DESIGN RESEARCH: OPTIMISING ROW-HOUSE ORIENTATION

Michael Donn[1], Elzine Braasch[1], Marc Woodbury[2], Evzen Novak[2], Andrew Banks[2]
[1]Victoria University of Wellington, New Zealand;
[2]Studio of Pacific Architecture, Wellington, New Zealand

ABSTRACT

A collaborative research study of modular terrace houses in Auckland, New Zealand has sought to find optimal building orientation, façade design and layout to inform the master plan for a housing development. Two terrace house modules of different size within a large multi-unit development were analysed. EnergyPlus models were based on the preliminary design concepts with sufficient zones that the thermal performance of each functional space within the terrace house could be studied. The smaller terrace house had the greatest difference in performance between best and worst orientations. Further investigation determined that the major determinant of this difference was neither size, nor plan layout of the buildings but was the larger imbalance in window to wall ratios of the two exposed facades.

INTRODUCTION

The city of Auckland, New Zealand's largest urban centre, aims to create a city where "…all people can enjoy a high quality of life and improved standards of living…" (Auckland Council, 2015). However, like all urbanised cities in the world, Auckland is experiencing a rapid upturn in population due to natural increase and migration (Auckland Council, 2015). The Auckland Council predicts the population of Auckland to increase by 1 million over the next 30 years. In an attempt to manage the natural and physical resources of the country while enabling growth and economic development, Auckland City Council has proposed the Unitary Plan to help implement the Auckland Plan (Auckland Council, 2013).

For the Environmentally Sustainable Design (ESD) award winning architecture firm Studio Pacific Architecture (SPA), the proposal of this new plan, which strives for sustainable growth, calls for the need to further improve their understanding of ESD to design high quality medium-density housing within Auckland (Studio Pacific Architecture, 2015). Previous studies done on improving thermal performance of new houses by SPA in collaboration with Centre for Building Performance Research at Victoria University of Wellington (CBPR) were useful. They had identified for the firm the importance of insulation, window size and orientation in the design of stand-alone houses (Sullivan, Novak, & Donn, 2012). However in working on a master plan design for terrace housing in Auckland the question of orientation of the maximum two external faces became the focus of a supplementary study. The orientation of the streets and thus the orientation of the terrace houses and their effect on thermal performance once again became a focus of a joint SPA/CBPR study.

The overall aim of this study was to determine the effect of orientation on the thermal performance of terrace houses designed by Studio Pacific Architecture. As with all studies of this type, the issue of creating a 'representative' building for the parametric study of orientation was a critical first step. Rather than generic simplified modules the decision was made to focus on actual SPA terrace house designs within Auckland's mild climate. As can be seen in Figure 1, almost no hours in the year are outside the zone where sensible passive solar design could maintain comfort.

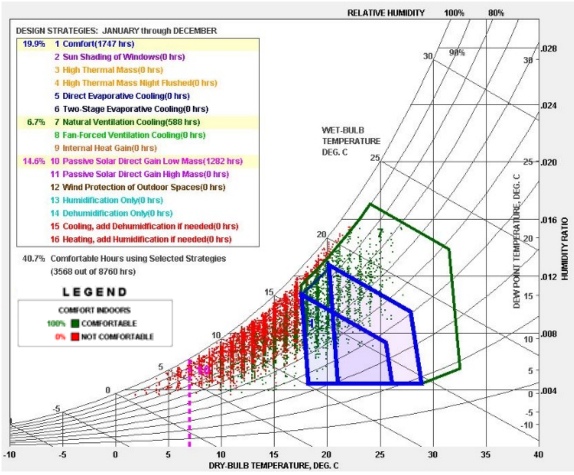

Figure 1 Climate Consultant (UCLA) Psychrometric chart of the Auckland TMY File: Blue are Summer (Right) and Winter (Left) comfort zones; Pink dotted lines shows Zone where Passive Solar can heat the building; Green where Natural Ventilation can cool.

