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A Thermal Storage Window System for Lightweight Construction

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Abstract

To overcome the problem of thermal storage in lightweight buildings a window system that collects and stores solar energy has been designed and tested. The window utilises an insulated glazing unit as the outer collecting surface. Surrounding the window internally is macro-encapsulated phase change material within aluminium frames that stores collected heat. An internal single glazing entrains warm air within the window system during the collection phase. The performance of the window system has been investigated experimentally and by computer simulation. Experimental results indicate that for a 2400mm x 2400mm single-room building in Wellington, insulated to current Building Code levels, a 1000mm high x 1000mm wide x 300mm deep thermal storage window system has the potential to store and make available approximately 11.5 GJ of useful energy per annum. The effect of the window system on energy use and indoor air temperature is predicted for three locations in New Zealand (Wellington, Auckland and Christchurch), for three different levels of building insulation. Simulation results are compared with the measured results with good agreement. Compared with a typical New Zealand, single glazed, aluminium framed window system of similar dimensions, an energy analysis of the proposed window system shows an 18.2 GJ increase in embodied energy and a 79 GJ decrease in energy demand, giving an overall predicted 50-year lifetime energy saving of 60.8 GJ

Introduction

A problem exists with passive solar energy collection in that the collection period is often out of phase with the period when heating is most needed. This is known as the diurnal solar-to-load asynchrony. For a passive solar building to maximise the solar contribution, some form of storage must be employed to ensure that this energy is available when required (Norton, 1992).

Studies have shown that thermal mass short-term storage has a positive influence on the proportion of direct window solar gain that can be used to offset heat losses and thus reduce auxiliary demand (Donn and Dechapunya, 1983; Balcomb et al., 1984; Balcomb and Wray, 1988; Lee et al., 1991; Isaacs and Donn, 1994; Isaacs et al., 1996). Short-term thermal storage addresses the diurnal solar-to-load asynchrony by storing solar gains made during the insolation period and making it available at night and to a lesser extent to reduce preheating of the building the following morning (Norton, 1992).

For thermally massive buildings such as buildings with exposed masonry surfaces internally, thermal storage may not be a problem, but for thermally lightweight (storage deficient) buildings such as many of the existing timber frame buildings in New Zealand, a problem exists.

The common practice of having thermally massive floors in heavyweight or lightweight construction has a major drawback in that they are often isolated from direct insolation by being carpeted. In addition to this, carpets effectively insulate the concrete, serving to decouple the thermal mass from the room air, which leads to a reduction in performance of the thermal storage of around 50% (Niles and Haggard, 1980; Givoni, 1991). Furthermore, in dwellings curtains and blinds are often used as an aid to providing comfort conditions, in that they provide shade from direct beam radiation and protection interior fittings and furnishings from ultraviolet radiation (UV) degradation. In many instances the use of blinds leads to greatly increased air temperatures adjacent to the window, and then ventilation is used to dump the excess heat. Thus while shading and ventilation may control daytime overheating; these strategies can actually increase auxiliary heat requirements due to the fact that heat is being dumped that might otherwise be stored and used (Jones, 1992).

Concept

Given that internal shading devices can increase air temperatures adjacent to the window, and that thermal mass has the capacity to store excess heat; if the mass were to be applied to the internal window reveals, head and sill where it will always be in the direct gain zone, it may be possible to use this stored heat to offset auxiliary heating. To be successful, it would be vital to resist the flow of heat from the thermal store back out through the window to ambient conditions.

In its simplest form the design concept is to place a thermally massive material such as concrete immediately adjacent to the internal window reveals head and sill of an insulated glazing unit, where the thermal mass will be in direct sunlight and will thus be able to store excess heat; even if a blind is used to cut out direct beam radiation. The concept is somewhat akin to that of a Trombe Wall, except in this case; the glazed area also serves as a direct gain window. The initial concept is illustrated in Fig. 1.

