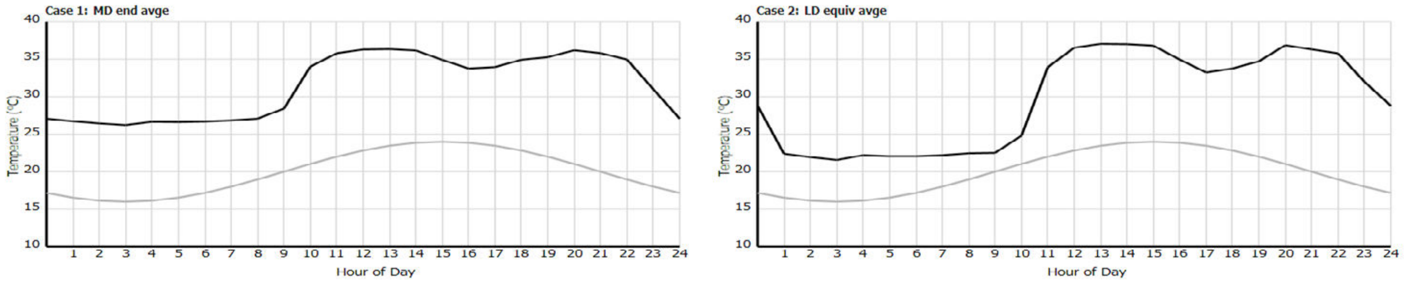

Figure 4. Internal temperatures over an average summer day.

penetrate deep into the space. The lower percentage of glazing on the north face and the high sun angle produced comparatively lower levels of gain. Table 2 shows that Low D warms to a slightly higher temperature than Med D at the peak and on an average summer day. This is due to the heat gain through the larger external surface area in the less efficient shape. They are both higher than the 32.5°C actually measured in the calibration house, but all are well outside acceptable comfort conditions. Importantly, Med D maintains a higher average temperature over a 24-hour period. Figure 4 shows that this result is because the temperature in Med D remains higher through the sleeping hours, consistently reaching above 25°C. The variation between daily maximum and minimum is lower in Med D. This is expected, and shows the positive effect of the increased mass associated with the concrete slab and the increased heat loss of the larger surface area of Low D.

The temperature experienced without modification would almost certainly cause owners to run heat pumps in cooling modes to bring temperatures down to a comfortable level, particularly permitting good sleeping conditions at night. The figure indicates that the period requiring active cooling for Med D is longer than for Low D, negating the savings made over the winter, possibly consuming even more energy.

Interventions

An examination of local and international research (Birchmore, Davies, Etherington, Tait, & Pivac, 2016) has indicated that the most frequent intervention to prevent summertime overheating is by reducing solar gain through external shading, window-to-wall ratios, window solar gain factors and increasing night-time ventilation. This current investigation focuses on interventions that are covered by current regulations, and so excludes the consideration of shading and solar gain factors.

VENTILATION

Increasing ventilation by opening windows is an obvious and well-reported summer intervention. The PSA tool permits a variety of ventilation levels to be chosen, but does not permit the levels to change at different times of the day. Calibration of the input data with output from an actual Auckland house required the initial ventilation level to be set at two air changes per hour. Figure 5 shows that increasing the two air changes per hour in the Med D end house to a medium level of five reduces the average peak by nearly 4°C to 32°C. The temperatures during key sleeping hours now average 22.5°C. This is still higher than optimal for sleeping, but a significant improvement.

Increasing the ventilation to ten air changes per hour reduces the maximum temperature to 29°C and sleeping temperatures to an average of 19°C.

