The Impacts of High Performance Glazing on Typical Light Timber Framed Houses in a New Zealand Winter.

ABSTRACT:

This paper reports on a project which uses two full-scale, three-bedroom standard houses to identify the impact of changes in building elements and materials on indoor environmental quality. The lightweight, timber framed, stand-alone houses are characteristic of New Zealand construction, and meet the requirements for the current New Zealand Building Code in terms of materials and insulation. One of the houses served as the test case for the research and incorporated high performance argon-filled Low-E double glazing. The second house acted as a control, with identical design and location but built using standard construction practice including conventional double glazing.

The paper details the impact of the Low E argon filled double glazing on internal temperature during a monitoring period which ran over the New Zealand winter. It compares results for this wintertime period to the results of previous testing of the same houses over the summertime period, and also examines results in relation to the short-term laboratory-predicted impacts of material thermal performance.

Findings indicated that throughout the wintertime period, both houses performed similarly. In both cases the most notable issue was the high internal temperatures reached on cold sunny days. There were minor performance differences between the standard double glazing and the Low-E glazing. The temperatures reached in the Low-E test house on cold sunny days were less extreme than in the control house, but overnight and early morning temperatures were lower with the high performance glazing. On cold overcast days there was negligible difference between the two double glazing types.

Conference theme: Buildings and energy
Keywords: glazing, thermal performance, monitoring, domestic buildings

INTRODUCTION

The World Health Authority (WHO) recommends an indoor air temperature between 18 to 24 degrees Celsius. Work by Howden-Chapman (2005), and French, Camilleri, Isaacs, and Pollard (2007) indicates that a vast number of New Zealand homes spend significant periods of time below the minimum levels. In 2007 changes to Clause H1, the Energy Efficiency section of the New Zealand Building Code increased minimum levels of insulation in residential properties to those shown in Table 1**.** Double glazing is required if compliance with the code is achieved by meeting standards in the schedule. Alternatives are possible by the use of verification methods employing calculation or computer modelling.

Laboratory based testing can provide short-term controlled condition performance data for individual building components. Computer simulations can predict energy consumption figures over a season or a year but variations between predictions and actual performance are well documented (Williamson 2010). The project reported in this paper monitors modifications to building materials and construction practices in full-scale test buildings, through full seasonal variations, to ascertain actual performance. A previous paper (Tait, Birchmore & Davies, 2011),examined the impacts of glazing changes on the summertime temperatures in a typical New Zealand house, comparing them to impacts on an identical house but using even higher performance glazing. This indicated that for significant periods, the summertime maximum comfort temperatures were exceeded and that the high performance glazing reduced the duration and scale of the deviation. This paper extends the examination into the winter season.

1. METHODOLOGY

The methodology is an extension of that detailed by Tait, Birchmore & Davies, (2011) and is summarised below.

1.1. Test houses

The houses are single storied with three bedrooms and two bathrooms. A standard floor plan (see Figure 1), and standard construction materials and techniques are used. Table 1 summarises the materials used in the construction of these houses and identifies the elemental R values in m2.0C/W. Overhangs on the north side of the house provide complete shading from direct solar gain through glazing during the hottest periods of the summer months.

Construction	Timber Frame on pile foundation				Walls	90x45 radiata pine framing
Sub-Floor	150x25 radiata pine boards with 20mm gap					20mm cavity battens
Floor	particle board, foil insulation draped 100mm between joists (R= 1.3)					Building wrap (stapled)
Ceiling	R3.6 polyester ceiling batts (R= 2.9),10mm plasterboard					R2.6 polyester batts (R = 1.9)
						10mm plasterboard
Roof	trussroof (radiata pine treated) Coloursteel roofing on building paper (stapled)					cedar weatherboard cladding, natural finish
Glazing	R $m^{2.0}C/W$	SHGF	Shading Coefficcient	Visible transmittance	Airtightness	No standard In NZ
Control	0.34	0.74	0.86	80%		
Test	0.55	0.69	0.81	74%		

Table 1: Construction materials of standard houses

1.2. Site selection

The site is on the Unitec Institute of Technology campus in Mt Albert Auckland. Auckland city is situated on a narrow isthmus between two harbours. The campus is approx two kilometres from the Waitemata harbour and four kilometres from the Manukau harbour. There is some influence from Marine weather conditions, as is the case for a large percentage of New Zealands residential buildings.The site is relatively exposed with an open grassed area to the northwest, and an area of well-established trees to the southwest. Surrounding buildings are reasonably distant to the south, north and east. Behind the houses to the southeast is a hilly incline and the students' building yard. The predominant weather in winter is from the southwest, and in summer from the northeast. The house are located with identical orientations but separated to avoid mutual shading. The houses are monitored in a passive, unoccupied condition.