This study primarily focused upon the design of these terrace houses within Auckland's mild climate to evaluate the design implications of only relying upon common 'rules of thumb'. As Auckland' climate is

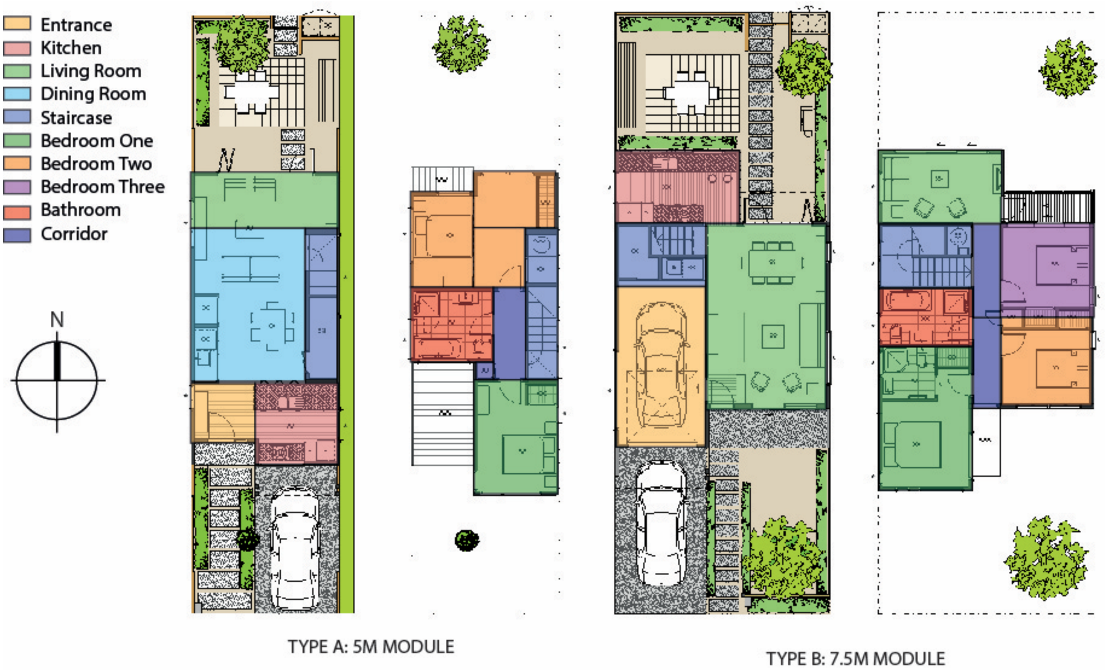

Figure 2 Plan view indicating zoning for the simplified model for Type A and B Terrace House

relatively warmer than other regions within New Zealand, it was hypothesised that the terrace houses would suffer from overheating due to the simple reliance on a 'rule of thumb' for daylighting – larger windows to the north would allow more penetration of light. With terrace houses being limited to only two exposed facades, the penetration of light was a key design aim.

A weather file produced by NIWA for Auckland was used within this study to provide climate data to test the models within a mild climate.

It was thought that the glazing levels on the external faces, and the internal plans and the size of plans might have a significant effect on the results. The focus of this project was on two of these three issues. Two different modules of the terrace house buildings in sketch design in the Studio Pacific Architecture offices were compared and analysed within the energy performance modelling program, EnergyPlus, to determine the effectiveness of size, modularity and the effect of orientation on specific layouts.

BACKGROUND

For stand-alone housing, the design of a master plan of the streets in which it sits has less significance to the thermal performance of the house design so long as the layout of the house can be orientated with minimal dependency on the orientation of the road. It is in the nature of terrace/row housing, with party walls separating the dwellings, that they are commonly restricted by the orientation of the roads in medium-density housing. Where an architecture practice like SPA is keen to improve the sustainability and hence thermal performance of their buildings, this dependency will have a large impact on master planning if the orientation of the road, and therefore the terrace house, is shown to have a large impact on the thermal performance of the house. Unfortunately, no standard passive performance guideline exists for terrace houses in New Zealand, nor can the currently published standard 'rules of thumb' developed for stand-alone houses be trusted for terrace house design.

