Practical assessment of window shutters for night insulation and solar shading for domestic buildings

JESSICA WINTER

Green Building Consultancy, P O Box 102, Wanaka

ABSTRACT

This paper is concerned with improving the thermal performance of windows to reduce energy consumption and improve comfort in domestic buildings.

Global and local climate systems are changing as a result of anthropogenic carbon emissions, part of which can be attributed to energy demand for domestic buildings. A reduction of energy consumption in buildings is therefore desirable, but buildings will also need to be adapted to suit the future climate. It is hypothesized that window shutters could assist in the adaptation of buildings, by protecting against heat loss in cold conditions and against excessive heat gain in warm conditions, effectively making buildings more robust. By reducing heat loss in winter, using shutters could prove to be a cost effective upgrade for New Zealand homes. Whilst overheating in summer is already an issue in Europe, it is likely to become more relevant to New Zealand in the coming decades. Introducing passive solutions, as an alternative to energy intensive systems such as air conditioning, should be advocated now to allow a market to be become established.

The results of the assessment of several generic window shutter systems will be discussed. The experiments take the form of a number of tests on test cells using data logging equipment, followed by a computer simulation of the thermal behaviour of a building fitted with the shading/insulating devices. This simulation allows for a comparison of internal temperatures and carbon dioxide emissions for variations of window treatment, both in the current climate and in several opposing climate change scenarios. A technical, social and economic evaluation of the technology will be performed, concluding with some recommendations for building designers and policy makers.

KEYWORDS:

energy; shading; passive; insulation; windows

INTRODUCTION

This paper is concerned with improving the thermal performance of windows to reduce energy consumption and improve comfort in domestic buildings. Energy consumption in buildings is linked to greenhouse gas emissions which are (partially or wholy) responsible for climate change. Therefore this paper can be seen as being concerned indirectly with **mitigating climate change**. Climate change is likely to increase internal temperatures in buildings which could lead to discomfort in summer. Therefore this paper is also concerned with **adapting to climate change** since comfort in buildings is directly affected by a warming or cooling of the local climate.

The proposed solution recommeded by this paper also reduces heat loss through windows which could reduce energy use in winter and/or could increase comfort in New Zealand homes.

A change in global and local climates will have a variety of impacts on the eco-systems of which humans are a part. Even if climate change is not predominantly caused by human activity, changes in temperature will undoubtedly affect people. Lifestyles, transport, infrastructure, agriculture, and buildings will all need to be adapted. The changes to local climates that have already occurred in countries such as the UK and Australia are having an impact on buildings and their occupants.

Windows are a weak point in a building's fabric. They provide daylight, ventilation and visual contact with nature, but they also compromise the thermal properties of buildings.

Windows

Windows typically make up just 10% of the total building envelope but through them the building losses around 20% of its heat.(Pilkington 2001) This does not include the 25% of heat losses that are as a result of infiltration and ventilation: Some infiltration occurs around window frames and ventilation is traditionally provided by windows. Aside from their thermal properties, windows are also a weak point in terms of acoustics, security and ingress of water.

Reducing heat loss in winter should still the primary aim of policy makers and building designers in New Zealand, but increasingly, buildings in other countries with temperate climates are suffering from overheating as a result of higher internal gains and a higher ambient air temperature. The 'urban heat island' in cities can exacerbate this problem, especially when issues such as noise, air pollution and security concerns prevent occupants from opening windows for ventilation.[1]

Trends around the world show a marked increase in air conditioning markets. In the UK this is as a result of higher ambient air temperatures in summer and decreased costs and greater availability of domestic systems. In New Zealand the air conditioning market has doubled in the last decade.

'Air-conditioning can double the electricity consumption of a house and its associated carbon emissions…' (EST (UK) 2005)

Some window treatments, such as blinds, curtains, shutters, can perform as both solar shading and insulation. They reduce heat loss, which can conserve energy used for heating. If solar radiation and high external air temperatures present a risk of overheating, these systems can reduce heat gains. Because they are adjustable, passive solar heating can still be utilised in winter. These systems can be adjusted to suit the season or the time of day, thereby improving the adaptability of the building. However, little data exists on the actual performance of these systems, or their potential as energy conserving measures.