1.3. Monitoring process

Within each of the houses, temperature sensors have been set up to sample the internal air temperature at hourly intervals. Sensors used are Lascar EL-USB-2 Humidity & Temperature USB data loggers. These measure and store relative humidity and temperature readings over 0%RH to 100%RH and -35°C to +80°C measurement ranges. Consideration of the location of sensors was given to align with practice outlined by Barley et al (2005), particularly the avoidance of direct solar radiation. Sensors have been located identically in the two houses. They have been suspended at a height of 1500m above ground level suspended from the ceiling by builders twine. A diagram of the sensor layout is given in Figure 1. Two sensors were placed in each major occupied space with the exception of the hall, third bedroom and ceiling void. In order to check the appropriate test location for the sensors, a third sensor was located at the edge of the room to check initial operation and determine the degree of variability experienced across each space. It was found that the average variation between measurements from the centre of the room and from the edge of the room vary by an average of $0.2^{0}C$ over the 168 hourly measurements, with the maximum variation less than $0.5^{0}C$. This is well within the accuracy stated for the sensors, and indicates that a single measurement in the chosen position is representative of the overall room conditions.

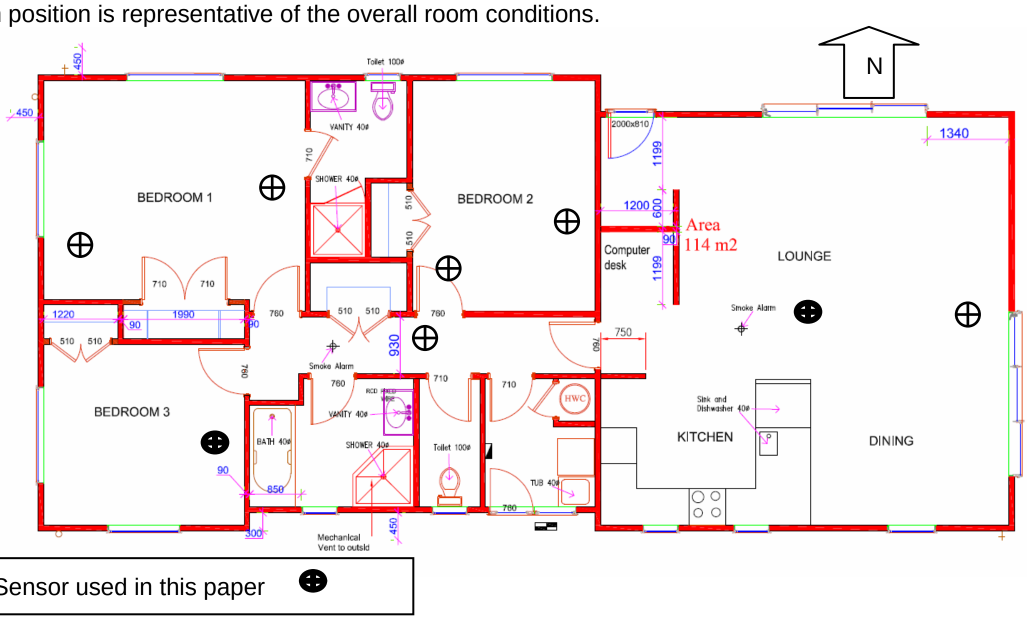

Figure 1: Building layout with sensor locations

A weather station has also been established on site which measures Air temperature, Relative Humidity, Wind Speed and Direction, Rainfall and Global Radiation at five minute intervals. This data is averaged over each hour to complement the hourly data measured internally.

1.4. Rooms for Analysis

The rooms chosen for analysis in this paper are the Lounge Kitchen Dining Room and Bedroom 3. Their North East and South West locations represent extremes of area, window ratio, overall orientation and likely occupation pattern within the one building. This indicates a wall window ratio of 29 and 18% respectively.