Furthermore, the layout plan of the house is heavily dependent on the exposed facades for access to natural lighting and ventilation to most commonly used areas such as the bedroom and living room. These complexities, and the previous experience with analysis of 9 of their stand-alone designs (Sullivan, Novak, & Donn, 2012) encouraged SPA to conduct a preliminary study *through simulation* .

THE TWO TERRACE HOUSES

The EnergyPlus models used within the study were simplified from the preliminary design of the terrace house buildings supplied by Studio Pacific Architecture. The models were divided into several zones, with the intent of determining how each functional space within the terrace house would perform thermally. These zones are illustrated in Figure 2.

To test accurately the effect of orientation on the terrace house's thermal performance, each terrace house was modelled and simulated in between two similar terrace houses. The goal was to ensure that the effects of the thermal properties of the thermal mass in the party walls between each house were accounted for as accurately as possible.

Each module is modelled and simulated firstly as illustrated in Figures 3 and 4 to determine the effect of the rows in orientation for master planning, assuming that road grids within master planning *can* be changed. These modules were then modelled and simulated as a row where each terrace house was individually orientated to determine the effect of orientation in master planning, assuming that the road grids within master planning *cannot* be altered.
Within this process of modelling, the configuration of how the terrace houses are connected to each other was tested. For example, Type B's terrace house configuration was set out where the houses mirror each other, rather than being copied next to each other as was the case in Type A's configuration.

Figure 3 Diagram showing configuration of Type A terrace houses

Figure 4 Diagram showing configuration of Type B terrace houses

However, in individually rotating the terrace houses, Type B might no longer be rows of terrace houses at a certain degree angle. Figure 5 and 6 illustrate how each terrace house was modelled in their configuration.

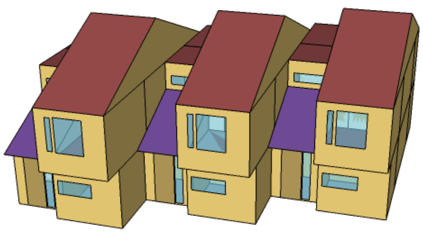

Figure 5 Diagram showing how each individual terrace house was spun for the Type A terrace house

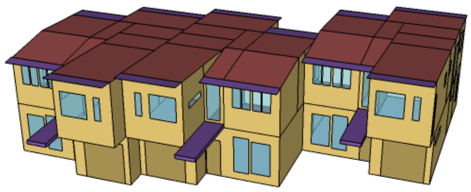

Figure 6 Diagram showing how each individual terrace house was spun for the Type B terrace house

To observe the sensitivities of orientations, the models were simulated with ideal loads in analysed rooms – kitchen and bedrooms – with heat pumps within the living rooms. To analyse the effect of orientation on each terrace house module, each house was modelled with the same parameters, construction types and lighting equipment – and was simulated at varying orientations. The construction of both module terrace houses was a mixture of masonry and timber construction designed to have R-values 50% above the building code requirements. All modelling parameter inputs were identical for simulation runs, with the orientation being the only parameter changed.

Internal loads were scheduled to represent working professionals at home to test the "worst" scenario. In simulating the worst-case scenario for internal heat gains, the maximum effect of orientation can be determined. These simulations process data outputs, which represent the total energy use if the rooms were to be heated and cooled to comfortable temperatures. The chosen best and worst orientations were further simulated without any heating or cooling to represent the real house in order to determine how well the terrace house would perform passively.

ANALYSING PERFORMANCE

Energy

For the purposes of understanding the effect of orientation on the thermal performance of the building, heating and cooling at 18°C -25°C set points were used to analyse the sensitivity of the different orientations.

No energy performance comparisons were made between modules as their comparison was not the subject of this study.