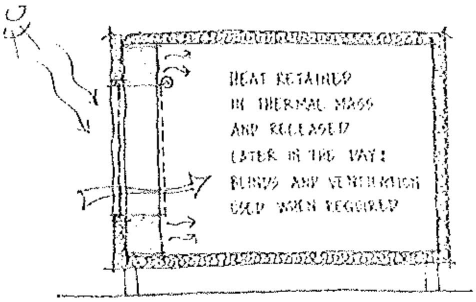


Figure 1: Schematic of Design Concept Showing Thermal Mass Applied to Window reveals

Experimental Investigation

In order to test the proposed window system at full scale and under real climate conditions it was decided to carry out side-by-side comparison tests with controlled internal conditions. To do this two matched test cells were constructed and located side-by-side at the Building Research Association of New Zealand (BRANZ) site at Judgeford, Porirua. The test cells were placed on a large flat concrete area in the south paddock testing area that afforded good solar access. The test cells are illustrated in Fig. 2. Parameters such as heat-loss, aperture size, tilt and orientation were carefully considered so that they would be equivalent in each test cell. In practice this was achieved by very careful construction, particularly in relation to sealing the air barriers and ensuring all cavities had the required level of insulation properly inserted. Blower door tests were used to balance air infiltration rates.

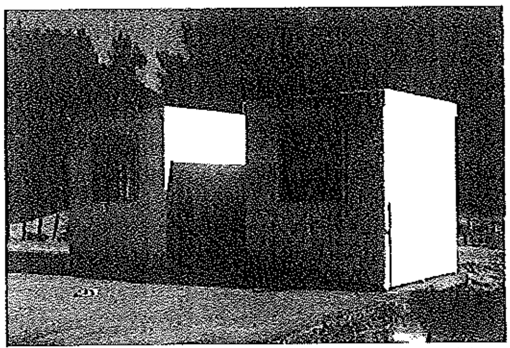


Figure 2: Matched Test Cells Used for Side-by-Side Comparison Testing.

The initial sketch design (Fig. 1) proposed concrete of 300 mm square section surrounding the window. In practical terms however, the self-weight of concrete dictates smaller sections than 300mm square. In order to manhandle the concrete into position, the concrete was cast in sections of 100mm wide x 300mm deep. This also had the affect of increasing the surface area of the concrete and optimizing the thickness for diurnal heat storage (Balcomb et al., 1984; Balcomb and Wray, 1988). The head and sill sections measured 1600mm in length, while the jamb sections measured 1000mm in length. Holes were cast into each section to facilitate fixing together. The concrete sections are illustrated in Fig. 3.

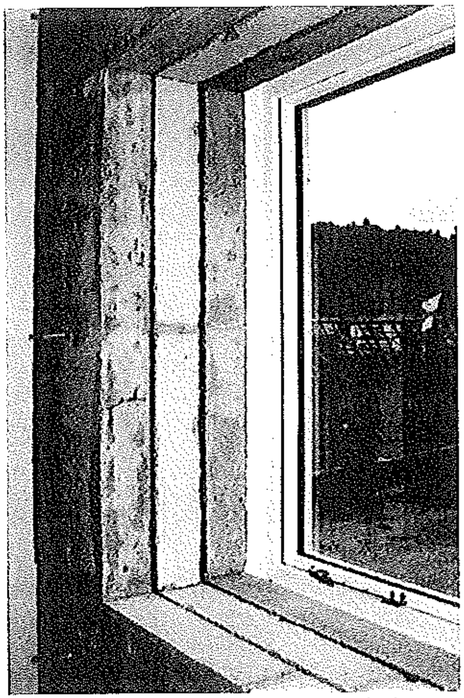
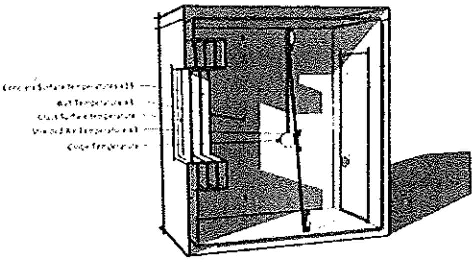


Figure 3: Concrete Internal Window Surrounds.

Type T thermocouples linked to an Agilent 34970A Data Acquisition/Switch Unit (data logger) were used to measure temperatures over a one-year period. Black-globe temperatures were measured in the centre of each test cell to give an approximation of comfort conditions, along with shielded air temperatures measured at three vertical positions. The location of the thermocouples is shown in Fig. 4



Source: (Author 2004)
Figure 4: Location of Thermocouples in Experiment Test Cell.