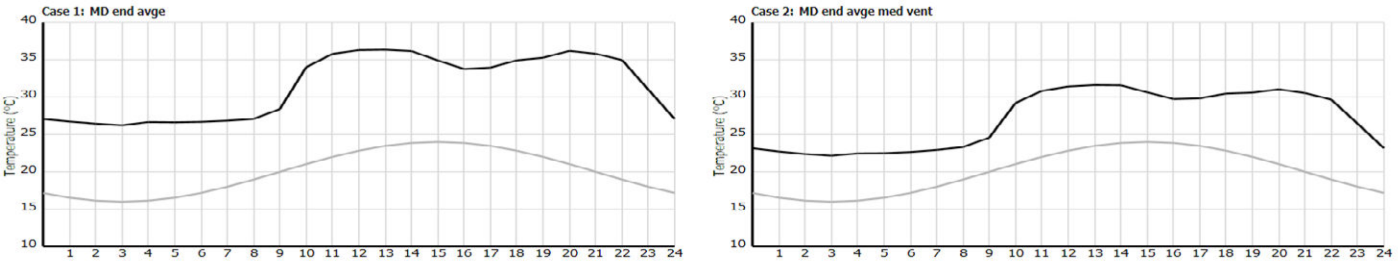

Figure 5. Comparison of Med D end house with low and medium ventilation.

Building type	Annual heating energy KW/h/yr. 20°C 24 hrs	Annual heating energy KW/h/yr. 20°C morning & evening	Maximum summer temp °C	Average summertime daily peak °C	Average space temperature over a summer's day
Med D	3469	3010	37.56	36.33	30.3
Med D Lo Wall R	3730	3147	37.63	36.31	30.4
Med D single G	4771	3585	37.68*	36.33*	30.4*
Med D small W	3112	3228	33.82	32.6	27.8
Low D	5490	3695	38.66	37.05	28.9

Table 5. Results of interventions for the Med D house. *Underestimated figures.

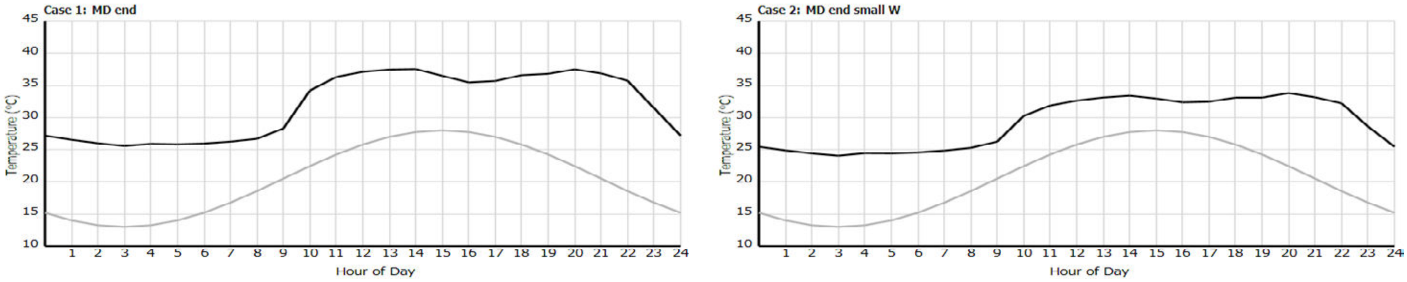

Figure 6. Comparison of Med D with initial and smaller windows.

INSULATION

With efficient heat pumps providing the heat in modern houses, the energy saving from the more efficient Med D house may enable a reduction in insulation levels, resulting in a possible first-cost saving and negligible running cost differences to the owner when compared to Low D. The heating energy in the Med D house was recalculated using the lowest R value permissible of 1.5 m2K/W (Med D Lo Wall R). This limitation is designed to minimise the risk of surface condensation, rather than guide heating efficiency. An option using single glazing (Med D single G) was also calculated, to test another option that would reduce first costs to an owner.

Table 5 shows that reducing either the wall insulation or the window insulation results in heating energy levels that are still lower that the Low D dwelling. However, the maximum and average summertime temperatures both increase further beyond comfortable conditions. Note that the PDA software would not accept the thermal resistance or solar gain properties for single glazing used in New Zealand, so summertime temperatures were underestimated.