Comfort Hours

Comfort hours were represented as a percentage of how many hours of the year the space will be comfortable. The temperatures for the entire day were separated between the hours of 7am-7pm for day readings, and from 8pm-6am for night readings. Morning temperatures were also analysed between the hours of 6am-8am. The quality of the space in terms of temperature is often related to the measure of "thermal comfort", or level of "satisfaction" felt by the building occupants. For the purposes of this study, “thermal comfort” was defined between the ranges of 18-25°C.

Analysis of the comfort hours for each simulated model was represented in a stack bar graph, with the categories of:

- Less than 18°C, represented as blue
- Between 18°C-25°C, represented as green
- Greater than 25°C, represented as red

The hottest peak day, 21st February, and the coldest peak day, 21st July, were analysed to determine how well the terrace building would perform on the worse days for heating or cooling. The values for this analysis were also given as a percentage for thermal comfort hours.

RESULTS

The following parameters and model configurations were tested:

- Bar Orientation: A row of three terrace houses orientated relative to each other
- Individual Orientation: Each individual terrace house was orientated separately along a set road direction to maximum of 45° - all orientations were tested where the road orientation was changed along with the individual terrace house orientation

In 5° steps, little difference was found between individual orientations. The terrace houses were individually orientated and tested in 15° steps.

Type A

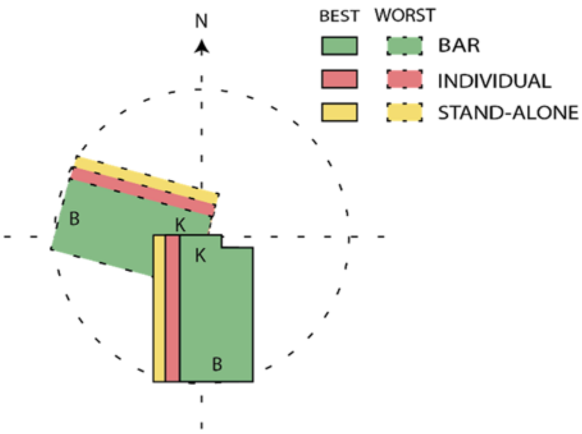

Figure 7 Best and worst orientation for the Type A terrace house, where K indicates the location of the kitchen in plan and B indicates the bedrooms in plan.

The Type A terrace house has an optimal orientation at 180° from its current design, orientating the larger window area to the south and exposing a smaller window area to the North. This optimal orientation was similar for all tested methods of orientating the building, including separating the terrace house from its neighbours by a 1 metre gap to make it a stand-alone house. Indicated in Figure 7 as “K”, the best orientation locates the kitchen to the North. This placement was ill advisable as the kitchen has the largest equipment loads contributing to the most internal heat gains when in operation. However, the kitchen within Type A performed well facing north due to the open-plan configuration with the surrounding rooms, allowing most of the internal heat to be distributed throughout the ground floor. The kitchen was scheduled to operate for a few hours in the early evening.

The worst orientation indicated in Figure 7 occurred when the largest window area faced to the west afternoon sun. In comparing the commonalities between these two findings, it was clear that the building performed poorly where large window areas face towards the North and West.

The differences between the various orientations were minimal, with a maximum 7% difference between the best and worst orientations found.

In analysing comfort hour temperatures, the performance of the terrace house on the hottest day illustrated by Figure 8 was poor during the day. Between the hours of 7am-7pm, the terrace house was comfortable less than 40% of the time. In orientating the largest window away from the North, the comfort hours during the day increased but not dramatically. In this case, the alterations of natural ventilation and insulation design options made a greater difference in increasing comfort hours. Facing the largest window away from the sun resulted in the best performance on the hottest and coldest day of the year, illustrated in Figures 8 and 9, and performed best on average across the whole year. This indicated that the designs of SPA for Type A had overheating issues from over-exposure to the sun and lack of cross ventilation.

These results indicated that reduction of solar penetration is required, particularly during the summer. This was observed where the largest Window to Wall Ratio (WWR) is best orientated away from exposure to the sun.