While window technology has improved and now perform better at retaining heat and can assist in passive solar heating in winter, high performance glazing is still expensive in New Zealand, often prohibitively so for retrofitting in existing buildings. Studies on the most cost effective retrofit options show that fitting thermally lined curtains and pelmets to single glazed windows result in a similar performance to double glazing (when the curtains are closed) (Lloyd, Callau et al. 2007). Shutters could provide a similar resistance to heat loss through windows.

The intention of this paper is to investigate the effectiveness of solar shading/insulation systems for both reducing the risk of overheating during the summer and for reducing heat loss when solar radiation is not present. It aims to compare and evaluate various systems that are already on the market that can be adopted immediately, rather than new or emerging technologies.

The experiments that form the first part of this paper will test the R-values and shading coefficients of several shading/insulating systems before applying them to a computer simulation of a 'real' dwelling in the second part. From the results of the simulation an assessment of the energy saving potential of the systems can be conducted.

---

[1] Urban areas are often 6 degrees above the air temperature of surrounding countryside, according to the Met Office www.metoffice.com

CLIMATE CHANGE

'Warming of the climate is unequivocal, as is now evident from increases in global average air and ocean temperatures, widespread melting of snow and ice, and globla mean sea level.'
(IPCC presentation to UN Climate Change Conference, Nairobi, 2007)

The incidences of heat waves in Europe have increased steadily since 1990. In New Zealand, NIWA have used IPCC data to predict the climate in New Zealand, which shows warming of average air temperature of between 1.5°C and 3°C by 2080 (for an IPCC mid-range emissions scenario)(NIWA 2007). An increase in the number of days above 25°C is expected, particularly at already warm northern locations,and potentially in the arid climate of central southern regions.

METHODOLOGY

The experimental process will consist of a number of experiments on test cells with shading/insulating systems fitted to the glazing. This will be followed by a computer simulation of the energy consumption of a 'typical' dwelling fitted with shading/insulating systems. The same building will be modelled in a future climate scenario.

The decision to only assess vertical window treatments, i.e. systems that are parallel to the glazing, was based on findings in existing research which suggested that vertical systems could act both as insulation and as solar shading (Pezzey, 1984) This dual use means that energy savings – and improvedcomfort – can potentially be made throughout the year.

The focus of this paper will be on shutters and blinds/curtains, since these are readily available products and familiar. Many complex façade arrangements have been developed in recent years but it was thought that these were not applicable either to domestic buildings or to the retrofit market.

Figure 1: R-values and solar heat gain coefficients of shading/insulating devices

Window treatment	Theoretical R-value (m^2KW^{-1})[1]	Approx. Solar Heat Gain Coefficient (SHGC)[2]
Unshaded single glazed window (glazing only)	0.18	0.70
Unshaded double glazed window (IGU) (glazing only)	0.36	0.64
IGU with external louvred shutters	0.44	0.11
IGU with external Solid shutters	0.60	0.01
IGU with internal louvred shutters	0.44	0.46
IGU with internal solid shutters	0.60	0.09[3]

[1] calculated using standard method as BS EN ISO 10077 – 1:2000

[2] based on data from IES guidance notes unless noted otherwise

[3] from manufacturer's literature: www.luxaflex.com.au

Test cells, or hot boxes, are used initially to test the systems; further analysis will be performed using building energy simulation software.

The test cell experiments are tested in real conditions in the UK (winter) and New Zealand (summer). The intention is to obtain empirical R-values and SHGCs.