To monitor the relevant ambient environmental conditions (solar radiation, wind speed and direction, ambient temperature, relative humidity, and rainfall), measurements were taken and recorded using a 'Skye Minimet' Weather Station. The data sample rate and recording rate were set to match the data being recorded within the test cells.

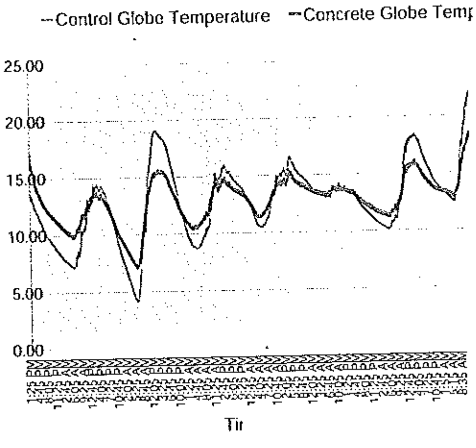
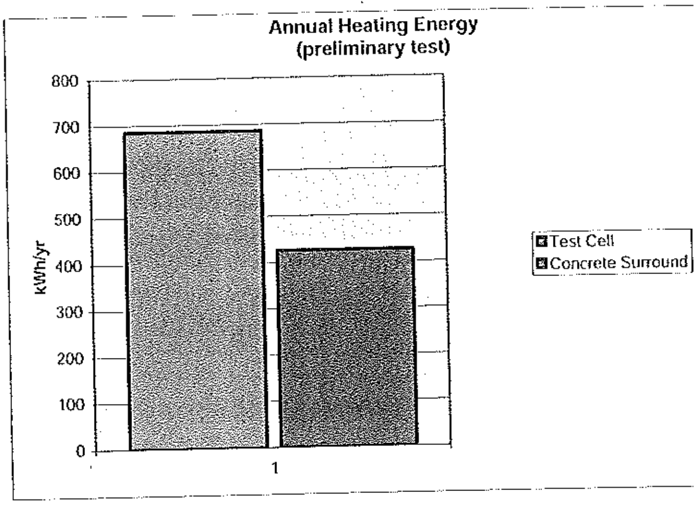


Figure 5: Globe Temperatures in Centre of Test Cells for One-Week Period

Fig. 5 shows a comparison of the free running (no heating) globe temperatures in the two test cells for a one-week period in September 2001. Throughout the year the Experiment Test Cell with the concrete window surrounds maintained more even temperatures compared with the Control Test Cell. This indicates that the thermal window system is absorbing solar thermal energy during the day and releasing it later in the day.

To reduce the time frame for the project, the computer simulation program SUNREL was used to predict yearly energy use for the preliminary design. The results illustrated in Fig. 6 indicate that the proof of concept thermal window is capable of storing and making available approximately 250 kWh/yr (900 MJ/yr).



Source: (Author 2004)
Figure 6: Comparison of Predicted Yearly Energy Use

Major difficulties with the concrete window surrounds however fall into two categories; weight related issues and lack of control of charging and discharging of heat. Weight related issues include difficulty with lifting the concrete into place, difficulty in securing the concrete, and, additional structure is required to support the total weight of the concrete for both static loading (self weight) and dynamic loading (seismic movement). Lack of control of when the concrete begins to absorb useful heat is a drawback in situations such as winter where the concrete absorbs heat that might otherwise be used for useful space heating. To overcome these difficulties an alternative form of thermal storage was sought.

Phased Change Thermal Storage

A review of the open literature indicated that Phase Change Materials (PCM's) were light weight, had 15-20 times the thermal capacity by weight, had been used for building solar energy storage applications, and had been widely investigated both experimentally and analytically. Containment methods for the PCM range from macro-encapsulation where the PCM is used as a mass storage unit, through direct incorporation into building materials at time of mixing, or by immersing the building material in liquid PCM to micro-encapsulation where the PCM is bound or encapsulated in small particles that can then be incorporated in normal building materials. (Hawes et al., 1993) investigated the characteristics of different types of PCM incorporated in wallboards and in concrete blocks. Manufacturing techniques were considered and applications of PCM wallboard and PCM concrete blocks were discussed. The melt temperatures for the PCM's were chosen to be within the human comfort range 16 - 25° C. One major drawback discovered was the leaching of PCM from the surface when not fully encapsulated. (Scalat et al., 1996) found that it was desirable to have a thermal storage system that was capable of being fully charged over a period of 7 hours and have the capacity to discharge heat over a period of not less than 16 hours. (Kissock et al., 1998) performed experimental and simulation studies on PCM wallboard using a PCM with a melt temperature range of between 23.9°C and 32.2 °C. They identified limitations with regard to the usefulness of storing energy at these temperatures with respect to the normal operating temperatures of buildings. They also concluded that to take full advantage of the PCM's latent heat storage the melting temperature should ideally be within the maximum allowable indoor temperature swing.

