RESEARCH REPORT

Assessment of Reflective Interior Shades at the Canadian Centre for Housing Technology

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Canadian Centre
for Housing Technology

Centre canadien des
technologies résidentielles

ASSESSMENT OF REFLECTIVE INTERIOR SHADES AT THE CANADIAN CENTRE FOR HOUSING TECHNOLOGY

Contract: B-6020

Manning M.M.; Swinton, M.C.; Ruest, K.

February 9, 2007

Canada

The Canadian Centre for Housing Technology (CCHT)

Built in 1998, the Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing. The twin houses offer an intensively monitored real-world environment with simulated occupancy to assess the performance of the residential energy technologies in secure premises. This facility was designed to provide a stepping-stone for manufacturers and developers to test innovative technologies prior to full field trials in occupied houses.

As well, CCHT has an information centre, the InfoCentre, which features a showroom, high-tech meeting room, and the CMHC award winning FlexHouse™ design, shown at CCHT as a demo home. The InfoCentre also features functioning state-of-the art equipment, and demo solar photovoltaic panels. There are over 50 meetings and tours at CCHT annually, with presentations and visits occurring with national and international visitors on a regular basis.

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Project Team

Marianne Manning (NRC Institute for Research in Construction) as project manager was responsible for monitoring data collection, performing data analysis and writing this report. Mike Swinton (NRC Institute for Research in Construction), expert in side-by-side evaluation, oversaw operations throughout the experiment, monitored results, and provided important feedback throughout the analysis and report writing. Ken Ruest (Canada Mortgage and Housing Corporation) developed the shading device concept and testing methodology, and assisted with data analysis.

Acronyms

ach – air changes per hour
cfm – cubic feet per minute
HRV – Heat Recovery Ventilator

CCHT - Canadian Centre for Housing Technology
CMHC - Canada Mortgage and Housing Corporation
NRC - National Research Council Canada
NRCan - Natural Resources Canada

Executive Summary

In the summer of 2005, an innovative reflective shading device was evaluated at the Canadian Centre for Housing Technology (CCHT) twin-house facility. The shades were built from materials readily available at the hardware store: foil covered bubble wrap (two layers of bubble wrap sandwiched between two layers of aluminium foil), and screen frames. The shades were installed on the interior of the south and west facing windows of the CCHT Test House, leaving a small gap (~3 cm, 1") between the window surface and the shade.

Past evaluations of shading systems at the CCHT had revealed that opaque exterior shading was more effective than interior Venetian blinds at reducing cooling energy consumption. The reflective shading experiment was led by CMHC, hoping to identify an inexpensive interior shading option that could be used in locations where exterior shading was not a possibility, or as a temporary measure during the hottest portion of the cooling season. During the experiment, two different shading strategies were evaluated: shading 24 hours per day, and shading from 9 a.m. to 5 p.m.

Results showed that both strategies were effective at reducing the house's cooling consumption. Over their respective test periods, the 24-hour shading strategy reduced cooling consumption by 9.1%, and the 9 to 5 strategy reduced cooling consumption by 10%. The 0.9 % difference in savings was attributable to differing outdoor conditions during the trials. As would be expected, savings were highest on days with high solar gains – vertical solar gains in excess of 12000 kJ/m^2/day. On these high solar days, both shading strategies produced an average of 12% savings in cooling consumption. Extrapolation of results to the entire 2005 cooling season revealed that the 24-hour shading strategy is expected to produce approximately 9.9% seasonal savings in cooling energy consumption, while the 9 to 5 shading strategy is expected to produce slightly less: 9.0% seasonal savings.

For the 24-hour strategy, a portion of the daily savings from use of the reflective shades occurred outside the hours of 9 a.m. to 5 p.m. This was likely caused by the shade on the west-facing window shading the house from evening solar gains. The opposite held true for the 9 a.m. to 5 p.m. strategy. Daily savings from this strategy were reduced by an increase in consumption during the hours that the house operated without the shades in place, compared to the consumption of the house without reflective shades. This increase could be attributable in part to heat that was trapped between the window and the shade being radiated back into the house upon removal of the shades at 5 p.m.

Measurements revealed that the reflective shades caused window surface temperatures to approach the operating limits. The temperature at the centre of the window surpassed 68°C on the sunniest day, and the temperature differential between the edge and centre of the glass approached 30°C. These high temperatures lead to thermal stresses that could potentially damage the glazing unit. For this reason, this particular shading device cannot be recommended for use with argon-filled windows with a low-e coating on surface 3. Further studies are required to determine the effectiveness and safety of these shades when combined with other types of windows. The performance of commercially available shading systems should also be examined.

RESEARCH HIGHLIGHT

March 2007

Technical Series 07-102

The Effects of Reflective Interior Shades on Cooling Energy Consumption at the CCHT Research Facility

INTRODUCTION

Past shading experiments at the Canadian Centre for Housing Technology[1] (CCHT) twin-house research facility revealed that opaque exterior shades provide an effective means of reducing air conditioner cooling loads. However, similar trials of interior Venetian blinds provided evidence of only a slight daily savings (<1 per cent) in cooling energy consumption on the clearest days. Unfortunately, exterior shading is not always an option due to location: the exterior of fixed windows on the upper stories of apartment buildings or homes is not easily accessed by residents for temporary shading during summer months. Cost can also be a limiting factor—it is difficult to justify the expense of an elaborate exterior shading system when the cooling season is so short in many parts of Canada. For these reasons, Canada Mortgage and Housing Corporation (CMHC) is interested in finding a simple and inexpensive means of reducing the cooling loads from the interior of the home.

The purpose of this project was to evaluate the potential of a reflective interior shading device to reduce cooling loads, while carefully observing the shade's effect on window temperatures. It was hoped that this device would offer significant savings in cooling consumption, producing energy savings for consumers, and helping to reduce the peak cooling-season demands on utilities.

RESEARCH PROGRAM

The evaluation of the reflective shades was carried out at the CCHT's twin-house research facility in Ottawa, Canada in the summer of 2005. The twin-house facility has been in operation since 1998, and has been the site of many side-by-side comparisons of energy saving technologies. The unique nature of the facility allows researchers to not only evaluate energy savings, but also the whole house effects including temperatures and humidity. The houses are equipped with over 250 sensors and continuous data monitoring.

BACKGROUND AND METHODOLOGY

Shading Technology

The reflective shading prototype was conceived by CMHC. The shades were built from materials readily available at the hardware store. The shade itself was made from a reflective insulation product: a double layer of 8-mm polyethylene bubble wrap sandwiched between two layers of 99.9 per cent aluminum foil. The foil-covered bubble wrap was mounted in a typical screen frame, sized to fit the window. A one-inch gap was left at the top and bottom of the screen, between the foil and frame, to encourage air circulation between the screen and window, prevent window temperatures from exceeding safe levels, and to maintain a more uniform temperature distribution (see Figure 1).

Figure 1 Three reflective shades mounted on the interior of a south-facing window

[1] The Canadian Centre for Housing Technology is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. This research and demonstration facility features two highly instrumented, identical R-2000 homes with simulated occupancy to evaluate the whole-house performance of new technologies in side-by-side testing. For more information about the CCHT facilities please visit http://www.ccht-cctr.gc.ca

Figure 2 Benchmark shading configuration – Venetian blinds in the down position with slats horizontal

Evaluation

Both CCHT houses feature argon-filled windows with a low-E coating on surface three. High-efficiency 12 SEER air conditioning units provide cooling, while standard furnace circulation fans provide continuous air circulation. To determine the effect of a given technology, the two CCHT houses are first benchmarked under identical conditions, and then a single element is changed in the "Test" house. In benchmark conditions, Venetian blinds in both houses were kept in the down position with slats horizontal (Figure 2). During the experiment, the reflective shades were installed on the interior side of nine south-facing windows, and one west-facing window of the CCHT Test House (see Figure 3). The shading devices were mounted in the normal interior side screen position (where possible), or 1-2" from the interior window surface. In total, the shades covered a south-facing window pane area of 9.4 m^2 and a west-facing window pane area of 1.3 m^2.

Two different shading strategies were evaluated:

- 24-hour shading: leaving the shades in place 24 hours/day
- 9 to 5 shading: installing the shades at 9 a.m., and removing them at 5 p.m.

The 24-hour shading strategy was evaluated over a total of 11 days, while the 9 to 5 shading strategy was evaluated for a total of 7 days.

Figure 3 Windows shaded during experiment, west face (left) and south face (right)

FINDINGS

Energy Savings

Both the 24-hour shading strategy and the 9 to 5 shading strategy produced substantial daily savings in cooling energy consumption (air conditioner and circulation fan electrical consumption). Savings were highest on days with the largest solar gains, when the shades were the most effective at reducing the amount of solar energy entering through the windows.

During their respective test periods, the 24-hour shading strategy produced up to 4.60 kWh of cooling energy savings on the sunniest days (13 per cent of that day's expected cooling consumption without shades, 34.2 kWh), while the 9 to 5 strategy produced up to 3.73 kWh of savings (11 per cent of that day's expected cooling consumption without shades, 34.39 kWh). To determine seasonal savings, the data were projected to the entire 2005 cooling season—a very warm season for Ottawa, with a total of 460 cooling degree-days above 18°C. Calculations revealed that the 24-hour shading strategy is expected to produce approximately 9.9 per cent seasonal savings in cooling energy consumption for the CCHT Test House, while the 9 to 5 shading strategy is expected to produce slightly less savings, 9.0 per cent. The difference between these seasonal savings is attributable in part to the shading of the west window. In the 9 to 5 strategy, all shades are removed from the house at 5 p.m. In the 24-hour strategy, the west window shade remains in place, shading the house from evening solar gains.

As expected, the majority of these energy savings occurred between 9 a.m. and 5 p.m. On the days with the highest solar gains, the strategies reduced the cooling energy consumption during the 9 a.m. to 5 p.m. time period by up to 29 per cent for the 24-hour shading strategy, and 27 per cent for the 9 to 5 strategy. This effect would not only benefit consumers, but also utilities. The largest savings from this shading device would occur on the hottest, sunniest hours of summer, times when summer utility peaks typically occur.

Window Temperatures

Practical experience indicates that while the glass and seal themselves are capable of withstanding high temperatures, the temperature limits for the glazing unit are defined by the temperature differential between the center and the edge of the glass. When the edge of the glass is cooler than the centre, tensile thermal stresses are produced that can lead to breakage. The higher the differential, the higher the tension introduced in the glazing unit. Window cracks are generally initiated at an edge defect created in manufacturing. Thermal cycling to high temperatures encourages damage to appear and propagate. For this reason, the centre to edge temperature differential should be less than 30°C in order to avoid potential cracking, particularly if the cut edge quality is poor.

Both during and prior to the experiment, window surface temperatures were measured at the edge and center of the interior pane. In normal operation, the window surface temperature reached 45°C, and the centre-to-edge temperature differential remained below 5°C. While shaded by the reflective shades, surface temperatures at the centre of the window exceeded the normal operating conditions by more than 30°C, reaching a maximum of 68.7°C on the sunniest day (see Figure 4). Additionally, the temperature differential between the centre and edge of glass approached the 30°C limit. Although no damage was observed during the course of the experiment, the use of the reflective shades with argon-filled windows with a low-E coating on surface three (exterior surface of interior pane) contributed to increased thermal stresses at the limits of normal operation, and could lead to breakage.

Without the air gap between the shade and the window to provide some air circulation, window surface temperatures skyrocketed to upwards of 80°C by 11 a.m., at which time the shade was removed to avoid damaging the glazing unit.

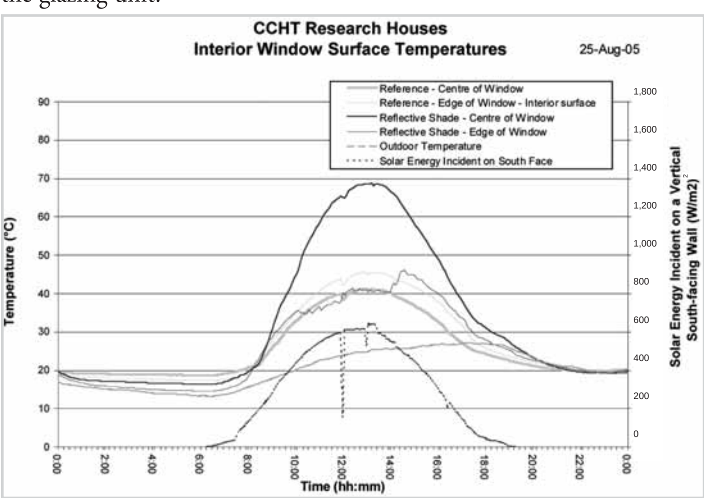

Figure 4 Window interior surface temperatures

LIMITATIONS OF THIS STUDY

Savings from shades will vary depending on the houses, types of window and mechanical setups. Care should be taken in applying these results to other homes, due to certain attributes of the CCHT facility. Some of the issues that should be kept in mind include:

- The CCHT houses are built to maximize the southern exposure of windows, and thereby solar gains. This reduces the winter heating load, but also contributes to an increase in summer cooling requirements. Because of the large contribution of solar gains to the summer cooling load, shading provides a substantial benefit. Less benefit from shading would be expected in houses with a smaller window area on the south face.
- The windows of the CCHT research houses are all double pane, argon-filled, with a low-emissivity coating on surface three. Solar radiation heats the interior pane of the window (containing the low-E coating), causing surface temperatures to rise. This heat is trapped, since the interior shade prevents radiation into the house and reflects it back to the window. Argon gas prevents the transfer of heat out through the window. The result is high temperatures building up between the shade and window surface, approaching the limits of safe operation. Different temperature effects, and energy savings, would be expected with other types of window. For example: an air-filled window would be expected to conduct heat more readily than argon, allowing the heat to dissipate outwards; the interior surface of a window without any coatings would be expected to stay cooler. More evaluations are required to explore the use of this kind of shading device with other types of windows.
- The CCHT houses are built to R-2000 standards; therefore, they prevent heat gains and heat losses better than older houses. In older, less insulated and looser construction, the solar heat gains through windows may be less significant when compared to heat gains from outdoor temperatures.
- The CCHT houses are unfurnished. Without furnishings, the houses contain less thermal mass than a typical inhabited house. Thus, the houses would respond more quickly to changes in temperature and retain less heat from the day.
- The CCHT houses were operated in air conditioning mode throughout the cooling season. In real life, a homeowner would likely shut off the cooling system periodically in favor of opening the windows on cool nights or days. For this reason, the projected seasonal savings from this study could be higher than would be expected in practice.
- Savings calculations were based on the installation of shades for 24 hours per day or from 9 a.m. to 5 p.m. every day for the entire cooling season. Lower seasonal savings would be expected from shorter periods of shading.

CONCLUSIONS/IMPLICATIONS FOR THE HOUSING INDUSTRY

The reflective shades proved to be effective in reducing cooling energy consumption by approximately 9 per cent for the entire cooling season. However, the use of this radiant barrier product as a shade cannot be safely recommended for use with argon-filled windows with a low-E coating on surface three, due to the resulting window surface temperatures.

A full report on this project is available from the Canadian Centre for Housing Technology.