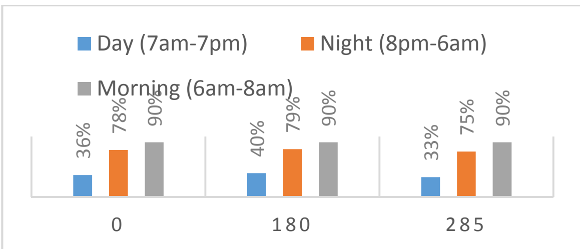

Figure 8 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations on the Hottest Day of the year (21st Feb) for Type A terrace house

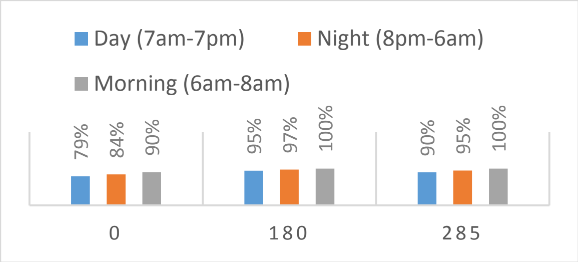

Figure 9 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations on the Coldest Day of the year (21st July) for Type A terrace house

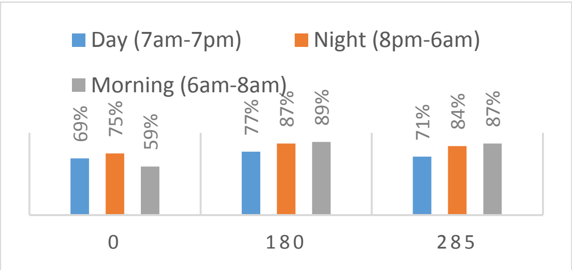

Figure 10 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations for Type A Terrace House

Type B

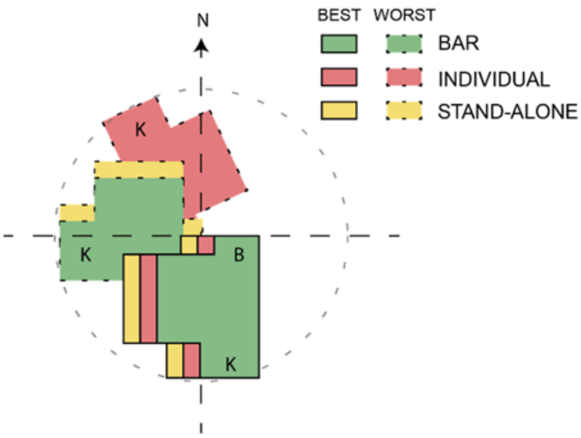

Figure 11 Best and worst orientation for the Type B terrace house, where K indicates the location of the kitchen in plan and B indicates the bedrooms in plan.

The Type B terrace house was optimal when flipped 180° from its planned orientation. For Type B, the worst orientation was significantly different for the individually orientated building, as illustrated in the summary diagram Figure 11. Due to the method of individually orientating the buildings, a greater surface area was exposed to the outside causing a larger overall heat loss through the exposed walls. In this case, the amount of heat loss dominated the effect of the orientation of the largest WWR.

In the case for the optimal orientation, the kitchen is no longer located north but rather newly located towards the South. Similarly to Type A, the larger WWR was no longer faced towards the north, indicating that the issue with the current design is overheating from solar gains. The worst orientation was found to be around 270°, where the largest WWR is faced towards the western afternoon sun.

The differences between the various orientations were minimal, with only a 5% difference between the best and worst orientations.

This result corresponds to the same result found with Type A, *suggesting that the module size and layout has little to no effect on which orientation is optimal.*

However, the kitchen layout is significantly different to Type A. It is connected to the other areas of the ground floor by a small opening – a door. The rate of distribution of heat from the kitchen is therefore significantly reduced and may contribute to the reasons why it performed best orientated away from the North. In analysing comfort hour temperatures, the best orientation for overall energy consumption, 180° from North, also performed the best on the hottest and coldest day of the year. Similarly, the terrace house performed best thermally on average across the year at 180° - away from the sun- as is shown in Figure 14.