Initial experiments for the thermal window system that utilised a PCM produced a concrete that incorporated a paraffin wax PCM in a bound matrix of diatomaceous earth in an effort not only to reduce the weight of concrete, but also to improve the thermal capacity. (Because PCMs change from a solid to a liquid state, they must be contained, if they are to be used in buildings) Experiments were carried out with various mixes of PCM impregnated diatomaceous earth, and although the weight was reduced by 20% and the thermal capacity appeared to be enhanced (Joubert and Skates, 2001), the strength of the concrete was seriously compromised (Corner, 2002). Since weight was an important consideration for the window system, the use of PCM on its own, in a lightweight container had obvious attractions.

Containment of Phase Change Material

A revised window arrangement was constructed that utilised Rubitherm™ RT20 PCM contained within a number of 50mm x 50 mm square hollow section aluminium frames that surround the window opening internally. The PCM containers were painted black to promote heat exchange within the system. The container frames in discharge mode are illustrated in Fig. 7.

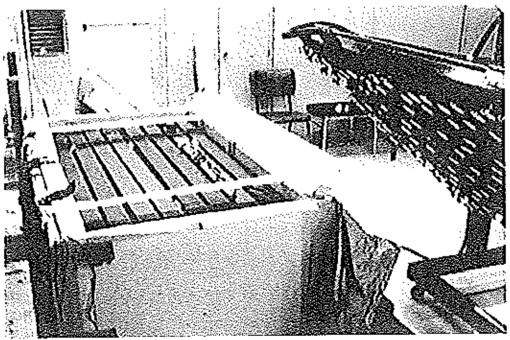


Figure 7: Black Painted Aluminium Frames Containing PCM (Discharge Mode)

The frames were attached to a mechanism that allowed each frame to be brought together to form a contiguous thermal storage mass with a continuous heat exchange surface facing into the system. The frames could be separated by an air gap of up to 10mm to provide a means of transferring the stored heat to the room air. Heat was supplied using a solar simulator with a similar spectral distribution to sunlight AM2. The total amount of PCM was based on obtaining total melt of the PCM within the system for the equivalent energy delivered by average New Zealand spring/autumn insolation. Results showed that while total melt took place and the system charged within 4-5 hours, the discharge period took more than 24 hours. The solidifying PCM on the inside surface of the aluminium frames appeared to be insulating the PCM at the core of the frame containers. One other drawback with using 50 x 50 mm frames with 10 mm gaps between the frames was the overall depth between glazings of 490 mm.

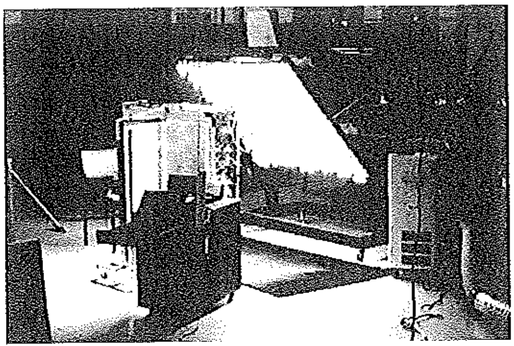


Figure 8: Experimental Set-up Showing Solar Simulator (Charging Mode)

Final Window Configuration

To overcome the long discharge period, the PCM container frame sections were changed to rectangular sections 100 mm x 25 mm in size. The window system enclosure was fabricated from sheet aluminium to promote heat exchange with the room air. The frames and enclosure are illustrated in Fig. 9.