Figure 2: test cell

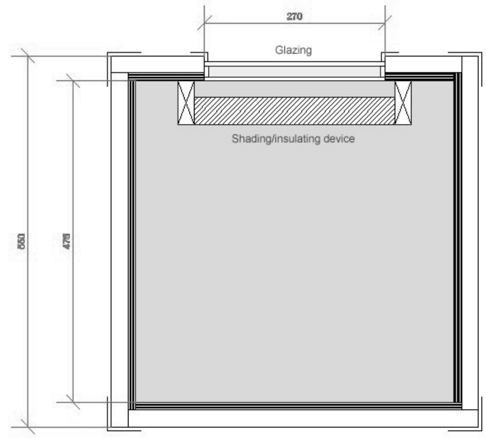


Figure 3: Plan of test cell [not to scale]

Gemini ‘Tiny Talk’ data loggers[2] are used to record internal and external temperature. An additional external logger is placed in direct sun to indicate when direct solar radiation is present. Temperature readings are logged every 2 minutes for a period of at least 16 hours (sunrise to sunset).

Thermal analysis software will then be used to predict the effect of the systems on the energy consumption of a theoretical building. The software (IES Virtual Environment) can simulate heat loss and solar gain through glazing and opaque materials, and can approximate the effect of solar shading and night insulation systems using R-values and shading coefficients.

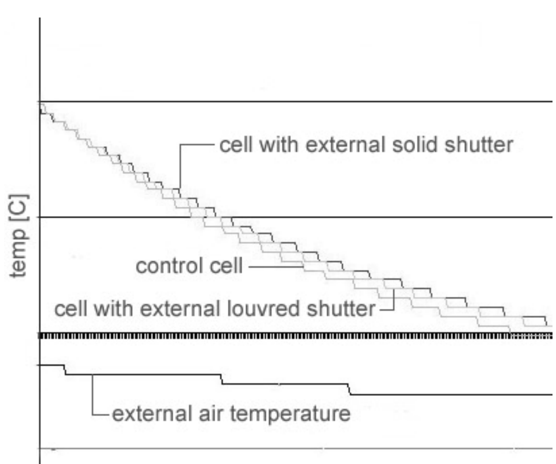
ANALYSIS

Winter

The resistances of louvred and solid shutters were compared to uninsulated glazing (see figure 1).

The value for the louvred shutter was approximated from the R-values of the control test cell and the test cell with a solid shutter, which can both be assumed to be reliable. This rate of heat loss corresponds to a U-value of 0.47 m^2KW^{-1}, which is slighter higher than the value of 0.44 m^2KW^{-1} calculated by the ISO standard method. An R-value of 0.47 m^2KW^{-1} for the window assembly corresponds to an R-value of 0.11 m^2KW^{-1} for the combined resistance of a louvred shutter + air-gap. This can also be expressed as a 25% overall reduction in heat loss through the window assembly, under winter night conditions. However, as a percentage of heat loss from the whole cell, the reduction in heat loss is small (figure 4).

During the course of the winter test cell experiments, differences in the formation of condensation on the exterior of the glazing were observed. Generally less condensation occurred on the externally insulated glazing. Further research into the affect of shading/insulating systems on the formation of internal condensation would complement this study, especially given the problems with condensation experienced in singled glazed dwellings in New Zealand.



[2] www.geminidataloggers.com

Figure 4: Internal temperature of test cells overnight

Summer

The shading systems were tested in various combinations to ascertain their relative performance.

The solid systems performed well at reducing heat gain due to solar radiation (see figure 5). This was anticipated because of the very low shading coefficient of impermeable, opaque shading systems.