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Housing Research at CMHC

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LE POINT EN RECHERCHE

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Les effets des stores intérieurs réfléchissants sur la consommation d'énergie pour la climatisation aux installations de recherche du CCTR

INTRODUCTION

Des expériences réalisées sur les stores des deux maisons de recherche du Centre canadien des technologies résidentielles[1] (CCTR) ont révélé que les stores extérieurs opaques constituent un excellent moyen de réduire les charges de refroidissement imposées au climatiseur. Cependant, des essais semblables effectués à l'aide de stores vénitiens intérieurs ont montré que seulement de faibles économies quotidiennes (<1 %) en consommation d'énergie pour la climatisation pouvaient être obtenues lors des jours les plus clairs. Malheureusement, les dispositifs d'ombrage extérieurs ne sont pas toujours envisageables en raison de la configuration des lieux : les résidents ne peuvent atteindre facilement l'extérieur des fenêtres fixes des étages supérieurs des immeubles d'appartements ou des maisons pour y installer des stores temporaires durant les mois d'été. Le coût peut aussi devenir un facteur limitatif : il est en effet difficile de justifier les dépenses pour un dispositif d'ombrage extérieur complexe lorsque la saison chaude est très courte dans certaines régions du Canada. Pour ces motifs, la Société canadienne d'hypothèques et de logement (SCHL) est intéressée à découvrir des moyens simples et bon marché de réduire les charges de climatisation à partir de l'intérieur de la maison.

Le but de cette étude était d'évaluer la possibilité d'avoir recours à des stores intérieurs réfléchissants pour réduire les charges sur le climatiseur, tout en observant les effets des stores sur la température des fenêtres. On espérait que ce dispositif permettrait d'abaisser considérablement la consommation d'énergie pour la climatisation, de générer des économies d'énergie pour les consommateurs et d'aider à réduire la demande de pointe en services publics pendant la saison de climatisation.

PROGRAMME DE RECHERCHE

L'évaluation des stores réfléchissants a été effectuée aux deux maisons de recherche du CCTR à Ottawa, au Canada, à l'été 2005. Depuis 1988, les maisons jumelles ont accueilli de nombreuses comparaisons parallèles de technologies d'économie d'énergie. La nature unique de cette installation permet aux chercheurs de ne pas évaluer que les économies d'énergie, mais aussi les effets sur l'ensemble des maisons, notamment la température et l'humidité. Les maisons sont munies de plus de 250 capteurs et d'un système de contrôle des données en continu.

CONTEXTE ET MÉTHODE

Technologie des stores

Le prototype des stores réfléchissants a été conçu par la SCHL et réalisé avec des matériaux disponibles dans une quincaillerie. Le store lui-même était fabriqué à partir d'un produit isolant réflecteur : une double épaisseur d'un film à bulles d'air en polyéthylène de 8 mm insérée entre deux épaisseurs de papier d'aluminium à 99,9 %. Le film à bulles d'air recouvert de papier d'aluminium a été monté dans un cadre pour moustiquaire ordinaire, taillé pour s'ajuster à la fenêtre. Un espace d'un pouce a été laissé aux parties supérieure et inférieure de la moustiquaire, entre le papier d'aluminium et le cadre, afin de favoriser la circulation d'air entre la moustiquaire et la fenêtre, d'empêcher les températures de la fenêtre de dépasser les niveaux de sécurité et d'assurer une distribution uniforme des températures (voir la figure 1).

[1] Le Centre canadien des technologies résidentielles est dirigé conjointement par le Conseil national de recherches, Ressources naturelles Canada et la Société canadienne d'hypothèques et de logement. Ce centre de recherche et de démonstration se compose de deux maisons R-2000 identiques dotées d'une batterie d'instruments. On y simule l'occupation humaine pour évaluer le rendement des nouvelles technologies dans l'ensemble des maisons grâce à des tests parallèles. Pour obtenir de plus amples renseignements sur les installations du CCTR, veuillez consulter le site Web http://www.ccht-cctr.gc.ca

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Figure 1 Trois stores réfléchissants montés à l'intérieur d'une fenêtre orientée au sud

Figure 2 Store témoin – Store vénitien abaissé avec les lames à l'horizontal

Évaluation

Les deux maisons du CCTR comportent des fenêtres à lame d'argon avec enduit à faible émissivité sur la paroi n° 3. Des climatiseurs d'air à rendement élevé présentant un taux de rendement énergétique saisonnier (TRES) de 12 servent à la climatisation, alors que les ventilateurs des générateurs de chaleur classiques font circuler l'air de façon continue. Afin de déterminer les répercussions d'une technologie donnée, les deux maisons du CCTR sont d'abord étalonnées suivant des conditions identiques, puis un seul élément est modifié dans la maison « d'essai ». Dans des conditions normalisées, les stores vénitiens des deux maisons ont été maintenus en position abaissée, les lames à l'horizontale (figure 2). Au cours de l'expérience, les stores réfléchissants ont été installés à l'intérieur de neuf fenêtres orientées au sud et d'une fenêtre donnant sur l'ouest de la maison d'essai du CCTR (voir la figure 3). Les stores ont été montés (dans la mesure du possible) dans la position normale d'une moustiquaire latérale intérieure ou de 1 à 2 po de la surface intérieure de la fenêtre.

Au total, les stores couvraient une aire de vitrage de 9,4 m^2 du côté sud et de 1,3 m^2 du côté ouest.

Deux différentes stratégies d'ombrage ont été évaluées :

- Ombrage de 24 heures : les stores sont laissés en place continuellement.
- Ombrage de 9 h à 17 h : les stores sont installés à 9 h et retirés à 17 h.

La stratégie d'ombrage de 24 heures a été évaluée sur une période de 11 jours, alors que la stratégie d'ombrage de 9 h à 17 h l'a été sur une période de 7 jours.

Figure 3 Fenêtres voilées pendant l'expérience, côté ouest (à gauche) et côté sud (à droite)

RÉSULTATS

Économies d'énergie

Les deux stratégies d'ombrage (celle de 24 heures et celle de 9 h à 17 h) ont généré des économies d'énergie quotidiennes importantes pour la climatisation (consommation d'électricité du climatiseur et du ventilateur de circulation d'air). Les économies maximales ont été réalisées lors des jours où les gains solaires étaient les plus élevés, lorsque les stores ont été le plus efficaces pour réduire la pénétration de l'énergie solaire par les fenêtres.

Au cours de leurs périodes d'essai respectives, la stratégie d'ombrage de 24 heures a généré des économies d'énergie pour la climatisation de l'ordre de 4,60 kWh lors des journées les plus ensoleillées (13 % de la consommation quotidienne prévue pour la climatisation sans stores pendant ces journées, soit 34,2 kWh), alors que la stratégie de 9 h à 17 h a généré des économies de 3,73 kWh (11 % de la consommation quotidienne prévue pour la climatisation sans stores pendant ces journées, soit 34,39 kWh). Pour établir les économies saisonnières, les données ont été extrapolées pour la saison entière de climatisation de 2005, une saison qui s'est avérée très chaude pour Ottawa, puisqu'elle a connu un total de 460 degrés-jours de climatisation au-dessus de 18 °C. Les calculs ont révélé que la stratégie d'ombrage de 24 h devrait générer des économies saisonnières d'environ 9,9 % en consommation d'énergie pour la climatisation pour la maison d'essai du CCTR, alors que la stratégie d'ombrage de 9 h à 17 h devrait générer des économies légèrement inférieures, s'établissant à 9,0 %. La différence entre les économies saisonnières est attribuable en partie au voilage de la fenêtre ouest. Dans la stratégie de 9 h à 17 h, tous les stores de la maison sont enlevés à 17 h. Dans la stratégie de 24 h, le store de la fenêtre du côté ouest demeure en place, protégeant la maison contre les gains solaires de la soirée.

Comme prévu, la majeure partie des économies d'énergie est réalisée entre 9 h et 17 h. Pendant la période de 9 h à 17 h lors des jours où les gains solaires sont le plus élevés, les stores ont réduit la consommation d'énergie pour la climatisation jusqu'à 29 % pour la stratégie de 24 h et jusqu'à 27 % pour celle de 9 h à 17 h. Ces résultats n'avantagent pas uniquement les consommateurs, mais également les fournisseurs de services publics. Les économies les plus importantes obtenues grâce à ces dispositifs seraient réalisées lors des heures les plus ensoleillées de l'été, moment où les services doivent faire face aux demandes de pointe estivales.

Températures des fenêtres

L'expérience pratique indique que même si le verre et les produits de scellement peuvent résister à des températures élevées, les limites de température pour les vitrages sont définies par la différence de température entre le centre et le bord du verre. Lorsque le bord du verre est plus froid que le centre, des contraintes thermiques de traction se produisent et peuvent provoquer un bris. Plus la différence est élevée, plus la tension exercée dans le vitrage est élevée. Les fissures dans les fenêtres commencent généralement en raison d'un défaut survenu sur le bord du vitrage lors de la fabrication. Le cycle thermique menant à des températures élevées favorise l'apparition de dommages et leur propagation. C'est pourquoi, la différence de température entre le centre et le bord doit être inférieure à 30 °C afin d'éviter les risques de fissures, particulièrement si la coupe des bords est de qualité médiocre.

Tant au cours de l'expérience qu'avant, les températures de surface des fenêtres ont été mesurées au bord et au centre de la vitre intérieure. Dans des conditions de fonctionnement normales, la température de surface des fenêtres atteignait 45 °C et la différence de température entre le centre et le bord était inférieure à 5 °C. Lorsque les fenêtres étaient recouvertes de stores réfléchissants, les températures de surface au centre de la fenêtre dépassaient les conditions normales par plus de 30 °C, pour atteindre un maximum de 68,7 °C le jour le plus ensoleillé (voir la figure 4). De plus, la différence de température entre le centre et le bord du verre frôlait la limite de 30 °C. Même si aucun dommage n'a été observé pendant l'expérience, l'utilisation de stores réfléchissants avec des fenêtres à lame d'argon comportant une couche à faible émissivité sur la paroi n° 3 (la surface extérieure du vitrage intérieur) a contribué à faire augmenter les contraintes thermiques aux limites de tenue normales de la fenêtre et pourraient provoquer un bris.

Sans l'espace d'air ménagé entre le store et la fenêtre pour permettre à l'air de circuler, les températures de surface de la fenêtre ont monté en flèche pour atteindre 80 °C à 11 h, moment où les stores ont été enlevés afin d'éviter d'endommager le vitrage.

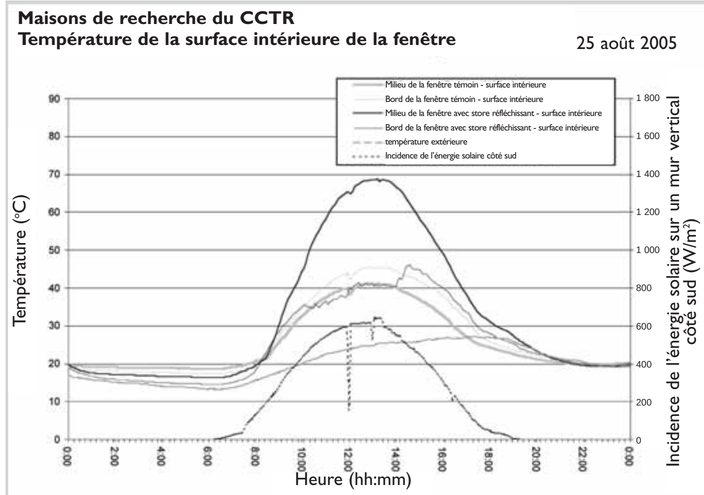

Figure 4 Températures de la surface intérieure de la fenêtre

LIMITES DE L'ÉTUDE

Les économies réalisées grâce aux stores varieront en fonction des maisons, des types de fenêtres et des installations mécaniques. Il faut donc faire preuve de prudence dans l'application des résultats à d'autres maisons, en raison de certains attributs des installations du CCTR. Voici quelques principes qu'il faudra prendre en considération :

- Les maisons du CCTR sont construites afin de maximiser l'exposition au sud des fenêtres et, par le fait même, les gains solaires. Cette orientation permet de réduire la charge de chauffage en hiver, mais elle contribue également à l'augmentation des besoins en climatisation durant l'été. Parce que l'apport considérable de gains solaires a une incidence sur la charge de climatisation estivale, les stores offrent des avantages importants. On pourrait s'attendre à ce que les stores offrent des avantages moins marqués dans les maisons ayant une moins grande aire de vitrage du côté sud.
- Les fenêtres des maisons de recherche du CCTR sont toutes à double vitrage, à lame d'argon et à couche à faible émissivité sur la paroi n° 3. Le rayonnement solaire chauffe le vitrage intérieur de la fenêtre (comportant la couche à faible émissivité), ce qui provoque l'élévation des températures de surface. Cette chaleur est emprisonnée, étant donné que les stores intérieurs empêchent le rayonnement de se répandre dans la maison et le réfléchissent vers la fenêtre. L'argon empêche le transfert de la chaleur vers l'extérieur par la fenêtre. Cette configuration contribue à l'augmentation des températures entre le store et la surface de la fenêtre, se rapprochant ainsi des limites d'une tenue en service sûre. Avec d'autres fenêtres, on peut s'attendre à des résultats différents quant aux températures et aux économies d'énergie. Par exemple, une fenêtre à lame d'air conduirait la chaleur plus facilement, permettant ainsi à la chaleur de s'échapper vers l'extérieur; la surface intérieure d'une fenêtre sans couche métallique devrait demeurer plus froide. D'autres évaluations devront être réalisées afin d'examiner l'usage de ces stores avec d'autres types de fenêtres.

- Les maisons du CCTR sont construites selon les normes R-2000; par conséquent, elles sont mieux protégées contre les gains et les pertes de chaleur que les maisons plus vieilles. Dans les anciennes constructions moins isolées et moins étanches, les gains de chaleur solaire générés par les fenêtres peuvent être moins importants lorsqu'on les compare aux gains de chaleur provenant des températures extérieures.
- Les maisons du CCTR ne sont pas meublées. Sans meubles, les maisons contiennent une masse thermique inférieure à celle d'une maison ordinaire inhabitée. Ainsi, les maisons réagiraient plus rapidement aux changements de température et conserveraient moins de chaleur produite durant la journée.
- Les maisons du CCTR ont été climatisées pendant toute la saison de climatisation. Dans la vraie vie, selon toute vraisemblance, un propriétaire arrêterait le climatiseur à l'occasion pour ouvrir les fenêtres lors des nuits ou des jours plus frais. Pour cette raison, les économies saisonnières projetées dans le cadre de cette étude pourraient être plus élevées que celles anticipées en pratique.
- Les économies sont calculées lorsque les stores sont en place 24 heures par jour ou de 9 h à 17 h chaque jour pendant toute la saison de climatisation. On peut s'attendre à des économies saisonnières moindres si les stores sont en place pendant des périodes plus courtes.

CONCLUSIONS/CONSÉQUENCES POUR LE SECTEUR DE L'HABITATION

Les stores réfléchissants se sont révélés efficaces pour réduire la consommation d'énergie de climatisation d'environ 9 % durant toute la saison chaude. Cependant, on ne peut recommander en toute sécurité l'utilisation, comme store, de ce produit de protection contre le rayonnement avec des fenêtres à lame d'argon comportant une couche à faible émissivité sur la paroi n° 3 en raison des températures à la surface des fenêtres qu'il entraîne.

On peut obtenir un rapport complet sur cette étude auprès du Centre canadien des technologies résidentielles.