Type B's coldest day results shown in Figure 13 compared to Type A's coldest day results shown in Figure 9 demonstrate the difference between the two modules. Where Type A's thermal performance was reasonably good during the winter, Type B was too cold during the night and early mornings. As Type B had a greater total surface area exposed to the outside, and contained an unheated garage modelled against the building envelope of the house, heat loss may be a contributing factor.

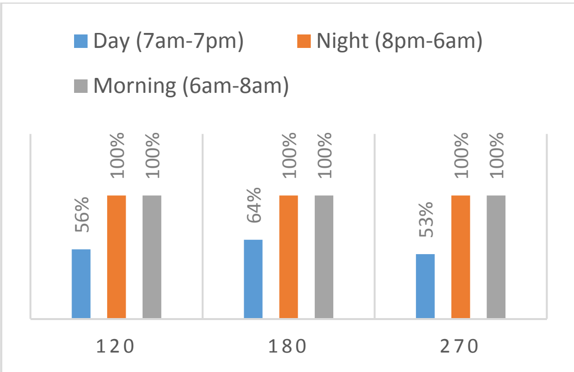

Figure 12 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations on the Hottest Day of the Year (21st Feb) For Type C Terrace House

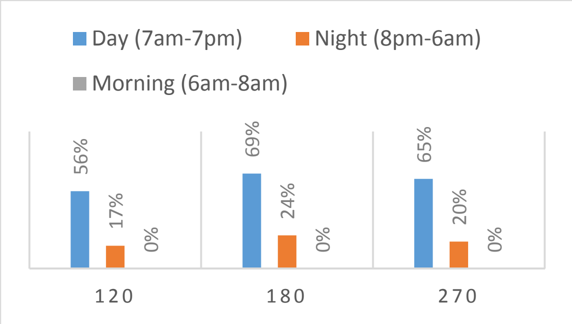

Figure 13 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations on the Coldest Day of the Year (21st July) For Type C Terrace House

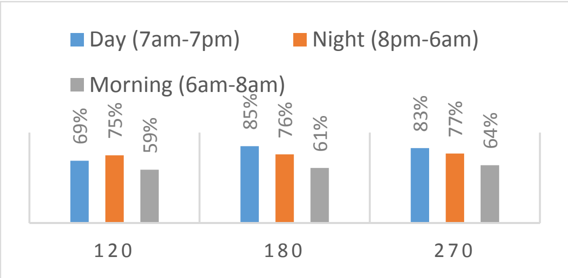

Figure 14 Comparison of Average Comfort Hour Temperature Percentages of Different Orientations for Type C Terrace House

FURTHER ANALYSIS

Type A

The Type A terrace house was designed with an average of 48% Window to Wall Ratio (WWR) on the northern end, and 19% WWR on the southern end. Due to the large amount of glazing on the northern side, it is not surprising that the building would operate better when rotated 180°. As the building's largest issue was overheating, the fact that a large value is facing south is not an issue, as the insulation of the windows prove to work well against the potential heat loss through the glazing on the southern end. This suggested that the WWR on the northern end could be reduced for improved thermal performance. If the WWR were to be reduced to 10%, would that make an effect on orientation?

With both ends of the terrace house designed having a WWR of 10%, Figure 15 illustrates that the differences in orientation were hardly noticeable. The best and worst orientations have a difference of less than 1%, indicating that the size of the windows had the greatest impact on how orientation might affect the thermal performance of the building. The difference between the reference model, with the specified WWR for Type A terrace house, and the modified terrace house with a 10% WWR was 5% however this did not make a significant reduction in energy consumption. In reducing the WWR, cooling was reduced by 15% due to a reduction in solar gains through the glazing.