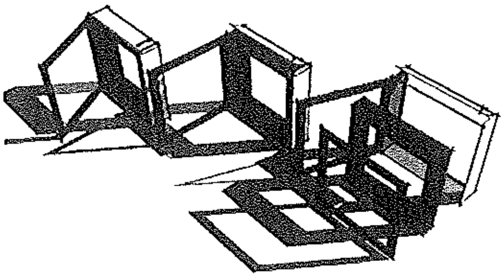


Figure 9: Final Window Configuration Showing Internal Opening Glazing

Control over the charging and discharging is achieved by an internal glazing that provides a complete air barrier to prevent loss of heat to the room from the thermal window system. Furthermore, a flap on the upper surface of the window enclosure promotes charging when closed, and discharging when open.

A low e coating on the inside face of the outer pane of the inner double glazed unit prevents the loss of radiant heat from the thermal window system to ambient.

The final window design was tested using the solar simulator as shown in Fig. 10. Charging time was between 4-5 hours and discharging time was 16 – 18 hours. This allows the window system to fully charge and discharge in typical diurnal cycle, thus promoting maximum heat storage.

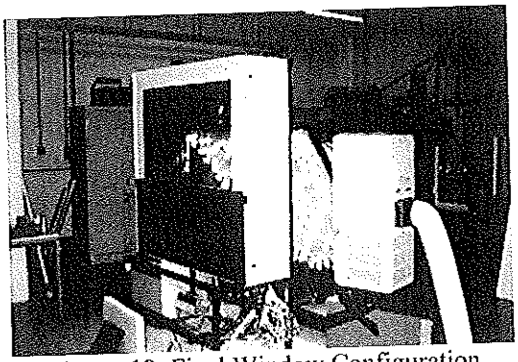


Figure 10: Final Window Configuration Showing Flap Used to Control Charging and Discharging

The final PCM thermal window system was installed in the experimental test cell and a typical single glazed window in the control test cell. The PCM window is shown in Fig. 11. The test cells were monitored for a period of 1 month with the test cells free running. The PCM thermal window system weighing 80 kg, exhibited a similar level of control over temperatures as the concrete thermal window system weighing 1100 kg. Subsequent tests with both test cells heated to 19°C over a one-year period, resulted in the experimental test cell using 28% less energy than the control test cell. Simulation results indicate a 30% saving per annum.

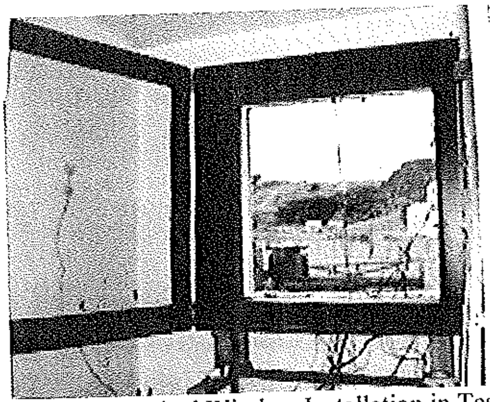


Figure 11: Final Window Installation in Test Cell

Results

The window has been experimentally tested under controlled conditions and under real conditions. Window performance has also been modeled by computer simulation. There is good agreement between the empirical and simulated results using the SUNREL thermal simulation.

With auxiliary heat input (T_{set} = 19°C 24hrs/day) in a building insulated to the current New Zealand Building Code insulation standards (R-1.8 KW^{-1}) the window system can provide in the region of 610 MJ $year^{-1}$, 970 MJ $year^{-1}$, and 1215 MJ $year^{-1}$, for Auckland, Wellington and Christchurch respectively.

With the building envelope insulated to R-3.6 KW^{-1} the energy contribution provided by the window system decreases to 508 MJ $year^{-1}$, 879 MJ $year^{-1}$, and 1103 MJ $year^{-1}$ respectively.

With the building envelope insulated to R-7.2 KW^{-1} the energy contribution provided by the window system decreases to 436 MJ $year^{-1}$, 798 MJ year^{-1}, and 1028 MJ year^{-1} respectively.

For current insulation standards, compared to a typical New Zealand window the window system has the potential to contribute in the region of 30% of the energy required to maintain 19°C. This represents a cost saving of $27, $43 and $54 per annum in 2005 figures for Auckland, Wellington and Christchurch respectively.