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1 Introduction

Canada Mortgage and Housing Corporation (CMHC) is interested in testing low cost/low energy solutions for minimizing cooling loads. Past experiments at the Canadian Centre for Housing Technology (CCHT) have proven the effectiveness of opaque exterior blinds at preventing solar gains and reducing air conditioner consumption. The same set of experiments also revealed the less than desirable performance of interior Venetian blinds in combination with argon filled low-e coated windows, producing only a minimal daily savings (<1%) in air conditioning cooling consumption on the sunniest of days. In many locations such as large apartment buildings, or on the upper stories of a house, it is difficult or impossible for residents to install exterior blinds. For this reason, an effective interior solution is required.

To this purpose, CMHC tested the effects of using a reflective interior blind at the CCHT twin-house facility in the summer of 2005. It was hoped that this interior blind solution could help lessen a house's peak air conditioning load during the hottest and sunniest days of summer, helping consumers to save money and utilities to manage peak demands.

2 Objective

The main objective of this project was to evaluate the effectiveness of reflective interior shades in reducing cooling load and air conditioning consumption, while monitoring the resulting window surface temperatures, to ensure that temperatures do not rise high enough to potentially damage the glazing unit.

Secondary objectives included: evaluating the effect of the shading devices on night time energy performance (cooling demand could increase due to any insulating effect from the shades) and to monitor indoor humidity (humidity could increased due to shortened air conditioning runs).

3 Background

3.1 CCHT Twin House Facility

Built in 1998, the Canadian Centre for Housing Technology (CCHT) (www.ccht-cctr.gc.ca) is jointly operated by National Research Council (NRC), Natural Resources Canada (NRCan), and Canada Mortgage and Housing Corporation (CMHC). CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing (Figure 1). These houses were designed and built by a local builder to the R-2000 standard. The houses are a popular model currently on the market in the region, and were built with the same crews and techniques normally used by the builder. A full list of the twin houses characteristics can be found in Table 1.

Table 1 - Twin House Characteristics

Feature	Details
Construction Standard	R-2000
Liveable Area	210 m^2 (2260 ft^2), 2 storeys
Insulation	Attic: RSI 8.6, Walls: RSI 3.5, Rim joists: RSI 3.5
Basement	Poured concrete, full basement Floor: Concrete slab, no insulation Walls: RSI 3.5 in a framed wall. No vapour barrier.
Garage	Two-car, recessed into the floor plan; isolated control room in the garage
Exposed floor over the garage	RSI 4.4 with heated/cooled plenum air space between insulation and sub-floor.
Windows	Area: 35.0 m^2 (377 ft^2) total, 16.2 m^2 (174 ft^2) South Facing Double glazed, high solar heat gain coating on surface 3. Insulated spacer, argon filled, with argon concentration measured to 95%.
Air Barrier System	Exterior, taped fiberboard sheathing with laminated weather resistant barrier. Taped penetrations, including windows.
Airtightness	1.5 air changes per hour @ 50 Pa (1.0 lb/ft^2)
Furnishing	Unfurnished

The CCHT twin houses are fully instrumented and are unoccupied. To simulate the normal internal heat gains of lived-in houses, these houses feature identical 'simulated occupancies'. The simulated occupancy strategy is described in Appendix B.

Figure 1 - CCHT Twin-House Facility - Test House (left) and Reference House (right)

3.2 Shading Experiments at CCHT

Past tests at the CCHT in July 2002 addressed the issue of blind placement. Galasiu et al. (2005) conducted a shading experiment at the CCHT twin-house facility to determine the effect of two types of shadings devices in July 2002 – an exterior opaque shading device, and common indoor manual aluminum Venetian blinds. Results showed that on days with clear skies, interior blinds reduced cooling loads from 9 AM to 5 PM by approximately 10-12%. However, in the evening and overnight this effect was counteracted, the house with the interior blinds requiring 5-10% more cooling energy. The resulting total daily savings from use of the interior blinds on clear days was less than 1%. By contrast, the opaque exterior blind strategy offered savings of 70-75% from 9 AM to 5 PM, and 20-25% over 24 hours.

3.3 Reflective Shading Device

The reflective shading “proof of concept” prototype was conceived by CMHC. The shades were built from materials readily available at the hardware store. The shade itself was made from a reflective insulation product: a double layer of 8 mm polyethylene bubble wrap sandwiched between 2 layers of 99.9% aluminum foil. The foil-covered bubble wrap was mounted in a typical screen frame, sized to fit the window. A one-inch gap was left at the top and bottom of the screen, between the foil and frame, to encourage air circulation between the screen and window and prevent window temperatures from exceeding safe levels, and to maintain a more uniform temperature distribution.

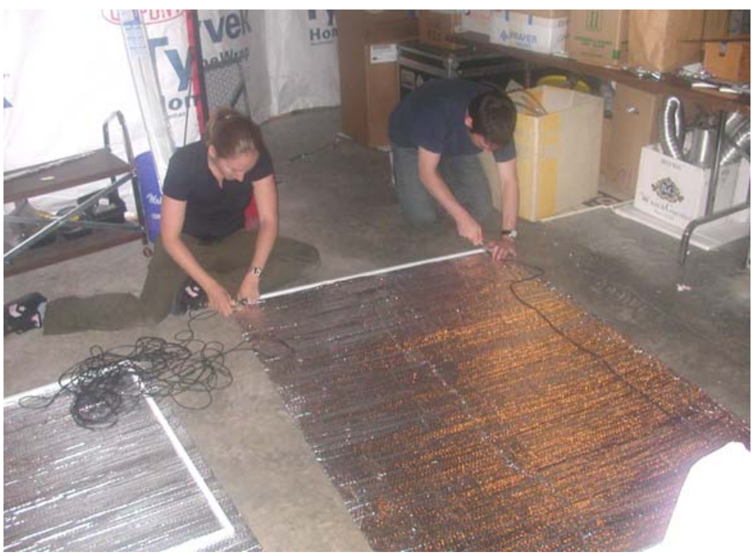

Figure 2 - Shading device construction

Figure 3 - Interior view of shaded window

4 Methodology

4.1 Installation

The shades were installed on the interior side of 9 south-facing windows, and one west-facing window of the CCHT Test House (see Figure 4). The shading devices were mounted in the normal interior side screen position (where possible), or 1-2" from the interior window surface. In total, the shades covered a south-facing window pane area of 9.4 m^2 and a west-facing window pane area of 1.3 m^2.

The experiment consisted of two different trials:

- 24-hour shading: leaving the shades in place 24 hours/day
- 9 to 5 shading: installing the shades at 9 am, and removing them at 5 pm

Because of the heat transfer characteristics of the shades (i.e. reflective surfaces, trapped air in the layers of bubbles), it was proposed that removing them overnight would allow the house to dissipate heat through the window, and some difference would be seen between the results of the two trials.

Figure 4 - Windows shaded during Experiment, west face (left) and south face (right)

4.2 Side-by-side testing procedure

Throughout the shading experiment, the houses were operated in identical configuration, differing only in respect to the shading configuration. Operating conditions are listed in Table 2.

Table 2 - Operating Conditions for the Shading Experiment

	System	Reference House	Test House
1	Air Conditioner	12 SEER unit, 2 ton	12 SEER unit, 2 ton
2	Furnace	PSC motor provides high speed cooling and low speed continuous circulation	PSC motor provides high speed cooling and low speed continuous circulation
3	Thermostat	Setpoint: 22°C, standard central location on main floor	Setpoint: 22°C, standard central location on main floor
4	Heat Recovery Ventilator (HRV)	Constant ventilation, 65 cfm 84% efficiency (nominal)	Constant ventilation, 65 cfm 84% efficiency (nominal)
5	Window Shades	No exterior shades, all interior Venetian blinds down with slats in the horizontal position (see Figure 5)	No exterior shades or Venetian blinds, Interior reflective shades installed on 1 West-facing and 9 South-facing windows
6	Simulated Occupancy	Standard Schedule	Standard Schedule
7	Humidifier	Off	Off
8	Hot Water Heater	Standard Gas 81% efficiency (measured)	Standard Gas 81% efficiency (measured)

Figure 5 - The Benchmark shading configuration - Venetian blinds in the down and horizontal position

4.3 Measurement and Instrumentation

4.3.1 Incident Solar Radiation

A vertically-mounted pyranometer on the south-facing wall of the Reference house measured global solar radiation (W/m^2), see Figure 6. Readings were taken every 5 minutes and integrated over a whole day to obtain total daily vertical solar radiation ($kJ/m^2/day$). A value of 12000 $kJ/m^2/day$ was arbitrarily chosen to divide the experiment data into days with high solar gains, and days with low solar gains.

Figure 6 - Pyranometer Location on Reference House South Façade

4.3.2 Electrical Consumption

Both air conditioner compressor and furnace circulation fan electrical consumption were measured in each house by individual electric meters with pulse output, at a resolution of 0.0006 kWh/pulse. Additional electric meters measured the electrical consumption of all other lights and appliances in the house. These meters were monitored to ensure that total house consumption remained similar in both houses.

4.3.3 Window Surface Temperatures

One set of south-facing windows on the second floor (top left on the South façade in Figure 4) were equipped with thermocouples to measure surface temperature at one exterior location and six interior locations on the window and sill (see Figure 7). The thermocouples were secured to the window and sill surface by means of a conductive epoxy (Figure 8). Surface temperature measurements were taken every 5-minutes, with an accuracy of 0.5°C.

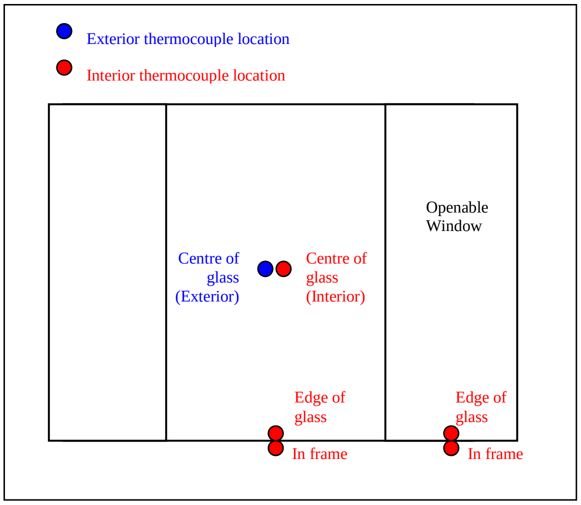

Figure 7 - Thermocouple Locations on Bedroom 2 Window

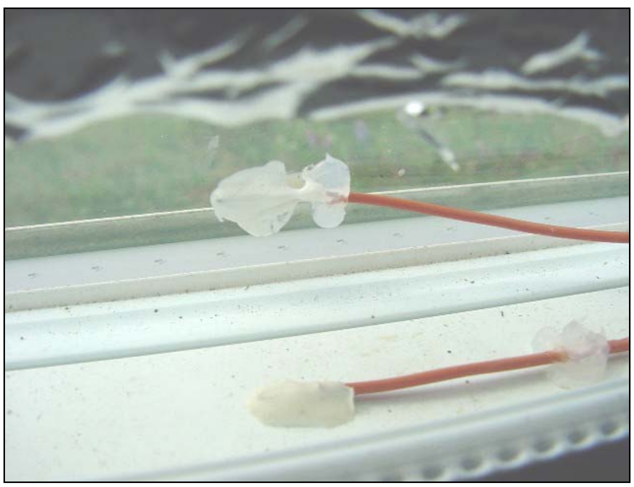

Figure 8 - Thermocouple location on edge of glass and interior frame

4.3.4 Air Temperature and Humidity

A thermocouple and humidity sensor located beside the central thermostat measured the main floor temperature and humidity of each house. A temperature and relative humidity sensor located on the north side of the Reference House measured the exterior conditions. Measurements were taken every 5-minutes, with an accuracy of 0.5°C.

4.4 Test Dates

The reflective shading experiment took place in August 2005. Table 3 lists the range of test dates and the variation in outdoor temperature during the experiment. Note that not all days in the listed date range necessarily belonged to that particular configuration. In the case of benchmarking, groups of benchmark days were spread throughout the cooling season to obtain a large range of outdoor conditions, and to ensure that the benchmark condition was maintained for the entire season.

Table 3 - Test Dates

Configuration	Date Range	Number of Days	Range of Average Daily Outdoor Temperature (°C)
Benchmark	21-Jun-05 to 21-Aug-05	17	15.7°C to 27.2°C
Reflective Shading 24h	04-Aug-05 to 25-Aug-05	11	20.2°C to 26.1°C
Reflective Shading 9:00 to 17:00	15-Aug-05 to 24-Aug-05	7	15.7°C to 22.7°C

Figure 9 shows the outdoor temperature and vertical solar radiation measurements during the shading experiments. While all shading experiment days are represented, only three of the 17 benchmark days are shown in this graph. The test period for both the 24-hour and 9 to 5 shading strategies contained a number of days with high solar gains. Outdoor temperatures during the evaluation of the 9 to 5 strategy were generally cooler than temperatures on days that the 24h shading strategy was employed.

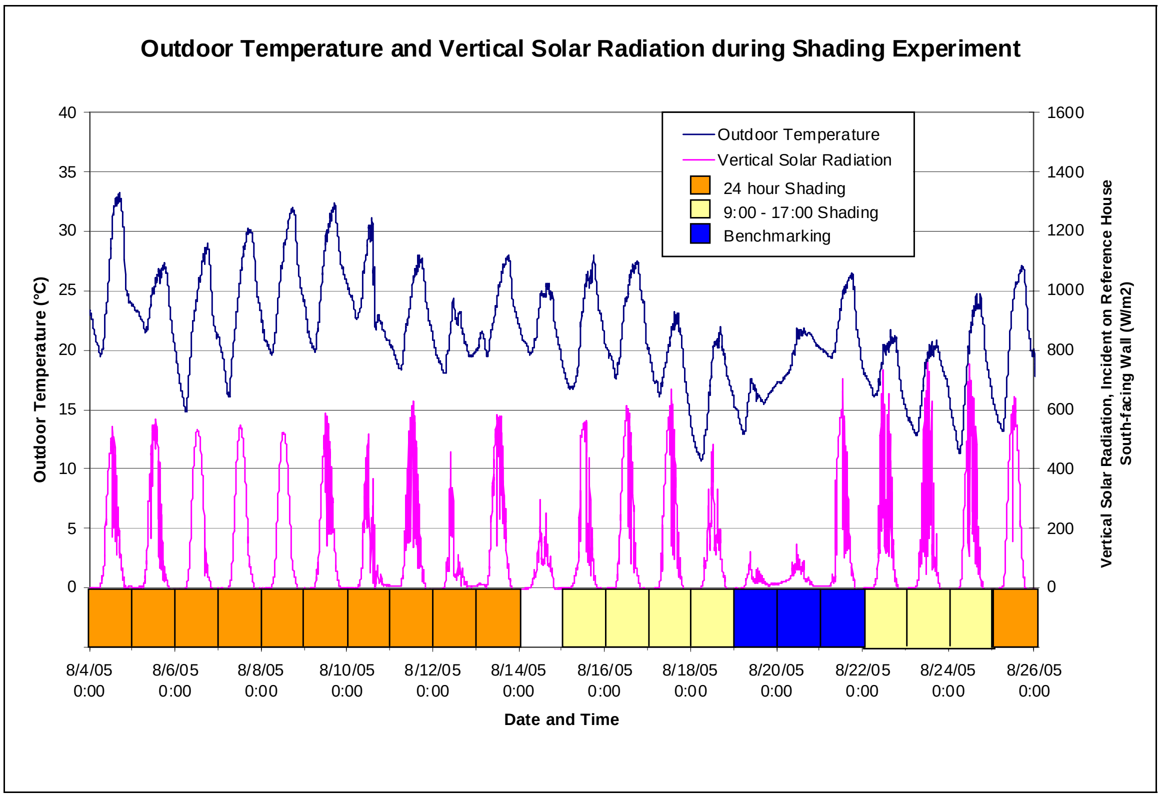

Figure 9 - Outdoor Temperature and Vertical Solar Radiation during Shading Experiment

5 Results

5.1 Cooling System Energy Consumption

Consumption data was analyzed using a side-by-side method, as described by Mike Swinton et al. in *Commissioning twin houses for assessing the performance of energy conserving technologies*. The method consists of plotting the daily consumption in the Test House against the daily consumption in the Reference House. During the benchmarking period, the houses are operated in identical configuration and a benchmark trend line is developed. Were the houses completely identical, this trend line would have a slope of 1 and intercept 0. However, the real benchmark trend line is never this perfect, since it takes into account all the small differences between the houses.