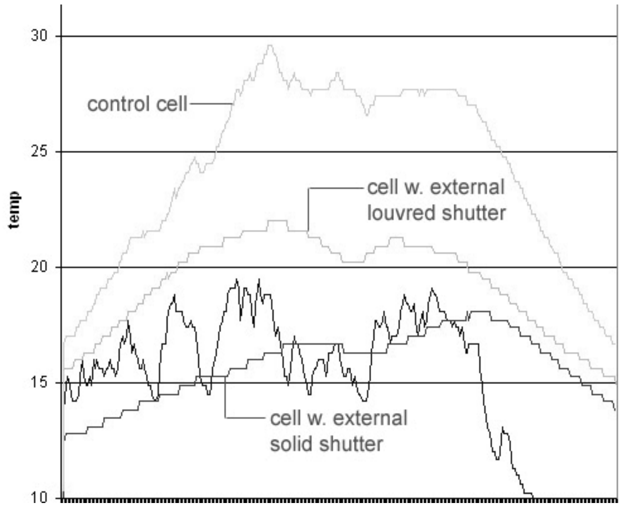


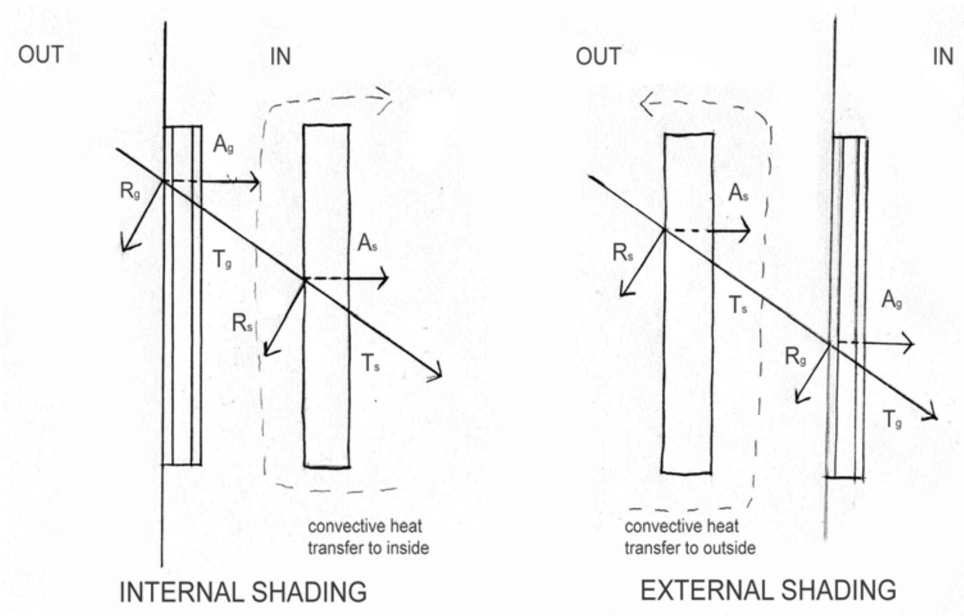
Figure 5: Internal temperatures in shaded test cells (external air temperature shown in black)

It is generally assumed that external shading systems perform better than internal systems (see figure 6). This was tested empirically.

When identical systems fitted internally and externally are compared, the external system does out-perform the internal system, but the difference is not as great as expected.

As expected the shading systems with the lowest shading coefficient reduced the heat gain most effectively. Whilst external systems are more effective than internal, the permeability of the systems also has a significant effect on the rate of heat gain, whether the system is internal or external.

Figure 6: Comparison of performance of internal and external shading devices



When solar radiation hits the external shading device, only the transmittance portion of the solar radiation incident on the shading system is transferred to the glazing.
R = reflectance A = absorbtance T = transmittance

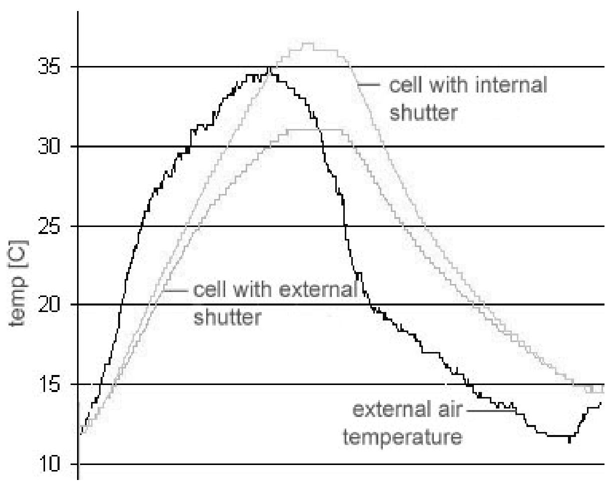


Figure 7: Internal shading compared with external shading

The tests were repeated with ventilation introduced to the test cells to simulate a combined cooling regime of shading and ventilation.