Room	Floor Area	Wall area	Window Area m^2 and Orientation			
	m^2	m^2	South	East	North	West
Lounge Kitchen Dining room	44.6	36.5	2.8	5.4	7.0	0
Bedroom 3	9.8	12.43	0.72	0	0	1.9

Table 2: Details of analysed rooms

1.5 Days for Analysis

The focus on the performance of glazing meant that days where the weather would reveal most about the impact on the internal temperature have been chosen. Hence the days chosen represent very high and very low levels of radiation measured for the seasonal period. These days rarely coincide with instances of the highest or lowest outside air temperatures. In winter the day of absolute highest radiation coincided with the lowest outdoor air temperatures and had a cancelling effect on the inside temperatures of both houses. Where neither exceeded 21.5^{0}C

2. FINDINGS

The two houses were monitored from December to August to provide data across the full range of seasonal variations. The focus of analysis has been on the summer period, comprising December, January and February, and the winter period of June, July and August

2.1 Summer time measurements.

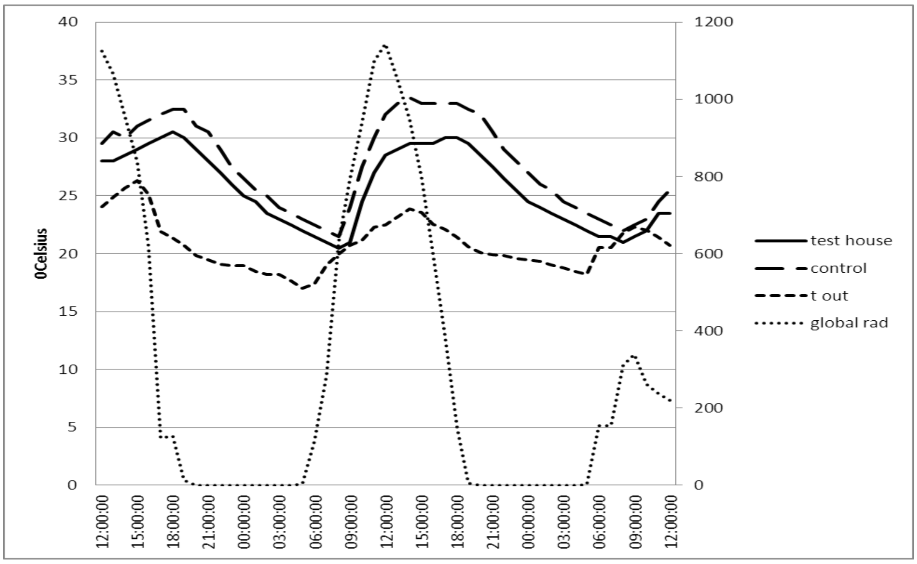

Figure 2: Typical temperatures on a hot, sunny day in Summer Lounge Kitchen Dining Room

Figures 1 and 2 shows that both houses experience temperatures well above 24^{0}C in the Lounge Kitchen Dining Room, peaking on the sample day at 30.5^{0}C and 33.5^{0}C. The shaded area on bar charts indicate the WHO comfort bands and shows that over a summer season from the beginning of monitoring on December 20th to February 28th both houses spent considerable amounts of time above the comfort temperature. The high performance glazing in the test house reduced the peak temperatures on the chosen day by 3^{0}C and reduced instances of temperatures higher than 24^{0}C from 68% to 55%, a reduction of 224 hours. The high performance glazing did not increase the time below 18^{0}C. Tait et al (2011) describes further similar broad performance results for Bedroom 3 and also outline a time lag between peak internal temperatures and peak external temperatures much higher than expected in a light timber framed building. They also reported that opening windows throughout the houses did not significantly reduce the temperature suppression resulting from the high performance glazing.