With the new technology installed in the Test House - in this case the reflective shades - the daily consumption is again plotted Test House VS Reference House. The benchmark trend and Reference House consumption can be used to determine the expected consumption for a particular day, were the Test House in benchmarking configuration (without the reflective shades). Savings can then be calculated by comparing the measured Test House consumption with reflective shades installed, to the calculated Test House consumption without reflective shades. This savings calculation method is described in more detail in Appendix B.

Cooling system electrical consumption is composed of air conditioner compressor consumption and furnace circulation fan consumption. For a breakdown of the consumption of these individual components refer to Table 4. The benchmark trendline for cooling consumption, shown in black in Figure 10, is slightly below the ideal 45° line, with a slope of 0.98 and an intercept of –0.99. This indicates that during benchmarking, the Reference House consistently consumed slightly more energy than the Test House for cooling.

The experiment points are also plotted in Figure 10: the 24 hour shading strategy plotted as diamonds, and the 9 a.m. to 5 p.m. shading strategy plotted as squares. Each experimental data set was divided into two categories based on measured daily vertical solar radiation: days with high solar gains (>12000 kJ/m^2/day) and days with low solar gains (<12000 kJ/m^2/day). Six out of 11 days of the 24-hour shading trials and three out of seven of the 9 a.m. to 5 p.m. shading strategy days fell into the high solar gain category. Both shading strategies revealed significant savings in cooling energy consumption. Savings were greatest on the days with the highest solar gains. This savings is shown graphically by the distance between the high solar gain data points (solid squares and diamonds) and the benchmark line.

A trend line is drawn through the five high solar gain 24-hour shading points in Figure 10. This trend line is almost parallel to the Benchmark line, with a slope of 1.0. The two lines are separated by approximately 4 kWh/day. This indicates that the 24-hour shading strategy would be expected to produce a constant amount of savings on days with high solar gains throughout a large range of outdoor temperature conditions.

The daily savings from the 24-hour shading strategy are listed in Table 4. The rows containing data for days with high solar gains are highlighted in yellow. Savings from the

24-hour strategy ranged from 1.10 kWh to 4.60 kWh. The average savings for the 11-day test period was 3.28 kWh/day, or 9.1% of calculated Test House consumption in benchmark configuration. Savings were highest on the days with vertical solar gains above 12000 kJ/m^2/day, averaging 4.14 kWh/day savings, or 12% of the calculated Test House benchmark consumption.

Slightly lower absolute savings in kWh were seen during the 9 a.m. to 5 p.m. shading strategy (see Table 5). This may have been due in part to the cooler outdoor temperature conditions and lower air conditioner consumption during these trials. Additionally, removing the shades from the west window at 5 pm allowed some evening solar gains to enter the house, and additional evening savings to be missed. 9 a.m. to 5 p.m. shading resulted in an average savings of 2.67 kWh/day (10%) savings over the test period. Savings were again highest on days with high solar gains, averaging 3.48 kWh/day (12%).

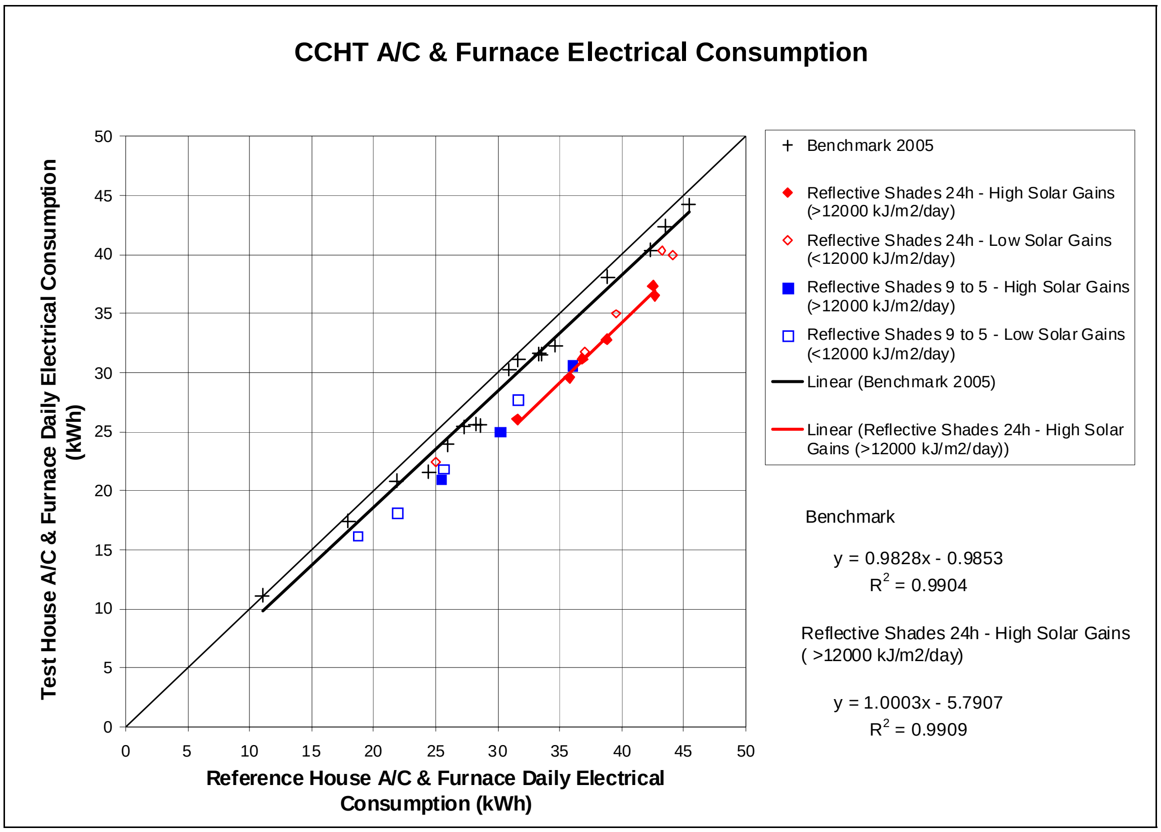

Figure 10 - Total Cooling System Electrical Consumption

Table 4 - Daily Shading Cooling Consumption Savings for 24-hour shading strategy

	Measured Air Conditioner Compressor Electrical Consumption (kWh)		Measured Furnace Fan Electrical Consumption (kWh)		Measured Total Cooling Electrical Consumption (kWh)		Calculated Total Test House Cooling Electrical Consumption with no reflective blinds (kWh)			Weather Conditions			
Date	Reference House	Test House	Reference House	Test House	Reference House	Test House	Based on the Benchmark Correlation	Savings from blind strategy (kWh)	Savings (%)	Max T (°C)	Min T (°C)	Average T (°C)	Solar Radiation Incident on South facing wall (KJ/m2/day)
04-Aug-05	28.99	27.16	14.22	13.19	43.20	40.35	41.47	1.13	2.7%	33.3	19.5	25.7	11125
05-Aug-05	28.27	23.75	14.40	12.78	42.67	36.53	40.95	4.42	11%	27.4	20	24	12665
06-Aug-05	22.64	17.99	13.16	11.60	35.79	29.59	34.19	4.60	13%	29	14.8	22	12858
07-Aug-05	25.26	20.78	13.54	12.04	38.80	32.82	37.15	4.33	12%	30.3	16.1	23.7	13132
08-Aug-05	28.38	24.63	14.12	12.72	42.50	37.34	40.78	3.44	8.4%	32	19.6	25.4	12748
09-Aug-05	29.78	26.87	14.35	13.10	44.13	39.97	42.39	2.42	5.7%	32.4	19.8	26.1	11850
10-Aug-05	25.79	22.52	13.79	12.47	39.57	34.99	37.91	2.91	7.7%	31.1	20.6	24.4	6794
11-Aug-05	23.69	19.80	13.35	11.95	37.04	31.76	35.42	3.66	10%	28	18.4	22.9	11805
12-Aug-05	13.81	12.04	11.17	10.43	24.98	22.47	23.56	1.10	4.7%	24.3	18	20.6	4141
13-Aug-05	23.58	19.36	13.26	11.80	36.84	31.16	35.22	4.05	12%	28	19.4	23.4	13544
25-Aug-05	19.25	15.09	12.30	10.94	31.55	26.04	30.02	3.98	13%	27.1	13.2	20.2	14725
Average	**24.49**	**20.91**	**13.42**	**12.09**	**37.92**	**33.00**	**36.28**	**3.28**	**9.1%**	**29.4**	**18.1**	**23.5**	**11399**
Average - Low Solar (<12000)	24.41	21.68	13.38	12.23	37.79	33.91	36.15	2.24	6.2%	29.8	19.3	23.9	9143
Average - High Solar (>12000)	24.56	20.27	13.46	11.98	38.03	32.25	36.39	4.14	12%	29.0	17.2	23.1	13279

Note: Highlighted rows indicate days with Total Vertical Solar gains in excess of 12000 $kJ/m^2/day$

Table 5 - Daily Shading Cooling Consumption Savings for 9 a.m. to 5 p.m. shading strategy

	Measured Air Conditioner Compressor Electrical Consumption (kWh)		Measured Furnace Fan Electrical Consumption (kWh)		Measured Total Cooling Electrical Consumption (kWh)		Calculated Total Test House Cooling Electrical Consumption with no reflective blinds (kWh)			Weather Conditions			
Date	Reference House	Test House	Reference House	Test House	Reference House	Test House	Based on the Benchmark Correlation	Savings from blind strategy (kWh)	Savings (%)	Max T (°C)	Min T (°C)	Average T (°C)	Solar Radiation Incident on South facing wall (KJ/m2/day)
15-Aug-05	19.22	16.41	12.37	11.30	31.59	27.71	30.06	2.35	7.8%	28.0	16.7	21.7	9758
16-Aug-05	22.88	18.91	13.12	11.74	35.99	30.65	34.39	3.73	11%	27.5	17.5	22.7	13843
17-Aug-05	17.89	14.03	12.30	10.98	30.20	25.01	28.69	3.68	13%	23.2	14.2	19.1	13372
18-Aug-05	8.71	6.87	9.99	9.31	18.70	16.18	17.39	1.21	7.0%	17.6	13.0	15.7	1754
22-Aug-05	14.24	11.52	11.39	10.37	25.63	21.89	24.20	2.31	9.6%	21.7	15.3	18.4	9165
23-Aug-05	11.29	8.50	10.61	9.65	21.90	18.14	20.53	2.39	12%	20.9	12.8	17.0	9719
24-Aug-05	14.20	10.87	11.24	10.11	25.44	20.98	24.02	3.03	13%	24.8	11.3	18.2	12434
Average	**15.49**	**12.44**	**11.57**	**10.49**	**27.06**	**22.94**	**25.61**	**2.67**	**10%**	**23.4**	**14.4**	**18.9**	**10006**
Average - Low Solar (<12000)	13.36	10.82	11.09	10.16	24.45	20.98	23.05	2.07	9.0%	22.1	14.4	18.2	7599
Average - High Solar (>12000)	18.32	14.61	12.22	10.94	30.54	25.55	29.03	3.48	12%	25.2	14.3	20.0	13216

Note: Highlighted rows indicate days with Total Vertical Solar gains in excess of 12000 kJ/m^2/day

5.2 Energy Savings and Time of Day

The reflective shades work to primarily reduce solar gains in the house, so theoretically most of the savings are expected to occur during the day. For this reason, the consumption data was further analyzed by daytime (9 a.m. to 5 p.m.) and night time (midnight to 9 a.m. and 5 p.m. to midnight) consumption.

As expected, the majority of savings occurred during the day for both strategies (see Figure 11 and Figure 12). On average, the 24-hour shading strategy produced daytime savings of 2.31 kWh (14% of benchmark daytime consumption). This was again highest on the days with the highest solar gains, averaging 3.16 kWh in savings (19% of benchmark daytime consumption). See Table 6 for details of nighttime and daytime savings for this strategy.

Large daytime savings were measured during the 9 a.m. to 5 p.m. shading strategy as well (Table 7). This strategy produced an average daytime savings of 2.95 kWh (24% of benchmark daytime consumption). On days with high solar gains, the savings were slightly higher at 3.52 kWh (25% of benchmark daytime consumption).

Figure 13 and Figure 14 show the nighttime savings from the two shading strategies. The nighttime consumption data revealed that 24-hour shading provided additional savings overnight on most days during the experiment. On average, overnight shading produced an additional savings of 0.9 kWh (4% of benchmark nighttime consumption). The maximum nighttime savings produced by the strategy was 2.41 kWh (10% of the benchmark nighttime consumption for that day) on August 5th. There are two factors that are likely contributing to these nighttime savings. First, during the 24-hour shading strategy the shade on the west-facing window shaded the house from evening solar gains. Second, on the majority of test days, the average outdoor temperature overnight was warmer than the indoor conditions (~21°C). On these nights, the shades may have provided added insulation, reducing heat gains to the house and increasing savings. More evidence of this effect is provided by the glass surface temperature analysis in Section 5.3. Were the nights cooler than indoor conditions, the insulating effect of the shade would adversely affect savings – decreasing the ability of heat to leave the house through the windows.

The nighttime analysis of the 9 a.m. to 5 p.m. shading data revealed a slight increase in consumption over the benchmark case. On average, an additional 0.63 kWh (a 6.1% increase from the benchmark nighttime consumption) of electricity was consumed per night. Outside the hours of 9 a.m. to 5 p.m. the house was returned to its benchmark configuration, and so cooling consumption would be expected to be the same as the benchmark cooling consumption. One possible explanation for the increase in nighttime consumption from this strategy is that each evening the heat trapped behind the blind during the day radiated from the hot window surface into the house when the shades were removed at 5 p.m.