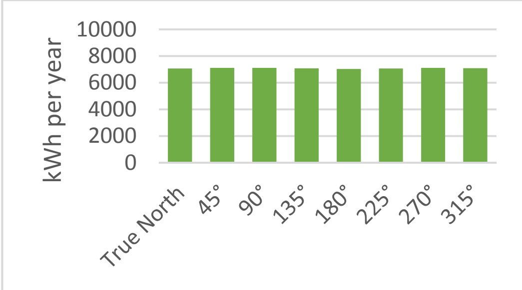

Figure 15 Comparison of the Bar Orientation of Type A Terrace House Total Energy Use in 45° step stages from True North, 0, with 10% WWR on both ends of the terrace house

Type B

Similarly to Type A, the Type B terrace house was designed with a large WWR, with a maximum of 50% on the northern end and 19% on the southern end. As already noted, the Type B terrace house performed best with its northern end facing south. The large size of the WWR on the northern end was causing it to overheat to the point where it performed best faced in a direction which would minimise solar gains. To further understand this, the terrace house windows were changed to have a 10% WWR.

After modifying the WWR, orientation made no real difference to total energy consumption, demonstrated in Figure 16. Similarly to Type A, the reduction in window area decreased the amount of cooling and increased the heating required to maintain a comfortable temperature range. Best and worst orientations found for Type B have not changed. However, the reduction in WWR in Type C makes a small 2% difference to overall total energy consumption due to the large proportion of energy used for equipment, rather than for heating and cooling.

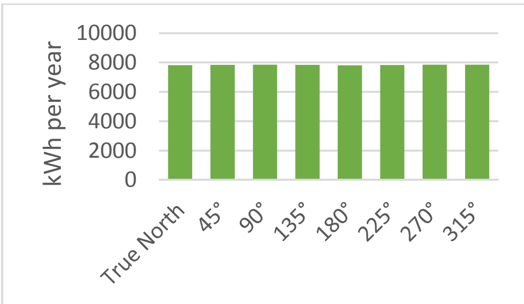

Figure 16 Comparison of the Bar Orientation of Type C Terrace House Total Energy Use in 45° step stages from True North, 0, with 10% WWR on both ends of the terrace house

DISCUSSION

The results from both terrace houses suggest the same conclusions, despite the various differences in layout and size. In both terrace house modules, the thermal performance was greatly affected by the size of the glazing on each façade. Both modules were designed with large Window to Wall Ratios (WWR) on the northern facades to allow for natural lighting. Due to this design choice, both modules performed better when these windows were orientated away from full solar exposure.

The layout differences were only significant when considering the kitchen connection to other spaces on the ground floor. Type B's kitchen temperatures rose much higher than those of Type A's when they were both facing north due to the small connection to the living room from the one door. The solar gains gathered within the kitchen, coupled with the high internal heat gains from the oven and other appliances, needed to be distributed to the other areas for optimal comfort. From this observation, it was suggested to SPA that high internal heat gain utility areas such as the kitchen should be connected to the other areas in open plan. In this configuration, as demonstrated by Type A, the layout should have little effect on thermal performance when orientation is considered.

The concluding result in further analysis with the window glazing alterations coupled with orientation is specifically significant in this study. Where both WWR of the two facades were brought down to 10%, the reduction in solar penetration and heat loss made the effect of orientation negligible. Further testing, bringing the WWR of both to 20% produced the same results (of no difference in thermal performance for the varying orientations). This suggests that equal façade WWR eliminates the need for optimal orientation considerations. This result is further emphasised by comparing the maximum effect orientation can have on the energy performance of the two module terrace houses. Type A had the greatest difference in orientation between best and worst compared to Type B primarily due to the large imbalance of WWR of the two facades. Type A has a WWR difference of 21% between the two facades, whereas Type B had a difference of 11%.

This finding at first glance suggests that orientation can be neglected when designing for optimal passive performance of row houses. It is clear from these results that orientation will make a larger impact on the design if WWR differences between the two exposed facades is large when in Auckland. Making the leap to suggesting that North, South, East or West orientations are of equal thermal value for all row houses in New Zealand seems premature.