Ventilation improved the cooling effect when combined with solar shading but ventilation alone had little effect on reducing the internal air temperature. Solid shutters combined with ventilation was not the most effective option because the shutter prevented the free flow of air; the best result was produced by an external louvred shutter (see figures 8 and 9).

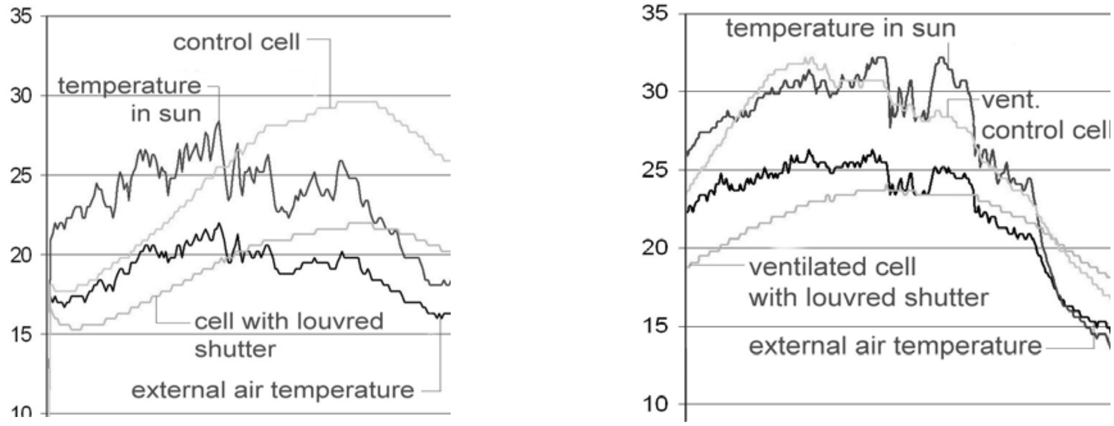


Figure 8 and figure 9: test cells with louvred shading: with and without ventilation

When combining solar shading and ventilation, a balance between a low shading coefficient and high permeability had the greatest impact on the internal temperature.

Application to simulated building

A building, based on the specifications of a typical 2 bedroom terraced house as described in Approved Document L1 of the 2002 UK Building Regulations, was created in IES and the temperature and energy consumption was modelled for the southern UK.
In winter (between October and March) the shading/insulating systems are closed between 18:00 and 08:00, and in summer (between April and September) the systems are closed between 08:00 and 18:00. This profile was chosen to reflect the occupancy pattern of the building rather than sunset and sunrise times as this was considered more realistic.

Figure 10: Energy consumption in typical dwelling (UK climate)

	Heating energy (to 18°C) kWh	Cooling energy (to 23°C, using air conditioning) kWh	Total heating and cooling energy kWh
Base (IGUs with no window treatment)	1890	315	2205
Solid external shutters to all windows	2010	12	2022
Louvred external shutters to all windows	1960	29	1989
Solid internal shutters to all windows	1790	40	1830
Louvred internal shutters to all windows	1840	105	1945
Blinds to all windows	1900	53	1953

In the climate simulated, internal shading systems provide the greatest energy savings, when heating and cooling loads were combined. An unexpected outcome of this research is that while the external shading systems were more effective at reducing summer heat gain, they blocked some useful solar gain during the spring and autumn. The resulting increase in heating load was more significant that the cooling benefit.

In a warmer climate scenario (UKCIP02 B2 scenario: medium-high emissions profile), the demand for heating decreases slightly while the demand for cooling increases fourfold, representing a 75% increase in energy consumption overall. This result confirms the findings of a report by the Tyndall Centre which states that **as the UK climate warms, energy consumption for cooling will increase faster than energy consumption for heating will fall** (Levermore et al., 2004) In this scenario, external systems, which have the greatest cooling potential, are ultimately more appropriate.