An energy analysis has revealed that the SCATES window system has 19.7 GJ of embodied energy, but will be capable of collecting and storing 30.4 GJ, 48.5 GJ and 60.8 GJ of useful heat for Auckland, Wellington and Christchurch respectively, for a 50-year life. In financial terms the cost of the system would have a discounted payback of 65, 41 and 15 years for Auckland, Wellington and Christchurch respectively.

Conclusion

A window system has been designed specifically for lightweight construction that collects and stores useful solar energy in the form of sensible and latent heat that can be used to offset auxiliary heating.

To achieve this, The thermal storage utilizes a phase change material (PCM) inside 25mm x 100mm rectangular hollow section containers that surround the air gap between the glazing units within the window system. The design of the window frame and glazing units has been configured to retain heat within the system. An insulated glazing unit on the outside surface and a single pane of glass on the interior surface are used to help control heat loss from the system to the outside air and to the room air respectively. A mechanical opening / closing device at the top of the window system facilitates thermal discharging / charging. . The PCM selected to store the solar energy collected by the external insulated glazing has a melt temperature of 21°C.

The window is capable of storing 903 MJ of heat per annum that can be used to offset auxiliary energy use.

Compared to a New Zealand typical single glazed window, the window system is better able to control diurnal induced temperature swings.

References

Abhat A. 1981. Low Temperature Latent heat Thermal Storage. In *Ispra Courses on Energy Systems and Technology*, ed. Beghi G. Amsterdam: Reidel Publishing Company.

Balcomb, J. D., R. W. Jones, R. W. McFarland, and W. O. Wray, 1984, *Passive Solar Heating Analysis, A Design Manual.* Report prepared under contract to U.S. Department Of Energy, ASHRAE.

Balcomb, J. D., and W. O. Wray, 1988, *Passive Solar Heating Analysis. Supplement One: Thermal Mass Effects and Additional SLR Correlations.* Report prepared under contract to U.S. Department Of Energy, ASHRAE.

Corner, A., 2002, Strength Testing Report: Thermally Enhanced Concrete, Victoria University of Wellington, Wellington.

Donn, M. R., and H. Dechapunya, 1983, *Utilisation of Window Solar Gains.* Energy Research Group, School of Architecture, Victoria University of Wellington, Prepared under contract to BRANZ.

Givoni, B., 1991, *Characteristics, Design Implications, and Applicability of Passive Solar Heating Systems for Buildings.*

Hawes, D. W., D. Feldman, and D. Banu, 1993, *Latent Heat Storage in Building Materials.*

Isaacs, N., M. Donn, J. Lee, P. Bannister, L. Guan, M. Bassett, I. Page, and A. Stoecklein, 1996, *A Sensible Step To Building Energy Efficiency: 1995 Revision of NZBC Clause H1.* Centre for Building Performance Research (CBPR), Victoria University Of Wellington.

Isaacs, N. P., and M. R. Donn, 1994, *Effect of Thermal Mass on House Energy Use and Internal Temperatures.* Centre for Building Performance Research (CBPR), School of Architecture, Victoria University of Wellington.

Jones RW. 1992. Analytical Results For Specific Systems. In *Passive Solar Buildings(7)*, ed. Balcomb JD. Cambridge, MA: MIT Press, pp. 235-292.

Joubert, B., and Skates, H., "Thermally Enhanced Concrete", Computer-Mediated Reality: Crafting Design Quality, Proc. 39th Annual Conference of The Australian and New Zealand Architectural Science Association (ANZAScA), Wellington, New Zealand, November 2001.

Kissock, J. K., J. M. Hannig, T. I. Whitney, and M. L. Drake, 1998, *Early Results from Testing Phase Change Wallboard.* Adana, Turkey.

Lee, M., E. K. Rhee, and G. Song, 1991, *Development of Design Strategies for Thermal Mass in Passive Solar Direct Gain System.* Denver, Colorado, USA.

Niles PWB, KL Haggard. 1980. *Passive Solar Handbook.* Sacramento, CA: Californian Energy Commission.

Norton B. 1992. *Solar Energy Thermal Technology.* Springer Verlag.

Scalat, S., D. Banu, D. Hawes, J. Paris, F. Haghighata, and D. Feldman, 1996, *Full Scale Thermal Testing of Latent Heat Storage in Wallboard.*