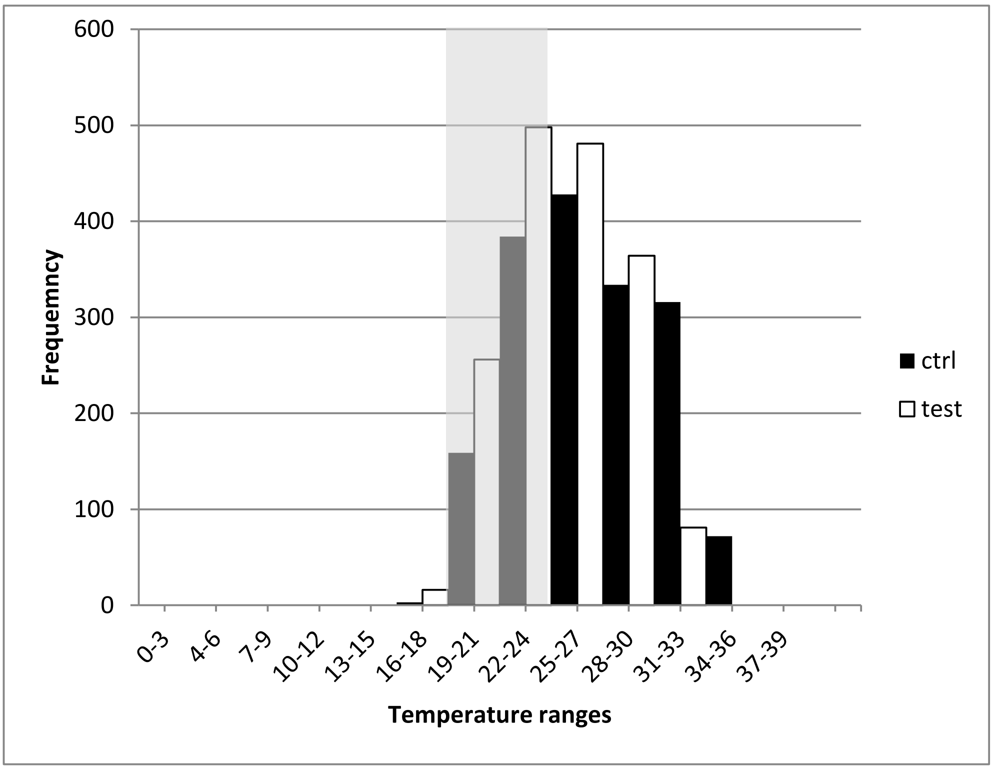

Figure 3:No. of Hours at given temperature ranges in Summer Lounge Kitchen Dining Room

2.1 Winter time measurements.

Although the high performance glazing was shown to improve summertime performance considerably by reducing the levels of overheating experienced in the building, the concern for wintertime performance was whether the effect of the high performance glazing would be to suppress temperatures to levels below those recommended by the WHO. However, although temperatures overall are considerably lower over the winter months, the houses still reach temperatures considerably higher than the WHO recommendations

Lounge kitchen Dining Room

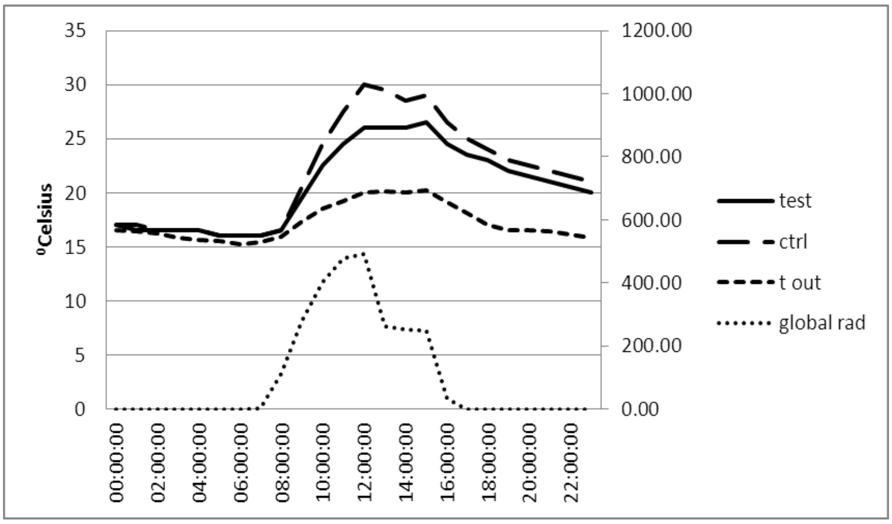

Figure 4: Temperatures on a warm sunny day in Winter Lounge Kitchen Dining Room June 5

Figure 4 & 5 indicate the comparative performance examples of the glazing over the June 1st to August 31st winter period. Room temperatures rise between 6 and 10^{0}C above the ambient temperature. These elevations are similar to those measured in the same space in summer time. Again the high performance glazing reduces undesirable peaks in this case by 4^{0}C on sunny winter days. The temperature between midnight and 8.00am are exactly the same for each house which follows two days of cloudy weather. The temperatures within the control house then begin to exceed the test house showing a 1^{0}C difference at 9,00am. This is 1 hour after the global radiation reaches a level of 110W/m^2. A temperature elevation of 1^{0}C remains in the control house at the end of the day. As expected on overcast days as shown in Figure 5. the difference between the two is minimal being a constant 0.5^{0}C and within the margin of accuracy of the sensors. Both houses follow the outdoor temperature closely. The lag between peak internal and peak external temperatures identified during the summer months also appears to have reduced to zero.