Quality Assurance

A significant proportion of the design analysis was spent in Quality Assurance measures to ensure the exercise produced robust results. The sensitivity analysis of a variety of different parameters within the model was performed to establish which factors have the greatest effect upon the results, thereby narrowing the focus on the accuracy of the parameter itself. Such variations included:

- Altering the kitchen appliance scheduling
- Altering daily scheduling
- Altering construction types
- Adding adjacent terrace house buildings
- Adding concrete slab edges

These were compared to a reference model with full ideal loads operating in order to better understand their effect on the temperatures within every room.

As a result special consideration was given to scheduling and equipment loads to ensure an accurate and realistic reading of the simulated model. Tests of the shading of other rows of houses were shown in the same exercise to cause less than 2% difference in total energy consumption.

CONCLUSION

Orientation has a less than 10% effect on the energy performance of these terrace houses in the Auckland climate. As the energy required for both cooling and heating were originally minimal due to the higher than minimum code insulation techniques and window technology implemented, the differences between best and worst orientations resulted in a tiny difference in energy costs. The greatest source of energy consumption and heat gains came from behavioural usage of the equipment specified within the house.

Implications towards Current Design Practice

The implications of these findings towards current design practice, and the use of simulation in current practice, are significant. The results convincingly demonstrate that when varying only orientation in row houses, in Auckland there is likely very little effect on the performance of a well-insulated terrace house building if the high performance windows have the same Window to Wall Ratio (WWR) on both ends of the terrace house. These results are consistent with the findings of most passive design studies for stand-alone houses such as "Designing Comfortable Homes" (Donn & Thomas, 2010). Passive Solar Design to work best requires careful maximising of windows facing North, careful shading for summer, and high performance building fabric.

The issue identified in this study was that a terrace house interior layout makes it difficult to design for optimal solar performance using only "rules of thumb" for orientation and placement of 'warm' living spaces facing North and 'cool' utility spaces facing South. Exposure to sunlight is limited to the windows on the ends of the house. Asymmetry of WWR has been shown to have the expected large impact on how orientation can affect the performance of the terrace house.

The conclusion drawn for Studio Pacific Architecture from this study was the need for the terrace house design teams to focus carefully on window sizing, window placement and orientation in relation to the internal planning of each house. Orientation alone cannot guarantee good passive performance. In fact, in the mild Auckland environment, local overheating of individual rooms no matter which way the building faces may be more of an issue for the people in the building than the energy costs of comfort.

ACKNOWLEDGEMENT

This study would not have been done without the support, access to design work and help which Studio Pacific Architecture offered to this project. The supervisors from both SPA and CBPR have been invaluable for this study.

REFERENCES

Auckland Council. (2013). Proposed Auckland Unitary Plan. Retrieved 10 May 2015, from http://www.aucklandcouncil.govt.nz/EN/plans policiesprojects/plansstrategies/unitaryplan/Pages/home.aspx?utm_source=shorturl&utm_medium=print&utm_campaign=Unitary_Plan

Auckland Council. (2015). Auckland Now and Into The Future. Retrieved 10 May 2015, from http://theplan.theaucklandplan.govt.nz/auckland-now-and-into-the-future/

Donn, M., & Thomas, G. (2010). *Designing Comfortable Homes* (2nd ed.). Wellington: Cement & Concrete Association of New Zealand.

Studio Pacific Architecture. (2015). Studio Pacific Architecture. Retrieved 10 May 2015, from http://www.studiopacific.co.nz

Sullivan, J., Novak, E., & Donn, M. (2012). Thermal performance modelling: design strategies for improved thermal performance in selected NZ houses. Presented at the ANZAScA Conference, Gold Coast, Queensland, Australia. Retrieved 10 May 2015, from http://anzasca.net/2012papers/papers/p28.pdf

UCLA Climate Consultant Software (2015). Retrieved 10 May 2015, from http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php