Figure 11: Carbon dioxide emissions (kgs) resulting from heating and cooling in the current UK climate and the predicted UK climate in 2050

	Current climate		2050 climate[1]	
	heat	cool (23°C)	heat	cool (23°C)
Base	359	135	351	528
Solid external shutter	384	4	351	102
Louvred external shutter	373	11	351	190
Solid internal shutter	341	19	323	217
Louvred internal shutter	351	46	337	327
Blind	362	23	344	251

[1] Annual average temperature increase of 2.5 °C (UKCIP scenario for the southeast UK in 2050s based on medium-high (business as usual) emissions)

Technical, social and economic evaluation

Technical:
The primary drawback of window treatments such as shutters,blinds or curtains is that they require user interaction. While it has been shown in other studies (e.g. Lloyd et al, 2007) that these systems can reduce heat loss and heat gain through single glazed windows as effectively as double glazing, this relies on sensible use being made of them by occupants.

Secondly it can be problematic to incorporate external shutters on most windows in New Zealand and countries like the UK and Australia since most windows are designed to open outwards. In Europe window designs take account of external shutters by opening inwards.

In terms of insulation, there is no difference between the performance of internal and external systems. This is relevant because internal shading is more user-friendly and more likely to be used effectively. The empirical data showed that internal shading devices can be reasonably effective in mitigating overheating.

In terms of cooling, sthe test cell experiments suggest that solar shading should be coupled with ventilation.
Social:
This technology could be applied to the building incrementally over time during periods of refit, renovation, and rebuild. This paper has confirmed that shading/insulating devices can reduce the energy consumption of buildings while at the same time making them more comfortable.

The need for more user interaction may not necessarily be a barrier to the implementation of this technology. Improved comfort is likely to be greater driver than energy savings. User education has an important role in establishing changes in builiding management habits.

Some reports in the past have explored the acoustic benefits of shutters, especially in cities (where they can double as security whilst allowing ventilation). While this is potentially valid, this effect has not been explored in this study.

<u>Economic:</u>
The small energy savings shown in Figure 10 would result in long payback periods and shutters may never recoop their cost. However, they can help make buildings more comfortable and can be more economic as energy prices rise and as the climate warms.

In New Zealand window treatments such as blinds, shutters and curtains can certainly be a more economic way of improving window performance (particularly if retrofitted to existing single glazed windows) than the currently very costly high specification frames and glazing available.

Passive systems are certainly preferable to air conditioning in terms of upfront cost and energy conservation: The cost of installing full air conditioning to the simulated house would be in the region of GB£4500 (approx. NZ$12,000). Window shading can achieve the same level of comfort (if operated correctly) for a fraction of the cost.

The analysis concludes the following:

- **Shading/insulating devices are more effective when used in conjunction with other passive cooling mechanisms such as ventilation.**
- **Permeable systems with a higher shading coefficient can be just as efficient as solid systems if combined with ventilation.**
- **Internal systems are less effective than external systems, but perform adequately provided they have a very low shading coefficient and are well sealed when closed.**
- **Internal systems are more convenient to use and are more likely to be used efficiently by occupants.**

CONCLUSION

This paper has examined the potential of devices that act as both night insulation and solar shading for windows in terms of mitigating climate change through saving energy, improving comfort and adapting to the future climate.

The investigation has taken the form of a practical and computer simulated assessment and a technical, social and economic evaluation.

The ability of the shading/insulating systems to reduce the inward heat flow through the window due to solar radiation is far more significant than their resistance to heat loss. Fitting shutters or blinds in the simulated house significantly reduced the energy consumption due to cooling (assuming that the same comfort level would otherwise have been achieved using air conditioning). In the case of the systems with very low SHGCs (solid shutters), the requirement for artificial cooling was virtually eliminated. When climatic data based on a UKCIP climate change scenario for 2050 was applied to the model (medium-high emissions scenario) the shading/insulating devices reduced the cooling load by between 50% and 80% of that of the unshaded building.

The impact on daylighting of shading devices with very low shading coefficients has been recognised. A test cell experiment into the combined effect of shading and ventilation was performed, and it was found that a permeable device combined with ventilation that afforded a reasonable level of daylighting could perform as well as a device with a very low shading coefficient with no ventilation.