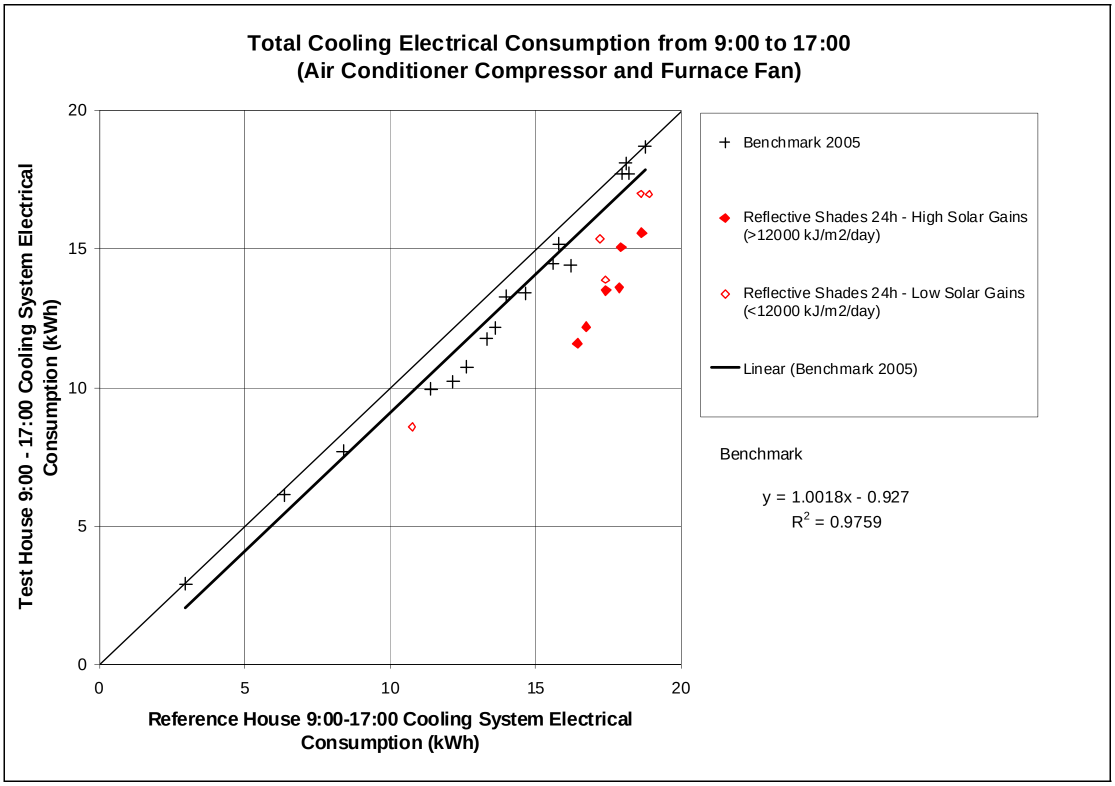

Figure 11 – Daytime Cooling Electrical Consumption (9 a.m. to 5 p.m.) for 24-hour shading strategy

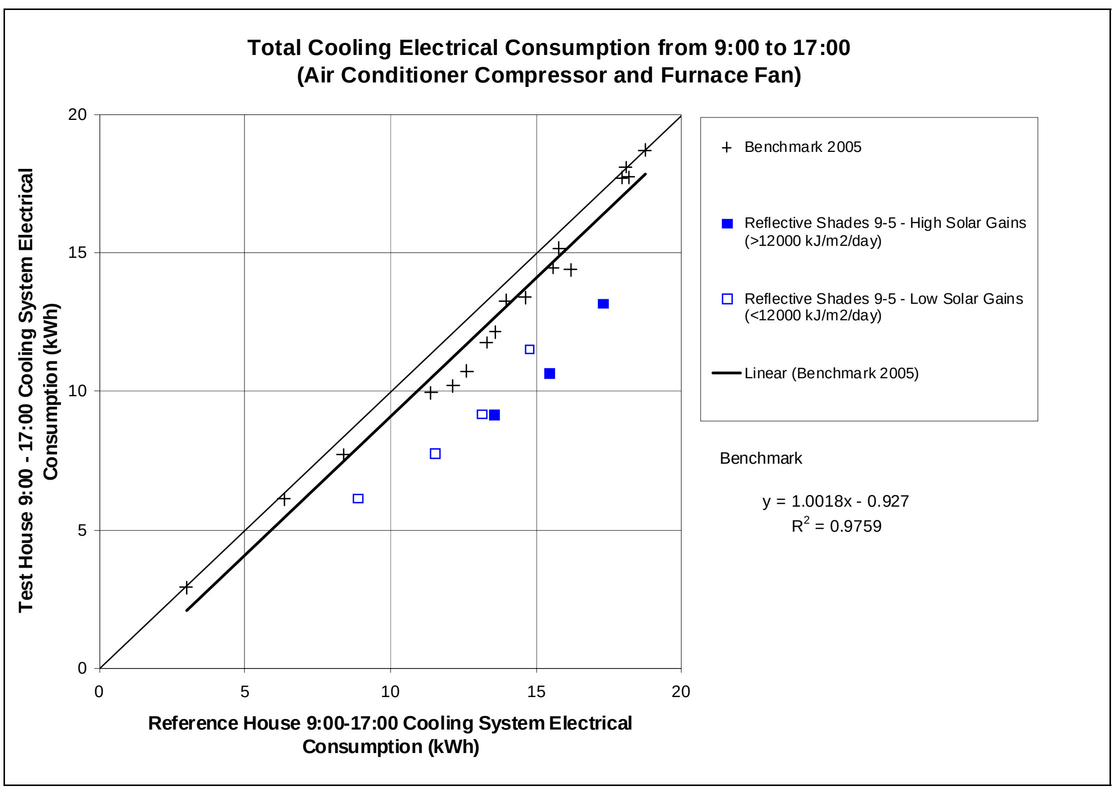

Figure 12 - Daytime Cooling Electrical Consumption (9 a.m. to 5 p.m.) for 9 to 5 shading strategy

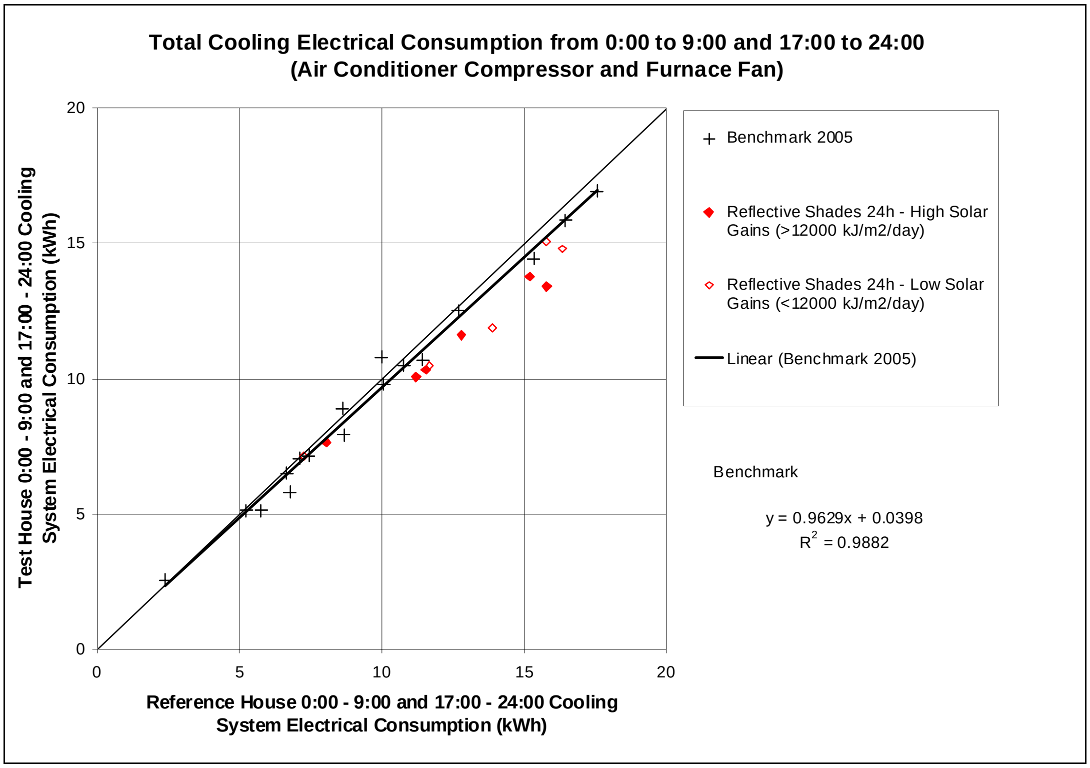

Figure 13 - Nighttime Cooling Electrical Consumption (midnight to 9 a.m. and 5 p.m. to midnight) for 24 hour shading strategy

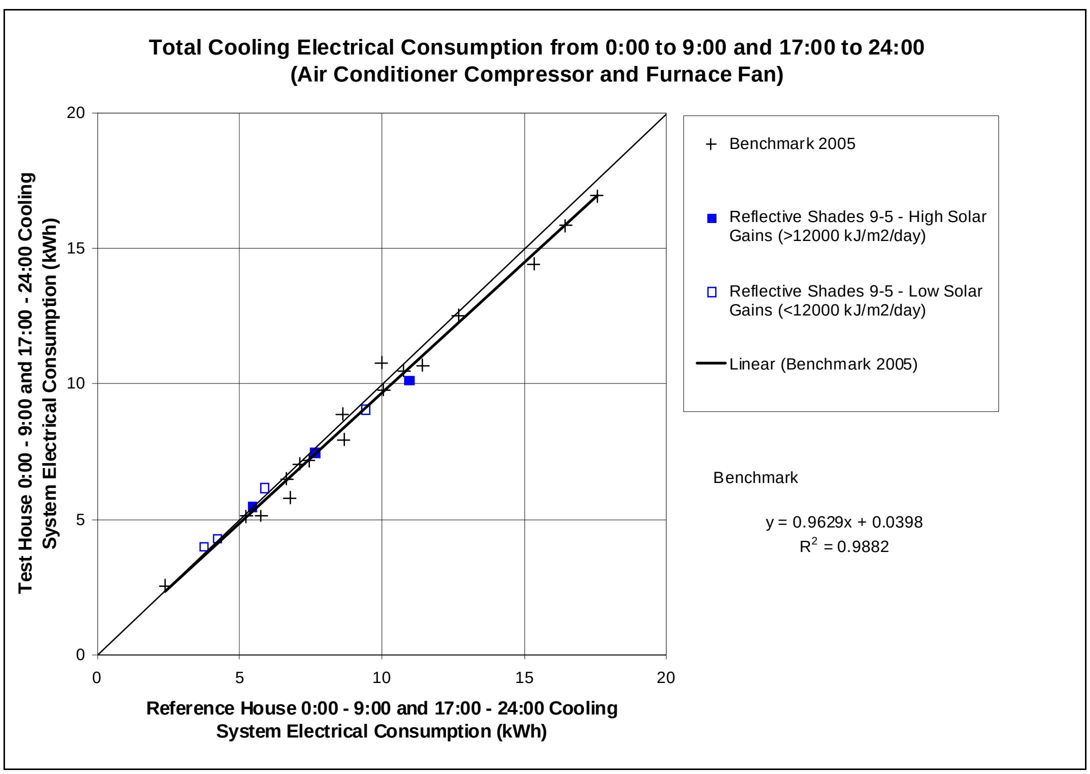

Figure 14 - Nighttime Cooling Electrical Consumption (midnight to 9 a.m. and 5 p.m. to midnight) for 9 to 5 shading strategy

Table 6 - Cooling Energy Savings by Time Period - 24 hour shading

Date	9:00 to 17:00						0:00 to 9:00 and 17:00 to 24:00					
	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)
04-Aug-05	18.60	17.00	17.70	0.71	4.0%	29.4	24.60	23.35	23.72	0.37	1.6%	23.8
05-Aug-05	17.93	15.08	17.04	1.96	11%	25.3	24.74	21.45	23.86	2.41	10%	23.4
06-Aug-05	16.73	12.19	15.83	3.65	23%	25.1	19.06	17.40	18.17	0.77	4.2%	20.5
07-Aug-05	17.86	13.61	16.97	3.36	20%	26.5	20.94	19.21	20.05	0.84	4.2%	22.3
08-Aug-05	18.64	15.58	17.75	2.17	12%	28.3	23.86	21.76	22.97	1.21	5.3%	24.0
09-Aug-05	18.88	16.99	17.99	1.00	5.5%	29.3	25.25	22.98	24.37	1.39	5.7%	24.4
10-Aug-05	17.19	15.38	16.29	0.91	5.6%	27.3	22.38	19.61	21.50	1.89	8.8%	23.0
11-Aug-05	17.40	13.90	16.51	2.61	16%	25.3	19.64	17.86	18.75	0.88	4.7%	21.6
12-Aug-05	10.75	8.57	9.84	1.27	13%	22.6	14.23	13.90	13.33	-0.56	-4.2%	19.6
13-Aug-05	17.40	13.52	16.51	2.99	18%	25.1	19.43	17.65	18.54	0.89	4.8%	22.5
25-Aug-05	16.43	11.60	16.43	4.84	29%	23.9	15.11	14.44	14.21	-0.22	-1.6%	18.3
Average	**17.07**	**13.95**	**16.26**	**2.31**	**14%**	**24.0**	**20.84**	**19.06**	**19.95**	**0.90**	**4.0%**	**22.1**
Average - Low Solar (<12000)	16.56	14.37	15.67	1.30	8.8%	26.0	21.22	19.54	20.33	0.79	3.3%	22.5
Average - High Solar (>12000)	17.50	13.59	16.75	3.16	19%	25.7	20.53	18.65	19.64	0.98	4.5%	21.8

Table 7 - Cooling Energy Savings by Time Period - 9:00 to 17:00 Shading

Date	9:00 to 17:00						0:00 to 9:00 and 17:00 to 24:00					
	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)
15-Aug-05	14.77	11.54	13.87	2.33	17%	24.1	16.82	16.17	15.92	-0.24	-1.5%	20.5
16-Aug-05	17.30	13.19	16.40	3.21	20%	24.8	18.70	17.47	17.80	0.34	1.9%	21.6
17-Aug-05	15.44	10.66	14.54	3.88	27%	21.0	14.76	14.35	13.85	-0.50	-3.6%	18.1
18-Aug-05	8.88	6.14	7.97	1.83	23%	16.4	9.81	10.04	8.90	-1.14	-13%	15.3
22-Aug-05	13.14	9.19	12.24	3.05	25%	19.7	12.49	12.70	11.58	-1.11	-9.6%	17.7
23-Aug-05	11.53	7.77	10.63	2.86	27%	19.0	10.36	10.38	9.46	-0.92	-9.8%	16.0
24-Aug-05	13.56	9.18	12.65	3.48	27%	21.4	11.88	11.81	10.98	-0.83	-7.6%	16.5
Average	**13.52**	**9.66**	**12.61**	**2.95**	**24%**	**20.9**	**13.55**	**13.27**	**12.64**	**-0.63**	**-6.1%**	**18.0**
Average - Low Solar (<12000)	12.08	8.66	11.18	2.52	23%	19.82	12.37	12.32	11.47	-0.85	-8.4%	17.37
Average - High Solar (>12000)	15.43	11.01	14.53	3.52	25%	22.40	15.11	14.54	14.21	-0.33	-3.1%	18.75

5.3 Approximation of Seasonal Savings

A rough correlation can be drawn between daily cooling system electrical and daily vertical solar radiation. As mentioned in the previous section, savings from shade use increase with increase in solar gains. The trends in Figure 15 are based on the assumption of a zero intercept since there was a limited amount of data at the low solar radiation end of the curve. More data is required to verify the exact correlations, however, these trends can still be used to approximate the expected savings for the 2005 cooling season.