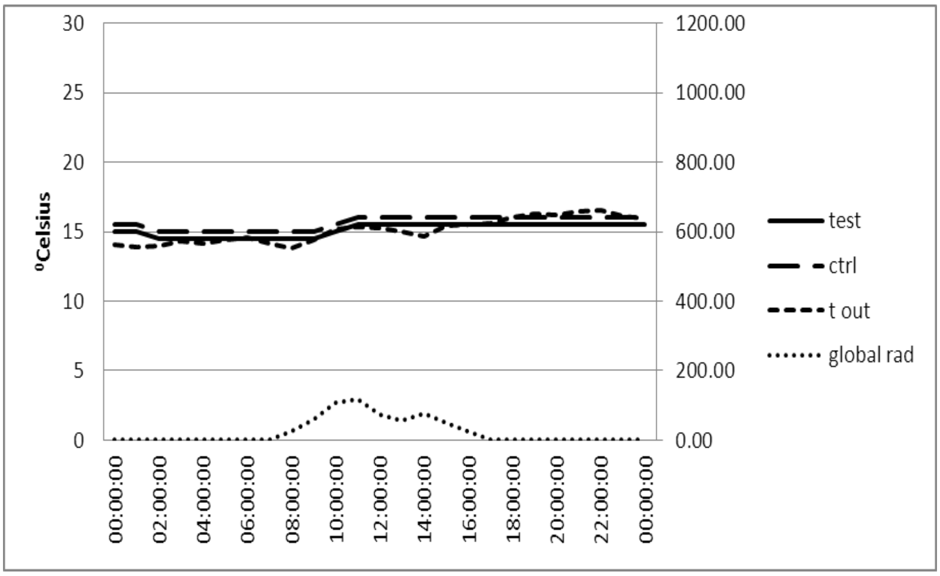

Figure 5: Temperatures on a cold cloudy day, Winter Lounge Kitchen Dining Room June 3

Whilst the figures for sample days appear to indicate negligible differences between the two houses when solar gain is absent, analysis of the full season indicates that the test house spend significant amounts below the temperature of the control house. Figure 6 plots the number of hours that each room spends on the Frequency axis against the noted temperature ranges ion the x axis. As expected, both unheated houses spend significant amounts of time below 18^{0}C. It shows that the high performance glazing has the positive effect of reducing the instances of temperatures higher than 24^{0}C from 0.4% to 0.04%, a total of 70 hours. However it also produces the negative effect of increasing the instances of temperatures below 18^{0}C from 74% to 86% being 263 hours over this period.

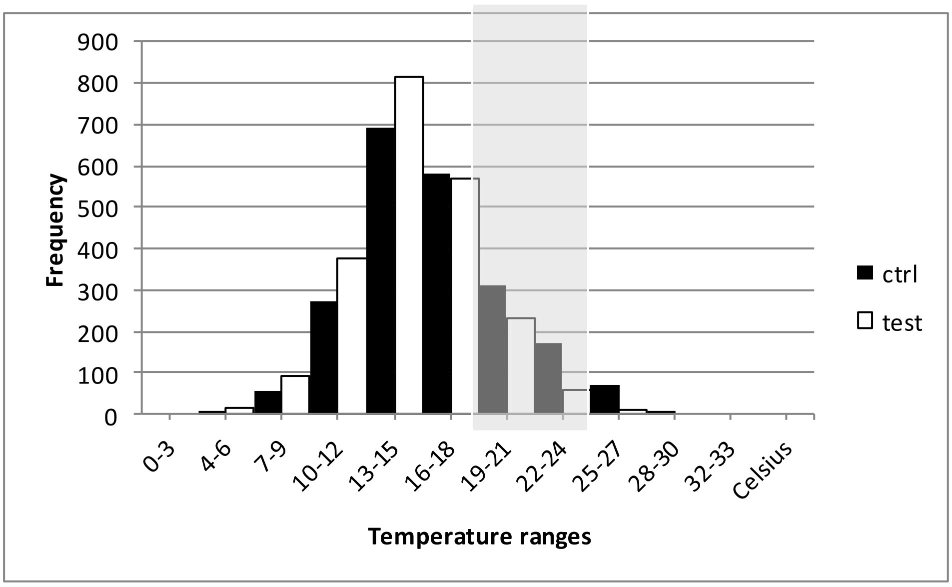

Figure 6: No of Hours at given temperature ranges Lounge Kitchen Dining Room in Winter.