While the results of the experiments and simulations show that shutters and blinds are not particularly effective at reducing energy consumption due to heat loss when installed on IGUs, other studies have shown that they can have significant benefits when retrofitted to single glazing, in terms of reducing heating energy use and improving occupant comfort (Lloyd, Callau et al. 2007). The savings from reduced heating loads through utilising shading/insulating devices are small (the best performing of the systems applied to the example house reduced the heating load by about 5%) but in terms of GHG emissions, these savings would add up if implemented on a wide scale. However, for reducing heat loss alone, they are not generally economically viable.

The results have shown that shading/insulating devices are effective technology for cooling, either alone or combined with ventilation, and are an economically viable alternative to air conditioning for cooling, if installed *instead* of a new air-conditioning system.

A mandatory standard for overheating in domestic buildings would encourage building designers to take overheating into account. Guidelines, similar to those offered by BCO(BCO, 2005) or the voluntary method in SAP2005(DEFRA/BRE, 2005) should be offered by the building code on how to reduce overheating without resorting to air-conditioning.

The uptake of air conditioning for domestic buildings in the UK and Australia is well established, and a market is emerging in New Zealand (especially as a result of the rapid growth of the heat-pump market). In New Zealand the air conditioning market has doubled in the last decade. This will increase domestic electricity consumption, a problem in terms of climate change (if demand is met by fossil fuels) but also in terms of peak loads. Shading/insulating devices could replace conventional air conditioning and achieve equally comfortable internal environments.

The use of air conditioned cooling can double the emissions associated with heating and cooling in a building (EST, 2005). UK Government statistics predict that 2.3 million homes will have air conditioning by 2050 (Baker, 2005)[3] If these homes were all like the simulated house in energy usage, the emissions from the cooling load of these buildings would be in the order of 1.2 million tonnes of carbon dioxide annually. In reality, it is likely that the first homes to retrofit air conditioning would be at the high end of the market and would probably be far bigger, and therefore more energy hungry, than the example house in this paper. If all 2.3 million of these dwellings had solid external shutters fitted, for example, the emissions from cooling them would be less than 250,000 tonnes of CO_2. This is an example of how small savings, minimal to individual households, can add up.

The results of other studies conducted in New Zealand suggest that shutters would be more effective when retrofitted to single glazed, rather than double glazing as assumed in this study. A study into the affect of shading/insulating devices on the formation of condensation would also be highly relevant to New Zealand.

REFERENCES

Lloyd, B, Bishop, T & Callau, M. Sept 2007 *Retrofit Alternatives for State Houses in Cold Regions of New Zealand* University of Otago

[3] A serious problem since nearly all the UK's electricity comes from non-renewable sources

Climate Variability and Change: Climate Change Scenarios for New Zealand. Retrieved 05 October 2005 from the NIWA website on the world wide web: http://www.niwascience.co.nz/ncc/clivar/scenarios

Energy Management report : Glass and building regulations: Thermal insulation and energy efficiency November 2001 Pilkington Group

Hot topic - the cooling issue (Hot homes - cold comfort)' EEPH News 20 09 05 retrieved 05 October 2005 from the Energy Saving Trust website on the world wide web: http://www.est.org.uk/partnership/energy/index.cfm?mode=view&news_id=458

Pezzey, J. 1984 *An economic assessment of some energy conservation measures in housing and other buildings* BRE

Levermore et al. 2004 Technical report 14: 'Accuracy of modelled extremes of temperature and climate change and its implications for the built environment in the UK' Tyndall Centre for Climate Change Research

BCO Guide 2005: Best practice in the specification for offices British Council for Offices

The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2005 edition DEFRA/BRE

'Hot topic - the cooling issue (Hot homes - cold comfort)' EEPH News 20 09 05 retrieved 05 October 2005 from the Energy Saving Trust website on the world wide web: http://www.est.org.uk/partnership/energy/index.cfm?mode=view&news_id=458

Question to the House of Commons on 07 June 2005 by Norman Baker MP regarding energy use and greenhouse gas emissions associated with air conditioning in UK homes. Retrieved from the United Kingdom Parliament website on 18 August 2005 on the world wide web at: http://www.publications.parliament.uk/pa/cm200506/cmhansrd/cm050607/text/50607w05.htm