Reducing window-to-wall percentages is another intervention reported as being successful, and is also a parameter identified in regulations. As windows, even double-glazed, are the thermal weak points in an external envelope, this reduction also explores the impact of raising the average R value of the building. Figure 2 shows that the window-to-wall percentages are collectively already within the thermal limits of 30% set by the Acceptable Solution in clause H1 of the Building Code, but further reductions were calculated. Reducing them to 50% of their initial values should reduce heat loss and gain significantly, while maintaining the minimum 10% of floor area

Building type	Annual heating energy KW/h/yr. 20°C 24 hrs	Annual heating energy KW/h/yr. 20°c Morning & evening	Maximum summer temp °C	Average summertime daily peak °C	Average space temperature over a summertime day
Med D	3469	3010	37.56	36.33	30.3
Med D Lo Wall R	3730	3147	37.63	36.31	30.4
Med D single G	4771	3585	36.95*	35.55*	29.8*
Med D south	3700	3296	37.09	36.66	30.2
Med D Lo R south	3969	3429	37.65	37.27	30.4
Med D single G south	5060	3881	36.66*	35.97*	29.7*
Low D	5490	3695	38.66	37.05	28.9

Table 6. Comparison of north- and south-facing versions of Med D. *Underestimated figures.

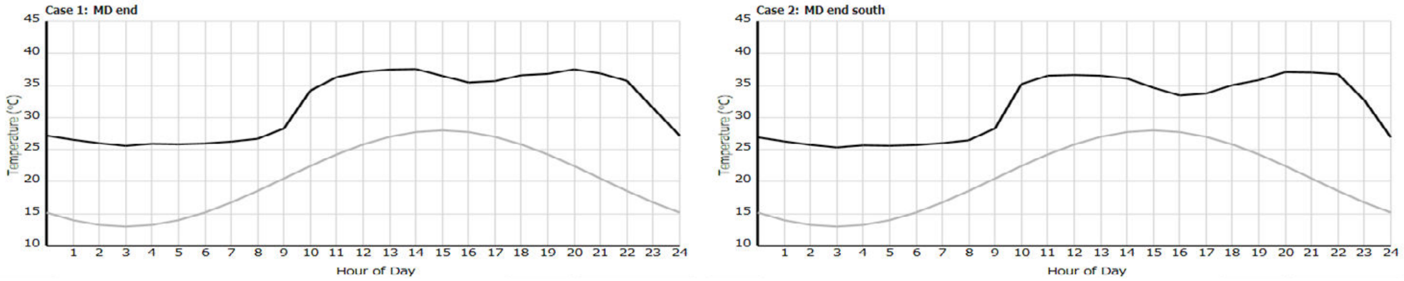

Figure 7. Comparison of peak temperature profiles in north- and south-facing dwellings.

window-to-wall ratio set by clause G7 (MBIE 2017d) to ensure minimal levels of natural lighting.

Table 5 shows that winter heating energy drops, as expected. However, the reduced solar gain through the smaller windows causes the 24-hour heating to be lower than the intermittent heating option. Figure 6 shows a significant drop in daytime temperatures when smaller windows are used, but still not to levels that are likely to be considered comfortable. There is a minimal improvement in the sensitive night-time conditions, dropping to 24°C.

ORIENTATION

The north-facing Med D dwelling will inherently have a south-facing partner, so the impact of the current standards and interventions on this orientation were also explored.

Table 6 shows that peak and average temperatures are only slightly lower than the Med D results and still create uncomfortably hot conditions. Comparison of the profiles between north- and south-facing units is shown in Figure 7, which indicates that much of the gain contributing to overheating comes from the east- and west-facing windows. The sun will be at a low angle during the early and late part of the day, penetrating well into the building, which coincides with the late morning and late evening peak temperatures. Unshaded, north-facing glazing is often considered to be problematic in summertime. However, these results indicate that the high sun angle in summer limits the penetration of sunshine into the occupied spaces and does not contribute much to overheating.

Concluding discussion

The trend in newly-constructed houses towards the more thermally-efficient typology of joined dwellings has a clear positive impact on winter heating energy use. This provides owners with the potential for hundreds of dollars a year in heating energy savings compared to the costs for more traditional, single-storey, detached dwellings. This could additionally reduce the reluctance of homeowners and tenants to pay for active heating, and could contribute significantly to improved internal conditions and the associated health benefits of warm, dry living conditions.