Bedroom 3

Figures 7 and 8 indicate similar trends for bedroom 3 on the opposite corner of the building. Despite the predominantly west and south facing windows the peak temperatures still rose above WHO guidelines. The elevation above ambient has reduced to between 3 and 5^0C. The orientation explains the peak occurring at 4.00pm compared to midday for the Lounge Kitchen Dining Room. The peaks for the control house are lower than those for the Lounge Kitchen Dining Room. The temperatures measured for cold cloudy conditions also follow the characteristics of the Lounge Kitchen Dining Room very closely with the average of the differences between the two houses being 0.46 ^{0}C and the lag remaining insignificant. Analysing across the three month winter season, figure 9 indicates that the instances of the peaks above 24^0C are very low. This aligns with the expected performance of the reduced areas of glazing combined with western and southern orientations. The impact of the glazing difference is shown by the fact that time spent above 24^0C reduces from 2hours to 1hour but the period below18^0C increases by 174 hours to 95% of the time.

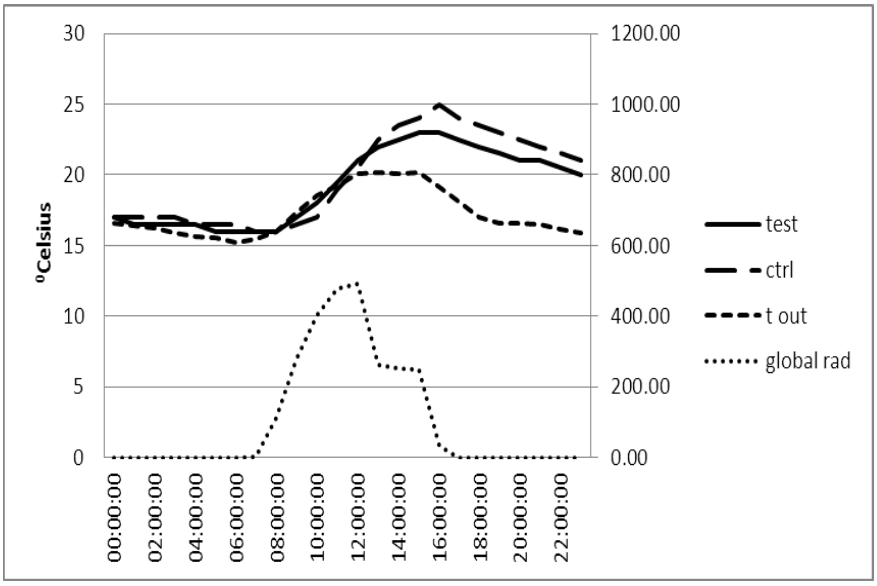

Figure 7: Temperatures on a warm sunny day Winter Bedroom 3 June 5

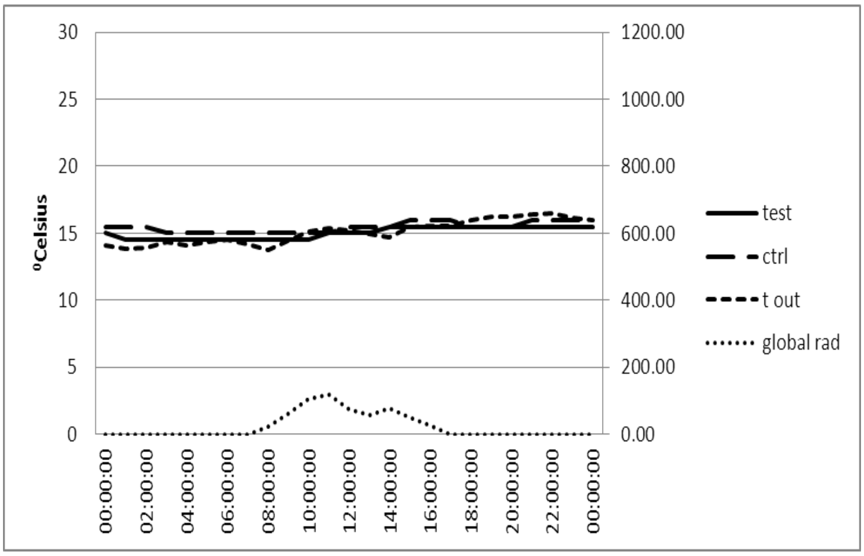

Figure 8: Temperatures on a cold cloudy day Winter Bedroom 3 June 3

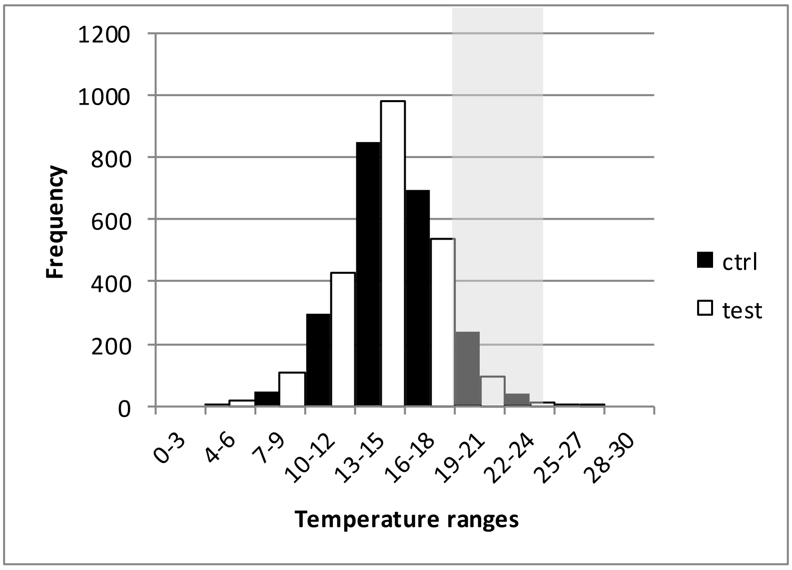

Figure 9. No. of Hours at given temperature ranges Winter Bedroom 3

3. ANALYSIS

Whilst the WHO identifies a preferred comfort band French et al (2007) note that on average houses in New Zealand are heated to 17.9^{0}C. The analysis over the winter period indicates that houses insulated to the current standard in Auckland can achieve 16^{0}C for nearly 50% of the time without any additional heating. The high performance glazing reduces this figure but contributes positively to comfort conditions during the summer. A calculation of the actual energy usage and therefore costs was undertaken to further quantify the balancing effect of the high performance glazing. The degree day technique is a simple manual method of predicting energy