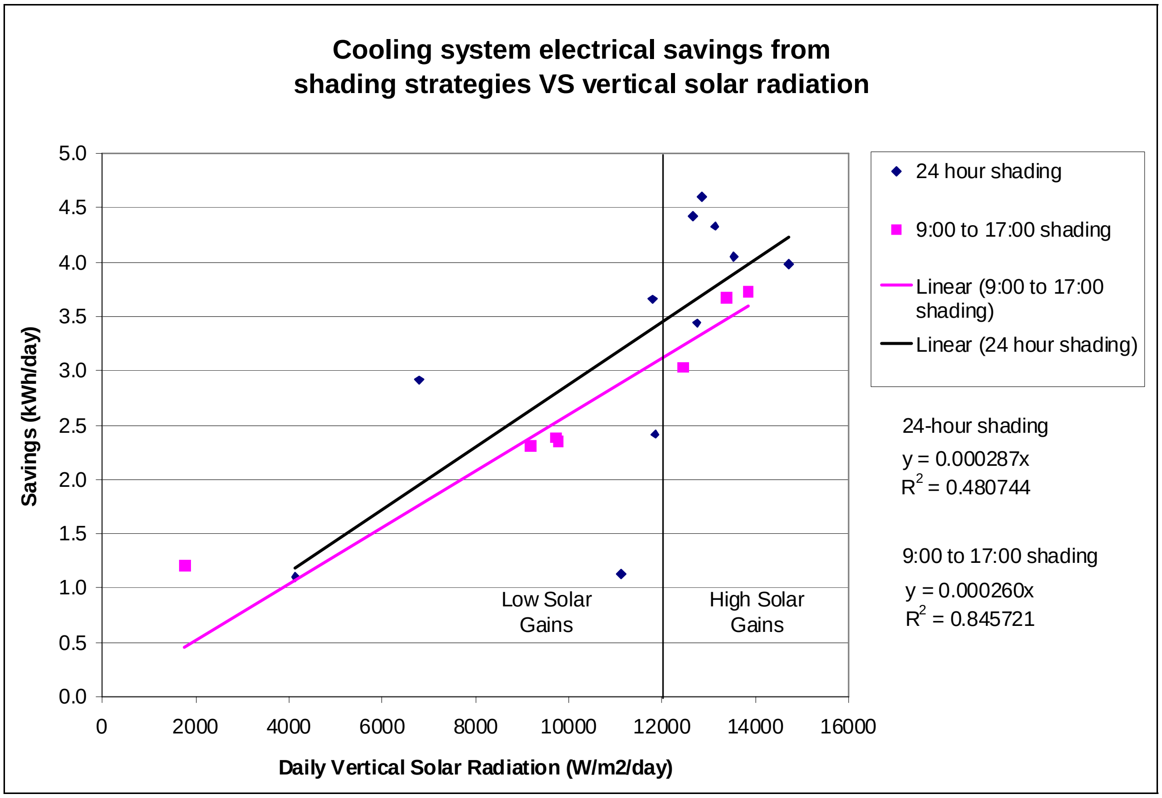

Figure 15 - Savings from Shading Strategies vs Daily Vertical Solar Radiation

Figure 16 presents a histogram of the varying daily amounts of vertical solar radiation throughout the 2005 cooling season. The cooling season at CCHT consisted of 128 days of air conditioner operation. This season was uncharacteristically warm for Ottawa, Canada, with a total of 460 cooling degree-days above 18°C (Environment Canada reports a 30-year average for Ottawa of 244.6 cooling degree-days above 18°C). Out of the 128 days, 38 days experienced a total vertical solar radiation in excess of 12000 kJ/m^2/day. During this season, the Test House with the standard benchmarking blinds configuration – interior Venetian blinds in the down and horizontal position - would be expected to consume 3822 kWh of cooling energy. The trend lines in Figure 15 predict that the 24-hour shading strategy would produce a total of 378 kWh of cooling energy savings, while the 9 to 5 shading strategy would produce slightly less savings at 342 kWh over the cooling season. This is equivalent to a seasonal savings of 9.9% and 9.0% in total cooling energy for the two respective strategies.

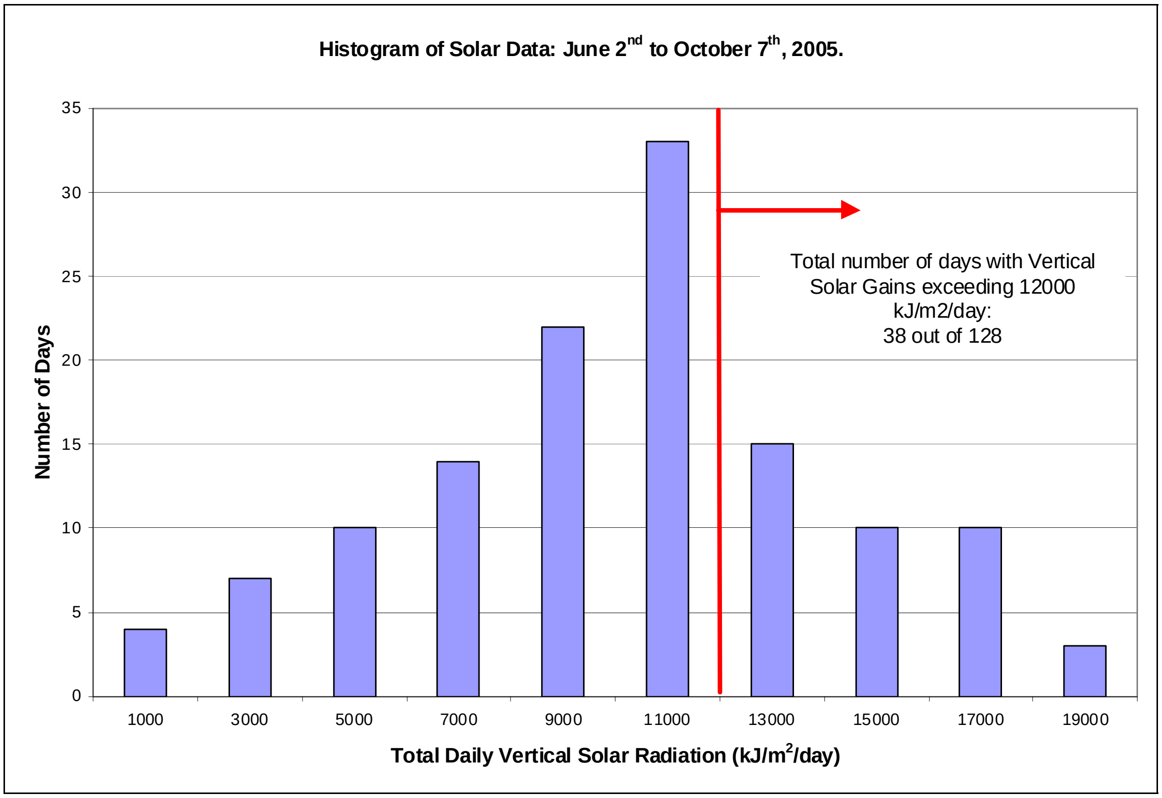

Figure 16 - Histogram of Total Daily Vertical Solar Radiation, Summer 2005

5.4 Glass Temperatures

Window pane surface temperatures were observed throughout the experiment. Particular attention was paid to the maximum surface temperature reached and the temperature differential between the edge and centre of glass.

Practical experience indicates that while the glass and seal themselves are capable of withstanding high temperatures, the temperature limits for the glazing unit are defined by the temperature differential between the center of the glass and the edge of the glass (Barry, 2006 and Lichtenberger, 2006). When the edge of the glass is cooler than the centre, tensile thermal stresses are produced that can lead to breakage (Sasaki, 1970). The higher the differential, the higher the tension introduced in the glazing unit. Window cracks are generally initiated at an edge defect created in manufacturing. Thermal cycling to high temperatures encourages damage to appear and propagate. For this reason, the centre to edge temperature differential should be less than 30°C in order to avoid potential breakage, particularly if the cut edge quality is poor.

Figure 17 and Figure 18 show the measured window surface temperatures at the centre and bottom edge of the interior pane. Under benchmarking conditions, the Test House interior window surface temperature reached a maximum of 45.7°C. The highest temperature occurred at the edge of the window. With the reflective shades in place, much higher surface temperatures were reached. The highest surface temperature was measured at the centre of the Test House window, reaching a maximum of 68.7°C, nearly 30°C higher than the normal operating conditions.

On the last day of the shading experiment, August 26th, the shade was removed from its frame and secured directly to the window. Temperatures were monitored, and at noon the shade was removed due to very high surface temperatures on the inner pane. At this time, the temperature at the centre of the Test House interior window pane surpassed 82°C, roughly 40°C higher than the temperature of its twin pane in the Reference House.

In the cool early morning hours of August 25th and 26th, there is some evidence that the shades were insulating the window. On these nights the shades remained in place and the outdoor temperature dropped below the 21°C interior temperature. In Figure 18, the window temperatures in the Test House can be seen to drop below those of the unshaded Reference House windows, providing evidence that the shades were trapping heat inside the house.

Figure 19 shows a plot of the temperature differential between the centre and edge of the window. In normal benchmarking operation, the maximum differential occurs in the middle of the day, when the edge of the window was up to approximately 5°C warmer than the centre of the window. The shades produced a much higher surface temperature differential. On sunny days, the temperature at the centre of the window was up to 29.7°C hotter than the edge. This was considered to be at the 30°C limit of safe operation.

Although no windows were broken during this experiment, repeated cycling at these high temperatures from prolonged use of the shades could lead to window damage.