Reducing initial purchase costs of medium-density houses, by lowering initial insulation levels to absolute minimums, provides a small running-cost benefit over traditional house types. However, this reduction makes no noticeable improvement to summertime overheating. It appears to neither keep the heat out nor trap it in to a level that an occupant would notice. The orientation of the joined dwellings does have a small effect. The reduced solar gain through the absence of north-facing windows in the base example increases the heating costs by approximately $60 per year. Summertime temperatures are, again, not noticeably different. Reducing the percentage of window area also provided winter heating energy savings and lowered summertime peak temperatures, but did little to provide improved comfort during the sleeping hours. These results suggest that whilst individual projects may be able to adjust alternative levels of insulation, changes to clause H1 governing insulation levels do not seem to offer significant improvement across all seasons, and so are not recommended. Further investigation into dwellings joined on both sides and mid-floor units in multi-storey construction could provide new data, and is recommended. Consideration of the energy used to cool a dwelling, and likely peak summertime temperatures warrant further exploration. The current suite of Acceptable Solutions will ensure medium-density housing will have lower heating costs than for a traditional home, but will not assure comfortable summertime conditions. In Europe, *Technical Memorandum 52* (The Chartered Institute of Building Services Engineers, 2013) links external and internal conditions to gauge overheating, but this has been found to be too complex to calculate for anyone but technical experts and hard to communicate to occupants. Developing a simple guide for New Zealand conditions, supported by some post-occupational surveys of the current medium-density stock and a calculation tool to support new Verification Methods, deserves investigation.

The most significant change in this investigation was observed by increasing summertime ventilation rates. At the internal temperatures calculated, the external air temperature was always lower, providing some valuable, free cooling potential. Increasing ventilation rates to ten room-changes per hour brought uncomfortable night-time temperatures close to comfortable levels. Concerns about security, external noise levels in highly populated areas, and passive occupant behaviours such as failure to adjust windows are barriers to achieving these levels through natural ventilation. The drivers of natural ventilation are complex and hard to predict. Current regulations in clause G4 set ventilation levels around air cleanliness and prescribe a minimum openable area as a percentage of floor area. It is doubtful that air-change rates could be predicted with any confidence using these standards. Failure to consider summertime overheating challenges the clause's objective to "safeguard people from illness or loss of amenity due to lack of fresh air" (MBIE, 2017b, p.3). This absence warrants further investigation using more sophisticated simulation techniques to explore if there is potential for any new Acceptable Solutions. This could also include the beneficial impact on internal moisture levels and be extended to consider dwellings joined on two sides and in mid-storey locations. Mechanically-driven ventilation is one way of guaranteeing air-change rates. Challenges include delivering the air without excessive noise, especially at night-time, without creating draughts and the capital cost of equipment and user-friendly controls. These may not be high when compared to the health costs associated with poor sleep. Ten air changes per hour in winter would increase heating energy costs significantly. Either a system that can modify air-change rates, or one that recovers internal heat and preheats incoming air, is required.

If mechanical ventilation becomes a commonly applied solution to summertime overheating, the knock-on effect on the acoustic environment must also be considered. It must be ensured that the health benefits of sleeping in comfortably cool bedrooms are not negated by high levels of background noise from the delivery equipment. Clause G6 could set minimum background noise levels in these situations through new Acceptable Solutions.

Recommendations

1. **No changes to H1 Energy Efficiency Acceptable Solutions covering insulation levels are required.**
2. **More sophisticated simulation of end, mid-terrace and mid-floor dwellings be undertaken to verify the findings in this report.**
3. **Section 4.0. of the Acceptable Solutions, Control of Solar Gain be expanded to consider internal summertime temperatures in medium- and high-density housing.**
4. **A Verification Method be developed to ensure that comfortable summertime temperature levels are maintained in medium- and high-density housing.**
5. **Acceptable Solutions in G4 Ventilation be expanded to consider summertime temperatures in medium- and high-density housing.**
6. **Acceptable Solutions in G6 Airborne and Impact Sound be expanded to set maximum background-noise levels from mechanical ventilation equipment.**
7. **Potential cost increases associated with any of the recommendations above be balanced against the potential health and social costs of not making any changes.**

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