usage based on a comparison of external weather data to a known base temperature. The base is an outside temperature which triggers the need for active heating or cooling. The technique has been long used for estimating heating energy. Accounting for intermittent heating and useful heat gains requires the inclusion of factors that can reduce accuracy of the predictions. Estimating cooling energy requires increased complexity to reflect the effects of internal and most significantly solar gain on the base temperature. In this case the base is not a theoretical calculation but the actual temperatures measured in the Control and Test houses. Therefore solar gains are included. Internal gains and intermittent heating are likely to have very similar impacts on both houses so will not reduce the accuracy of the comparisons. In this instance instead of calculating the degree days to an external base, the difference of degree hours between the Test and Control house temperatures is available from the measured data. The degree hours are the product of the temperature difference between the control and the test house for each hour, measured outside the comfort bands. The equation below from CIBSE (2006) outlines the technique.

$$F = 24\,U'\,D_d/\eta \qquad (1)$$

F = the seasonal fuel consumption kWh

η= seasonal system efficiency (COP)

U' = room heat loss coefficient kW/K

24 = factor to adjust to degree hours

D_d = degree days to a base

The room heat loss or heat gain is calculated manually at a design outside temperature. This is divided by the difference between outside and inside design temperatures to give U'. It was assumed that if the house was to expend energy cooling to a comfortable temperature then the same equipment would be used to heat. Therefore a reverse cycle heat pump with a minimum seasonal Coefficient of Performance (COP) of 3.33 (as recommended as minimum by the Energy Efficiency and Conservation Authority for equipment below 4kW) was examined to represent typical performance. (*Air conditioners and heat pum*ps 2012) The cost of electricity per kWh is taken from *Appliance running costs* (2012) and includes GST.