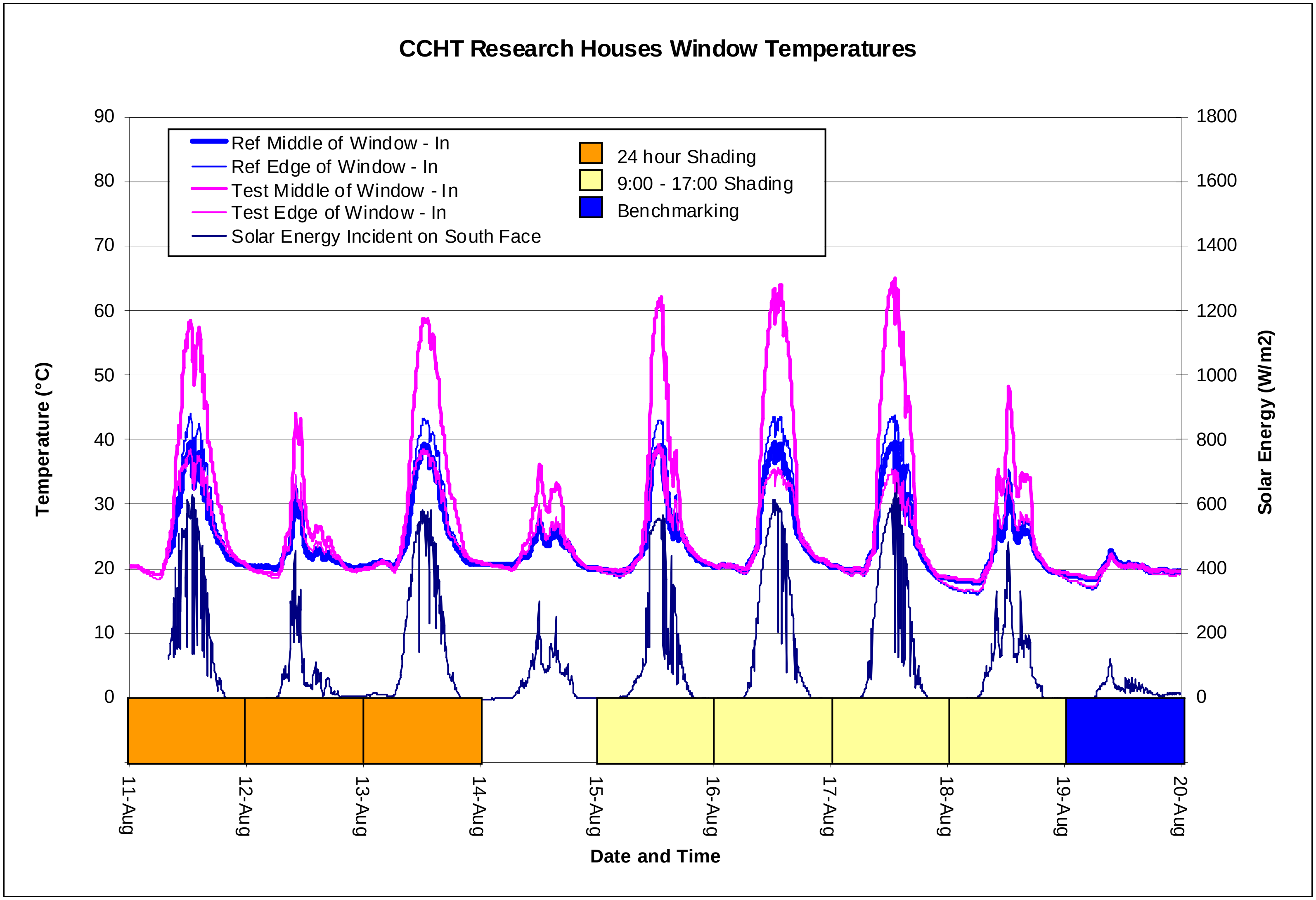

Figure 17 - Window Surface Temperatures August 11th to August 19th

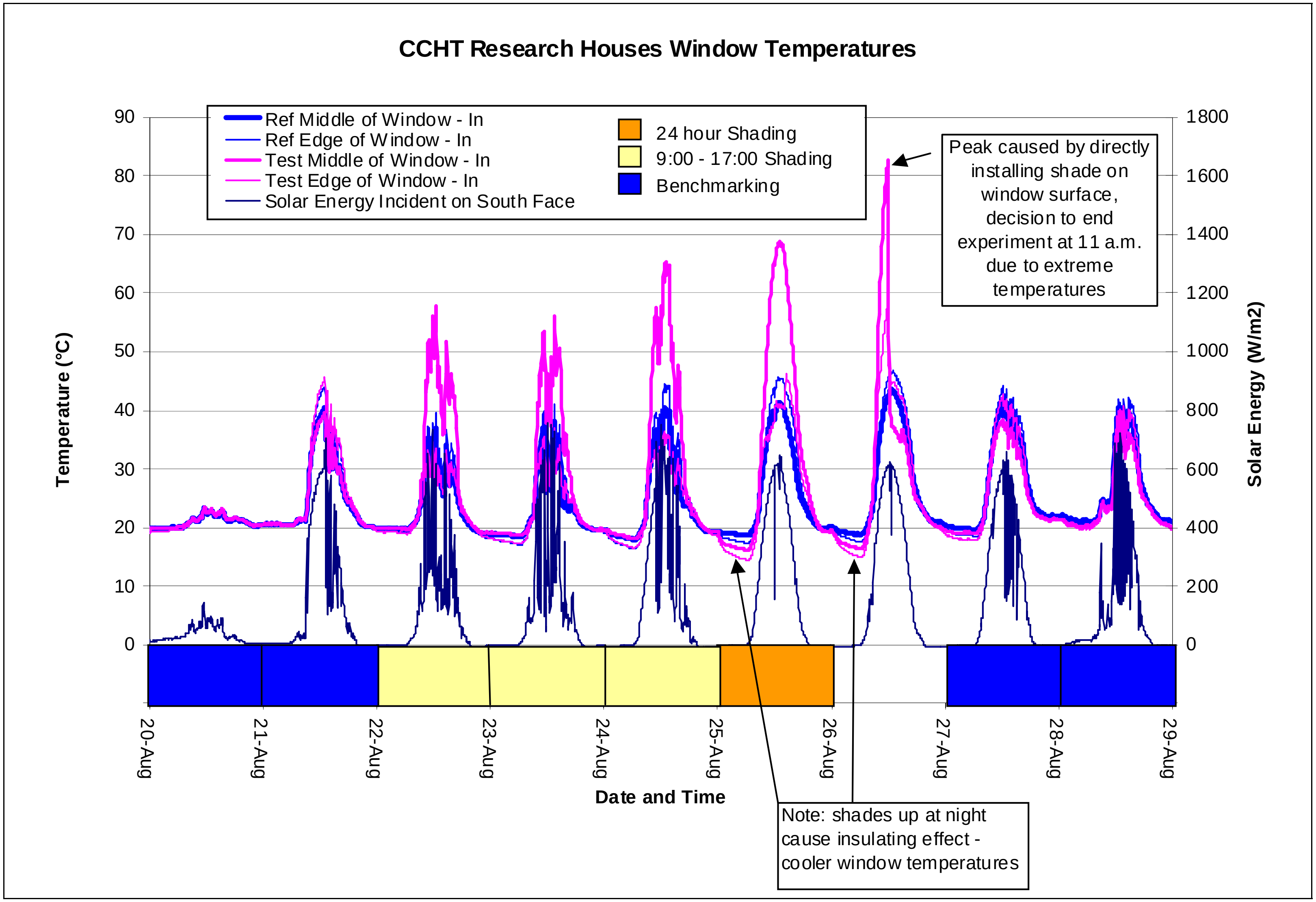

Figure 18 - Window Surface Temperatures – August 20th to August 29th

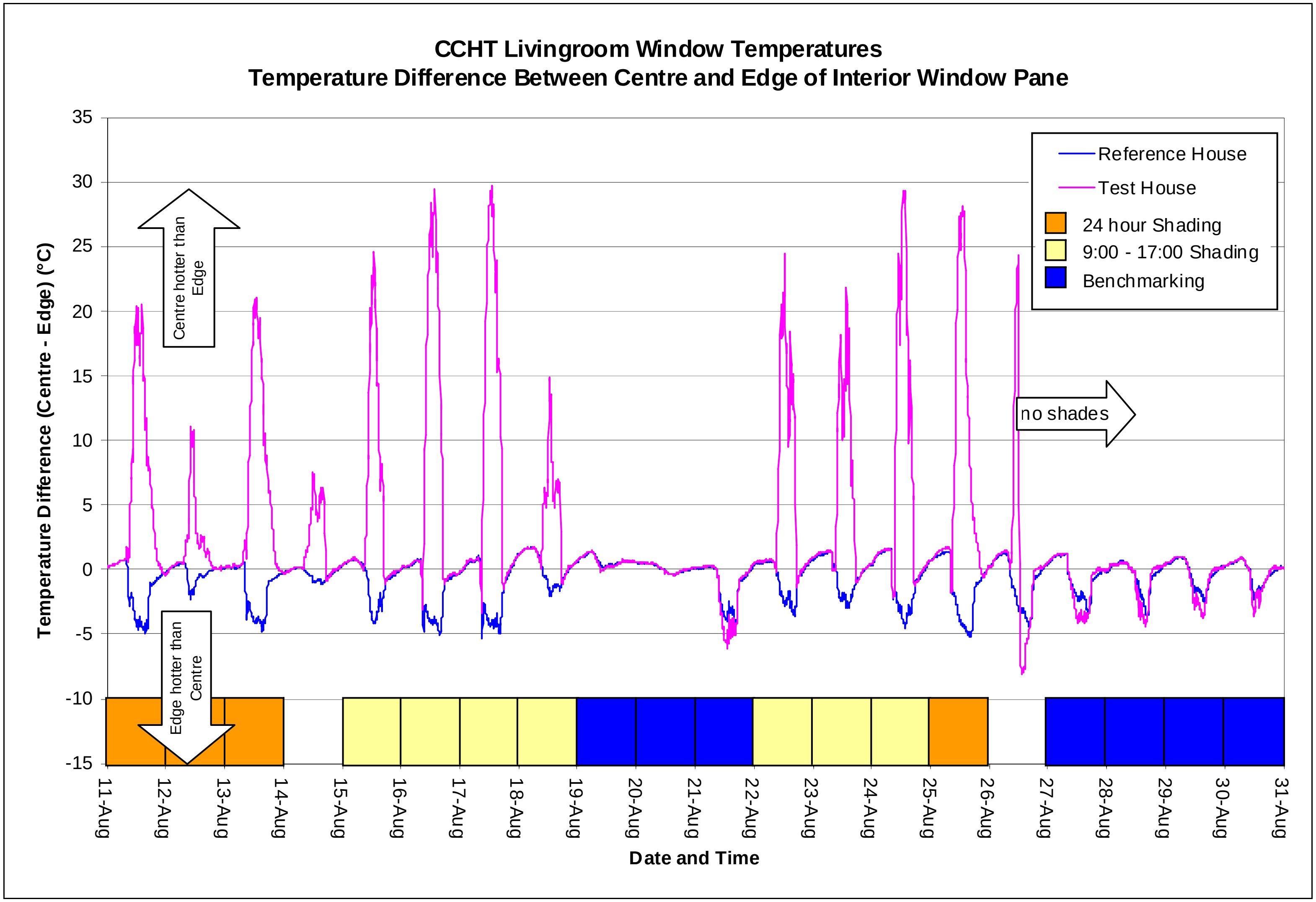

Figure 19 - Surface Temperature Differential between Centre and Edge of Interior Window Pane

5.5 House Humidity

It was predicted that since the use of shades resulted in a reduction in air conditioner on-time, the cooling system would not remove as much moisture from the air, and the humidity would be higher in the shaded house. This should be detected as an increase in humidity levels in the Test House during the shading experiment. Some difference in humidity was detected during the daytime hours when the shades had the greatest impact on the cooling system, see Figure 20. During the day, humidity levels in the Test House rose approximately 0.7 grams of water vapor per kilogram dry air (g_w/kg_{da}) above the levels in the Reference House. This is equivalent to roughly 2% RH at 21°C. However, this small increase in humidity is within the 2% RH accuracy of the humidity sensor and therefore should not be considered significant.

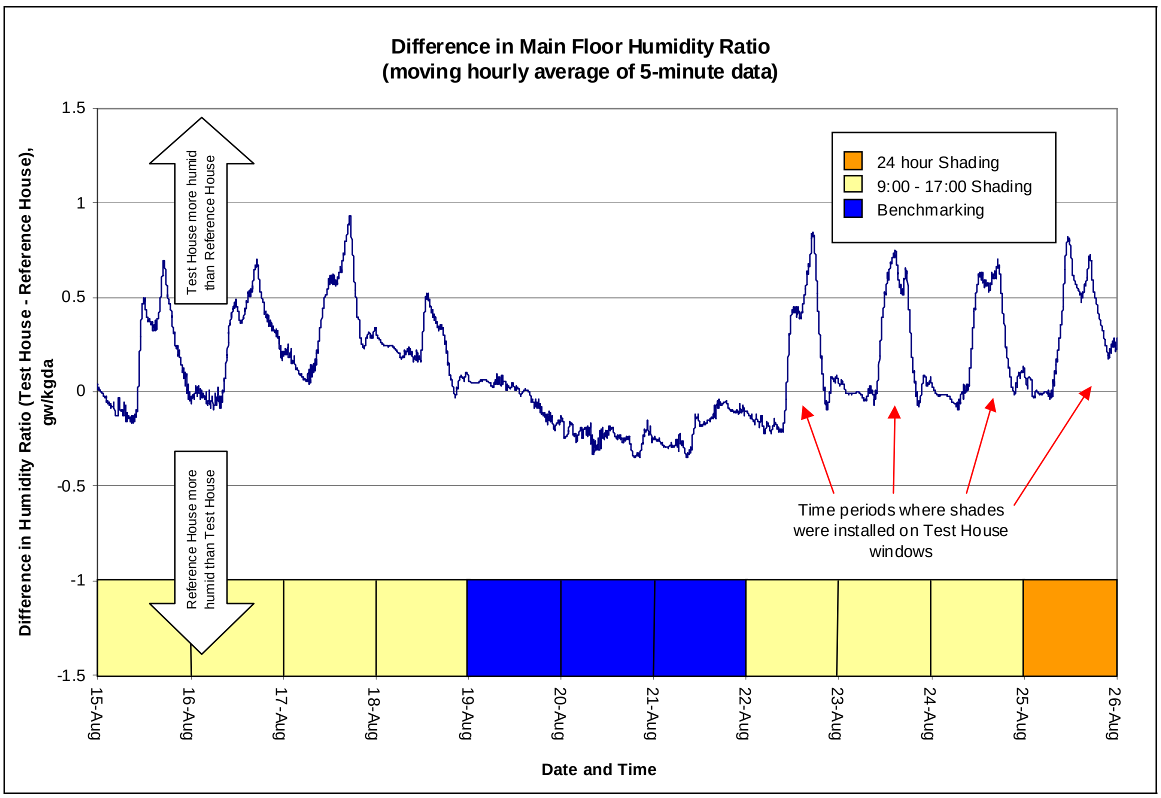

Figure 20 - Difference in Main Floor Humidity Ratio during 9a.m. to 5 p.m. Shading

6 Discussion

The 24-hour strategy proved only slightly more effective than the 9 a.m. to 5 p.m. strategy at providing energy savings during this experiment. Over the entire heating season it is predicted that cooling system electrical savings from the 24-hour shading strategy would be only 0.9% higher than savings from the 9 to 5 shadings strategy. In total, the 24 hour shading strategy is expected to produce seasonal savings of approximately 9.9%, while the 9 to 5 shading strategy would produce seasonal savings in cooling electrical consumption of 9.0%. The main cause of this difference was the shading of the west-facing window. This window remained covered in the evening during the 24-hour shading strategy, reducing evening solar gains to the house and producing additional savings. There is also some evidence – from window temperatures and the 9 a.m. to 5 pm analysis of the consumption data – that removing the shades at 5 p.m. in the 9 a.m. to 5 pm shading strategy allowed the hot window surface to radiate heat into the house.

Table 8 provides a summary of the results from the reflective shading experiment, and the previous Venetian blinds and Exterior shading trials. Generally, the reflective shades proved more effective at reducing air conditioner cooling loads than the interior Venetian blinds, and less effective than the exterior shades. The 9 a.m. to 5 p.m. savings of the Venetian blinds (12%) was countered by nighttime heat gains from heat trapped between the blind and the window radiating back into the house overnight. On the clearest of days, the Venetian blinds produced only small cooling energy savings in the order of 1%. By contrast, both reflective shading strategies produced larger savings during the day (19-25%) and a substantial total daily savings (~12%) in cooling energy consumption on days with high solar gains. Exterior shading still remains the most effective strategy. This strategy generated daytime cooling energy savings of 77% and overall daily savings of 26%, when compared to the house's daily cooling consumption with closed Venetian blinds.

Table 8 - Summary of Average Daily Savings from different Strategies on Days with High Solar Gains

Trial	Daytime savings (9:00 to 17:00)	Total Daily Savings Over 24 hours
Reflective shades 24 hour shading VS Venetian blinds down and slats horizontal	19%**	12%
Reflective shades 9 to 5 shading VS Venetian blinds down and slats horizontal	25%**	12%
Venetian blinds closed 24 hours* VS Venetian blinds open from 9 to 5	12%	<1%
Exterior blinds VS closed Venetian blinds * 24 hour shading	77%	26%

* Savings results are taken from Galasiu et al., 2005.
Note: savings percentages shown in this table are based on an average of the experiment data for each trial, and are not extrapolated to the entire season.
** Differences in daytime savings from the two strategies is attributable to differing weather conditions during the trial periods

Window temperatures and temperature differential across the glazing unit achieved high levels during the shading experiments, increasing the chance of window breakage. The low-e coating on the third surface of the window contributed to these high temperatures. Lower surface temperatures would be expected on a clear glass double pane window.

More tests are required to determine whether the temperature levels on other types of windows would be within a safe range.

Some features of the houses may affect results, including the fact that they are unfurnished. Without furnishings, the houses contain less thermal mass than a typical inhabited house. Thus, the houses would respond more quickly to changes in temperature and retain less heat from the day. The extent of this mass effect has yet to be evaluated.

A large amount of scatter was present in the data for the daily vertical solar radiation and energy savings relationship (Figure 15). This is partially due to the small quantity of data, but also may be in part a result of the lack of shading on the east-facing windows of both houses. In the early morning hours, the Reference House may have experienced more solar gains than the Test House on days with sunny mornings. In order to construct a better trend line, future tests should be planned to include shading on a minimum of 3 facades: East, South and West.

7 Conclusions

In the summer of 2005, the performance of reflective shading devices was evaluated at CCHT. These shades were installed on the south and west facing windows of the CCHT Test House. Two shading strategies were employed: shading 24 hours and shading 9 a.m. to 5 p.m. Cooling energy consumption (the electrical consumption of the air conditioner compressor and furnace fan), window surface temperatures and house humidity were evaluated.

Results from the experiment revealed that the reflective shading devices produced substantial savings in cooling energy consumption throughout both shading strategies. Savings were the highest on days with the highest incident solar radiation, days when the shades were most effective at reducing solar gains. During the test period, the 24-hour shading strategy produced an average savings of 4.14 kWh/day (12%) on the days with the highest solar gains, and 3.28 kWh/day (9.1%) savings over the entire test period. The 9 a.m. to 5 p.m. shading strategy produced slightly lower absolute savings in kWh, with an average of 3.48 kWh/day (12%) savings on days with high solar gains, and 2.67 kWh/day (10%) average savings for all days the test period. Seasonal calculations predict a cooling system electrical consumption savings of 9.0% for the 9 a.m. to 5 p.m. strategy, and 9.9% for the 24 hour shading strategy over the entire 2005 cooling season at the CCHT Test House.

The majority of savings from the shading strategies was produced between the hours of 9 a.m. and 5 p.m. During this period of time, the 24-hour shading strategy produced an average savings of 2.31 kWh/day (14%), while the 9 a.m. to 5 p.m. shading strategy produced an even higher average savings of 2.95 kWh/day (24%). Outside the hours of 9 a.m. to 5 p.m., the 24-hour shading strategy produced additional savings on these same days of approximately 0.90 kWh/day. By contrast, during the non-shaded hours, the 9 a.m. to 5 p.m. strategy produced an increase in consumption of 0.63 kWh/day. It is likely that the 24-hour shading strategy provided this additional nighttime savings due to the shading of the west-facing window after 5 p.m. reducing evening solar gains to the house.

The window surface temperatures at the centre and edge of the interior pane were evaluated. While shaded, surface temperatures at the centre of the window were roughly 30°C higher than normal operating conditions, reaching a maximum of 68.7°C on the sunniest day. The temperature differential between the centre and edge of glass approached the 30°C limit. For this reason, this use of the reflective shades with argon filled windows with a low-e coating on surface 3 should not be recommended. Use of the shades in this manner would contribute to increased thermal stresses outside the normal operating limits of the window, and could lead to breakage.

The small gap (~3 cm [1 inch]) between the window surface and the shading device did help to alleviate high temperatures slightly – without this air gap, the surface temperature at the centre of the window exceeded 80°C by 11 a.m.