Season	Design indoor temp ^{o}C	Design outdoor temp ^{o}C	Heat loss or gain kW/^{o}C	Difference in Degree hours	Seasonal Energy Consumption kWh	COP	Seasonal Energy input kWh	Electricity Cost $/kWh	Seasonal cost $
Summer	24	25	0.67	2421	1634	3.33	558	0.235	115.32
Winter	18	6	0.086	2065	177	3.33	60	0.235	12.47

Table 3 Energy and cost differences

Results of the calculation for the Lounge Kitchen and Dining Room are tabulated below and indicate a saving of $115.32 in summer cooling energy and an additional cost of $12.47 for the additional heating energy.

3. CONCLUSION

Initially the full scale testing demonstrates that the winter time performance of the Low E, argon filled double glazing compared to conventional double glazing does not always follow expectations set by manufacturers data produced under laboratory conditions. The resistance to solar heat gain as expected suppresses levels to a useful degree on very sunny winter days and reduces solar gain at times when it might be useful. However expectations that the higher R values associated with the argon gas maintains temperatures no higher than the control house have not been met. The unheated test conditions might help explain this. If the spaces were actively heated to maintain comfort conditions the higher R value should enable comfort temperatures to be achieved with lower levels of heating energy compared to conventional double glazing.

Analysis over full seasons indicates that the Low E, argon filled double glazing provides significant improvements to summer time overheating, reducing the occurrence of conditions above 24^0C by 224 hours and reducing the cooling degree hours by 2421. The occurrence of temperatures below 18^0C of an occupied house would reduce as a result of internal gains. This may in turn increase occurrences of temperatures over 24^0C.The majority of these hours are during typical occupied periods of a house and are likely to provide real energy savings in an air conditioned environment. The temperature suppression in winter time increases the heating degree hours by a similar margin but due to the lower heat loss coefficient have a smaller effect on energy consumption. Summertime running cost savings far outweigh the winter time costs by a factor of nearly ten.

A lifecycle carbon and cost analysis could quantify the full impacts of the alternative glazing selection along with testing the impact of the glazing differences on the energy consumed by an active heating system set to maintain comfortable conditions.

REFERENCES

Barley, D., Deru, M., Pless, S., & Orcellini, P., (2005). Procedure for measuring and reporting commercial building energy performance, *Technical Report NREL/TP-550-38601*, National Renewable Energy Laboratory, Battelle, USA,

CIBSE (2006) *Degree – days: theory and application*. TM41; 2006. The Chartered Institution of Building Services Engineers, London.

Appliance running costs (2012). Retrieved from http://www.contactenergy.co.nz/web/saveenergy/appliances

Air conditioners and heat pumps. (2012) Retrieved from http://www.eeca.govt.nz/content/air-conditioners-and-heat-pumps

French, L.J., Camilleri, M.J., Isaacs, N.P. & Pollard A.R., (2006). Exploration of summer temperatures in New Zealand houses and the temperature drivers, 2006 Windsor Conference, 'Comfort and Energy Use in Buildings-Getting Them Right' Windsor UK,.

French, L.J., Camilleri, M.J., Isaacs, N.P. & Pollard A.R., (2007). "Temperatures and heating energy in New Zealand houses from a nationally representative study—HEEP."
Energy and Buildings, 39 (7), pp 770-782.

Howden-Chapman, P., Crane, J., Matheson, A.Viggers, H., Cunningham, M., Blakely, T., O'Dea, D., Cunningham, C., Woodward, A. and Saville-Smith, K. (2005). Retrofitting houses with insulation to reduce health inequalities: Aims and methods of a clustered, randomised community-based trial. *Social Science and Medicine* 61: 2600-2610.

Tait, R., Birchmore, R., and Davies, K. (2011). The impact of changing the glazing on thermal performance of simple timber houses. *Proceedings of the World Sustainable Building Conference,* Helsinki, Finland. 18 - 21 October, 2011.

T. J. Williamson (2010). Predicting building performance: the ethics of computer simulation, *Building Research & Information*, 38:4, 401-410

World Health Organisation. (1987). *Health impact of low indoor temperatures: Report on a WHO meeting,* Copenhagen, 11–14 November, 1985, Copenhagen.