The shading experiment did not reveal any appreciable increase in house humidity levels due to the decrease in air conditioner operation (associated with cooling energy savings). The measured humidity increase was less than 2% RH in all cases, below the accuracy of the sensor.

8 Recommendations for Future Work

A number of additional tests could be conducted to further explore the nature of the reflective shades, and evaluate their effectiveness:

- The same 24-hour shading strategy could be evaluated on days with cooler nights (where the outdoor temperature dropped below the interior air temperature). It is expected that on such nights the shades may have insulating properties that would prevent heat losses, decreasing the overall savings from this strategy.
- The shading devices could be installed on clear glass windows (no coating). This would permit the evaluation of surface temperatures to determine whether this would be a safer application, or whether temperatures would exceed safe operating limits.
- A reflective shading film could be evaluated to isolate the savings from the reflective property of the shade from the thermal properties of the trapped air in the bubbles. Surface temperatures should also be observed during these trials to check whether window temperatures remain within a normal operating range without the insulation.
- The radiant barrier nature of the shade material prevented the heat dissipation into the house, and caused the glazing temperature to approach the limits of safe operation. This is not a typical application for this type of reflective product. Further studies are required to examine the performance of other interior shading products, including those that are commercially available.

This experiment also generated a few general recommendations for all future shading work at the CCHT twin-houses:

- A longer trial period is necessary for each configuration to generate a strong relationship between cooling energy savings and solar radiation. A minimum of 2 weeks in each configuration is recommended, with the possibility of extension depending on weather.

- Shades should be installed on the windows of 3 façades of the Test House at minimum: East, South and West. This will help eliminate differences caused by morning and evening solar gains, and reduce scatter in the data.

9 References

1) Barry, Christopher, Pilkington North America, Personal communications, October 2006.

2) Galasiu, A.D.; Reinhart, C.F.; Swinton, M.C.; Manning, M.M. Assessment of Energy Performance of Window Shading Systems at the Canadian Centre for Housing Technology (IRC-RR-196), May 2005.

3) Swinton, M.C.; Moussa, H.; Marchand, R.G. "Commissioning twin houses for assessing the performance of energy conserving technologies," Performance of Exterior Envelopes of Whole Buildings VIII Integration of Building Envelopes (Clearwater, Florida, Dec, 2001), pp. 1-10, 2001 (NRCC-44995)

4) Lichtenberger, Werner, TruSeal Technologies, Personal communications, November 2006.

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Appendix A - Simulated Occupancy

Monitoring the energy performance of actual houses for a full year has often been considered the most credible way of assessing the energy efficiency of a house design and its energy efficient components. In reality, the results of such experiments were always difficult to interpret, especially if the house had been occupied. From many such attempts, it was found that the occupant lifestyle had as much or more influence on the energy consumption of the house than any individual energy efficient component – thus reducing the credibility of the information provided by the monitoring. If the house were left unoccupied, the mode of operation of the house and its resulting energy budget would not be realistic. The interaction of internal heat gains from energy using appliances and occupant heat gain would be missing from the energy balance.

Sometimes, monitoring results were compared to computer simulations to try to detect whether the energy efficient devices had an impact on the overall energy consumption of the house. Yet predicting the exact performance of a house in a given year in a given climate is probably the most difficult challenge that a computer model can have. For example, models can't simulate people behaviour realistically. Thus, comparisons of measured and modeled results usually end up informing us more about shortcomings in the model than actual performance differences due to energy efficient measures.

The Canadian Center for Housing Technology has solved these problems in assessing energy efficient equipment and components. The twin-house research facility features a "simulated occupancy system". Each house features a standard set of major appliances typically found in North American homes. The simulated occupancy system, based on home automation technology, simulates human activity by operating major appliances (stove, dishwashers, washer and dryer), lights, water valves, fans, and a host of other sources simulating typical heat gains. The schedule is typical of activities that would take place in a home with a family of two adults and two children. Electrical consumption is typical for a family of four and hot water draws are set in accordance with ASHRAE standards for sizing hot water heaters. The heat given off by humans is simulated by two 60 W (2 adults) and two 40 W (2 children) incandescent bulbs at various locations in the house. The schedule can be easily modified to accommodate particular assessment requirements.

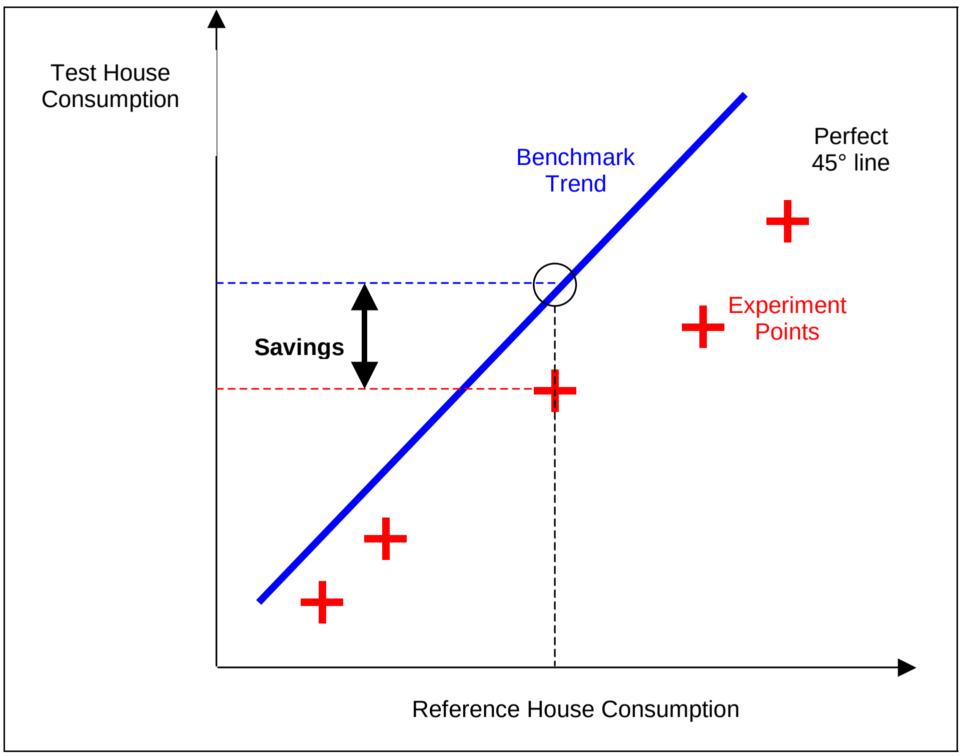
CCHT Simulated Occupancy Schedule

Note: Water draws shown here are for hot water only, in litres.

Overnight				
Device	Water Utility	Draw	Time	Duration
Bedroom 2 humans		66.4 W	0:00	6 hrs 45 min
Master bedroom humans		99.6 W	0:00	6 hrs 45 min
Morning				
Device	Water Utility	Draw	Time	Duration
2nd floor lights		410 W	6:45	60.0 min
	1. Master bedroom shower	36 L	6:50	10.2 min
Family room humans		166 W	7:00	60.0 min
Main floor lights		200 W	7:00	60.0 min
Kitchen products		450 W	7:30	10.2 min
Kitchen fan		80 W	7:30	10.2 min
Kitchen stove (intermittent)		1600 W	7:30	20.0 min
	2. Kitchen tap	13 L	7:45	3.0 min
Afternoon				
Device	Water Utility	Draw	Time	Duration
Kitchen fan		80 W	12:00	15.0 min
Kitchen stove (intermittent)		1600 W	12:00	15.0 min
Family room humans		166 W	12:00	30.0 min
Kitchen products		450 W	12:00	10.2 min
Main floor lights		200 W	12:00	15.0 min
	3. Kitchen tap	13 L	12:30	3.0 min
Evening				
Device	Water Utility	Draw	Time	Duration
	4 & 5. Clothes washer (46L)	400 W	17:00	60.0 min
Main floor lights		200 W	17:00	2 hrs 30 min
Kitchen fan		80 W	17:30	3.6 min
Kitchen stove (intermittent)		1600 W	17:30	30.0 min
Family room humans		166 W	17:30	2 hrs 30 min
Kitchen products		450 W	17:30	10.2 min
Dining room products		225 W	18:00	2 hrs
2nd floor lights		410 W	18:00	5 hrs
	6. Kitchen tap	27 L	18:30	6.0 min
	7 & 8. Dishwasher	650 W	19:00	60.0 min
Dryer		2250 W	19:00	25.2 min
Living room humans		166 W	19:00	2 hrs
Bedroom 2 humans		66 W	21:00	3 hrs
	9. Main bathroom bath	41 L	21:05	4.8 min
	10. Master bedroom shower	55 L	22:30	15 min
Master Bedroom Humans		100 W	23:00	60 min

Appendix B - Savings Calculation Method

The technique used to calculate the consumption savings at the CCHT twin house facility is described graphically below. Each red cross on this graphic represents the consumption data for a single day of an experiment with a new technology installed in the Test House. For a given day, the Reference House consumes a certain amount of energy. Given the amount consumed by the Reference House and the benchmark trend line, we can calculate how much energy the Test House would consume without the new technology (shown by the dashed blue line). To calculate savings, the measured energy consumption of the Test House during the experiment (shown by the dashed red line) is then subtracted from the expected Test House consumption without the technology. This is equivalent to the vertical distance between the experiment data point and the Benchmark trend.



Graphic Representation of the Savings Calculation Method for Summer Testing

The benchmark trend line is used in place of the benchmark data in order to minimize random errors. On any given day, some scatter is expected in the results both for the Reference House and the Test House. The scatter in the Benchmark data appears to be random error. One possible cause is that the houses' heating systems cannot be synchronized. When one house may be at the end of a heating cycle at midnight on one day, and the other house may be at the beginning, resulting in small and opposite errors on both the first and second days when this occurs.

Appendix C – Energy Consumption Graphs

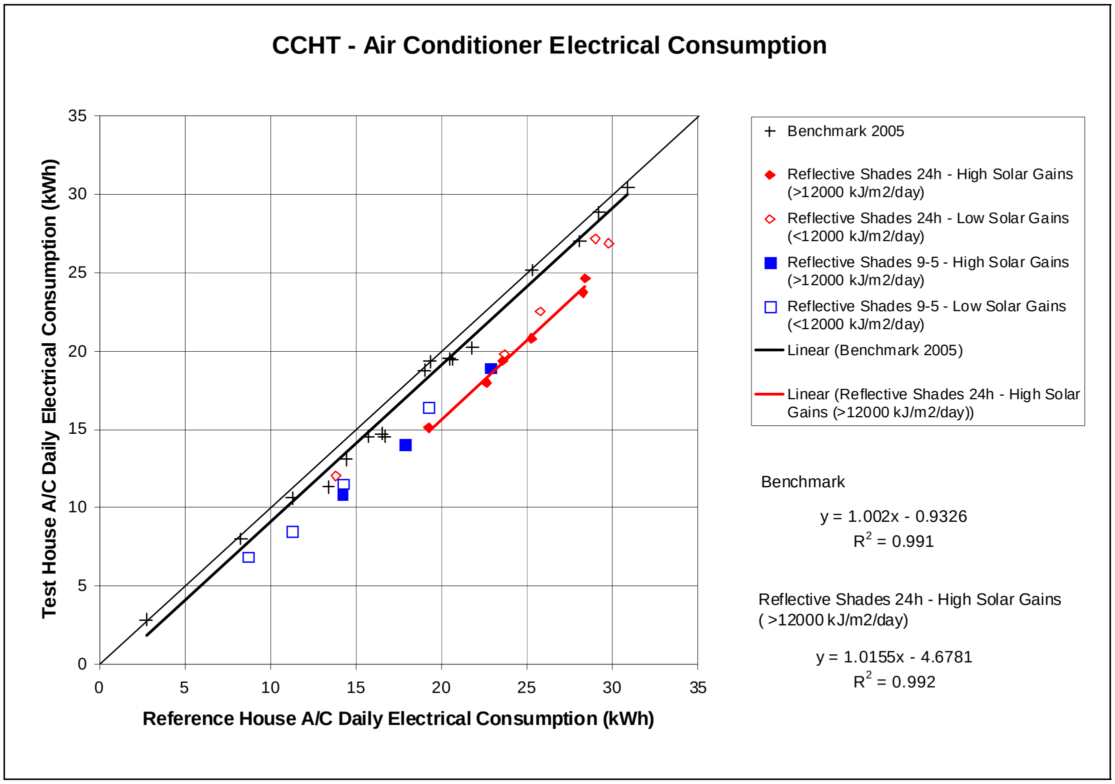


Figure C-1: Air Conditioner Compressor Electrical Consumption

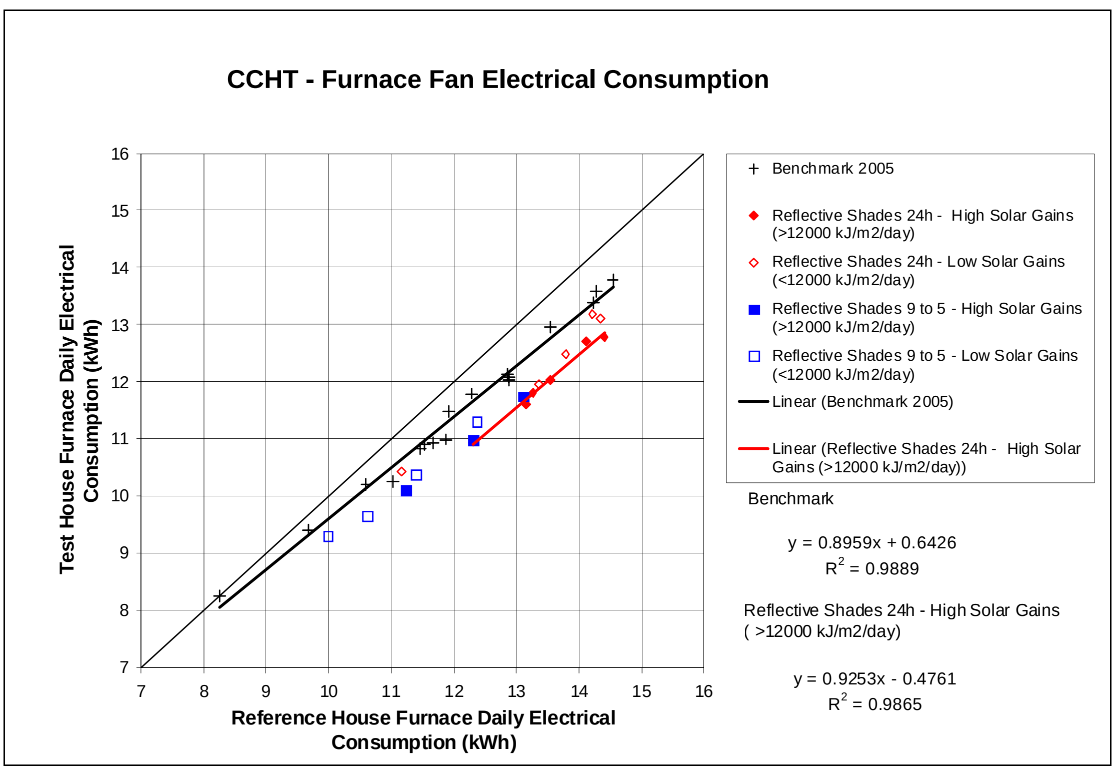


Figure C-2: Furnace Fan Electrical Consumption