RESEARCH REPORT

Monitored Performance of an Insulating Concrete Form Multi-Unit Residential Building

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MONITORED PERFORMANCE OF AN INSULATING CONCRETE FORM MULTI-UNIT RESIDENTIAL BUILDING

FINAL REPORT

December 2006

Prepared for
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ABSTRACT

A research project was undertaken to study the thermal and air leakage performance of an apartment building constructed with an insulated concrete forming system. Temperature sensors were installed in the walls on all elevations and at varying heights of the building during construction so that temperature profiles across the wall sections could be monitored. Additionally, airtightness testing was undertaken to assess the air leakage characteristics of the completed building. A thermographic survey of the ICF wall system was also undertaken to assess the system for thermal bridging. The research project found that while ICF walls offer a relatively well-insulated building envelope system, there was no apparent benefit of the thermal mass of the concrete that could be described in terms of an effective insulating value. However, the ICF wall system produced a remarkably airtight building and was highly effective at isolating exterior conditions from interior conditions.

Key Words:

Insulating concrete forms, multi-unit residential buildings, energy efficiency, innovative construction, insulation, airtightness, thermal performance

EXECUTIVE SUMMARY

In order to quantify and substantiate claims regarding the thermal performance of insulating concrete form wall construction, this study sought to assess the:

1. nominal and the effective thermal resistance of the ICF wall component,

2. air-tightness of the building envelope and identify areas of infiltration, and

3. thermal performance of the entire building envelope and identify areas of relatively high heat transfer.

The testing and monitoring regime was carried out on the seven-storey, 100 suite, Cedar Creek apartment building located in Waterloo, Ontario. The temperatures across the wall assembly at eight locations were monitored over a period of three months, from December 1, 2005 to February 28, 2006. In addition, blower door testing was conducted to quantify air leakage for the entire building and thermal imaging was used identify areas of relatively high heat transfer. Finally, computer energy modelling was undertaken to estimate the building's heating and cooling loads and annual energy use, accounting for infiltration and thermal mass, and to compare various wall constructions to the ICF system.

The overall ICF wall assembly, including the stucco exterior and gypsum board interior, has a thermal resistance (or R-value) of 3.9 m^2K/W (22.1 $hr.ft^2.F/BTU$). The concrete only accounts for 2.2% of the overall thermal resistance, while the two layers of expanded polystyrene insulation account for 91.8%, and the balance of 6.0% is attributed to the remaining components (stucco, gypsum board, inside and outside air films). The ICF wall construction does not contain any full thermal bridges, so that the thermal resistance is practically continuous over the wall area.

By comparison, the Model National Energy Code for Buildings (MNECB) requires that the minimum R-value of an above-grade wall for a natural gas heated building in southern Ontario be at least 1.76 m^2K/W (10 $hr.ft^2.F/BTU$). Hence, the thermal resistance for the wall assembly is more than double of what would be considered typical of natural gas heated buildings in Southern Ontario.

The monitored data confirmed that the volumetric heat capacity of the concrete does not increase the overall R-value of the wall assembly under steady-state conditions. During transient conditions, the data demonstrated that the concrete played a significant role in isolating fluctuations in the OAT from the interior wall surface. Although heat never actually moved from the concrete back into the building, the concrete did store heat that was lost from the interior and released the stored energy whenever the OAT decreased. The concrete temperature dropped slowly due to its low thermal diffusivity, which often buffered out overnight temperature drops.

The results of the blower door test indicated that the building was exceptionally 'tight' with a normalized air leakage index (at 75 Pa) of only 1.25 L/s/m^2. This is on the low end of the scale according to a CMHC study of 11 buildings across Canada, which found overall indexes in the range of 0.9 to 10.3 L/s/$m^2{}_{75}$. These results suggest that the design heating and cooling loads and subsequent sizing of the building's heating and cooling system may be based upon an air infiltration rate that is up to 60% lower than standard construction.

The thermographic investigation made it possible to identify areas of thermal bridging in the building envelope. The investigation confirmed that the significant thermal bridges were the through-wall penetrations, such as the condenser units for the in-suite HVAC systems, the 50 mm (2-inch) ventilation holes, the window and sliding door bucks, and the balconies. Consequently, the thermal performance of the building may be improved by carefully detailing wall penetrations such as the balcony, selecting high performance non-wall envelope components (window and door frames), and selecting mechanical equipment that do not, or at least minimally, penetrate the exterior wall (e.g., through wall condenser units).

Parametric energy simulations showed that the reduced air infiltration provided by the ICF wall construction resulted in significantly lower heating and cooling loads and yielded an estimated annual energy savings of 574,584 MJ and cost savings of $5,879 for this building. The simulations also showed that there were insignificant differences in energy performance between the ICF construction and a low-mass wall assembly achieving the same the thermal resistance and infiltration. Hence, the modelling did not show that there is an increase in ICF wall's effective R-value due to thermal mass.

Notwithstanding constructability features of ICF, perhaps the single greatest benefit to the ICF construction is the ability to significantly reduce air infiltration through the building envelope without implementing a stringent sealing program. In addition, the steady interior wall temperature indicates that the ICF construction also provided comfortable thermal conditions for the building's occupants.

This study was limited in scope to monitoring the building for a three month period in the heating season and assessed the opaque wall components. It is therefore recommended that the full building (opaque wall areas, window frames, and balconies) be monitored for a full 12 month period (ideally from January 1 to December 31). It is further recommended that the monthly utility bills be analyzed over this monitoring period in order to assess the overall energy performance of the building and attempt to draw correlations between the weather, the ICF wall system, and the heating and cooling plant energy consumption.

One observation of this study is that advanced control schemes could not be implemented in this building because of the continuous occupancy. It is therefore recommended that an ICF constructed building having significant unoccupied periods, such as a typical office building, be similarly monitored. Unlike the residential building used for this study which has a continuous occupancy pattern, this building could be used to assess the impact of various temperature setback/setup strategies and how to take advantage of the ICF thermal mass.

RÉSUMÉ

Dans le but de quantifier et soutenir les allégations faites à l'endroit de la performance thermique des murs réalisés avec des coffrages isolants, cette étude avait pour objectifs :

4. de caractériser la résistance thermique nominale et réelle des murs à coffrages isolants,

5. d'évaluer l'étanchéité à l'air de l'enveloppe du bâtiment et de repérer les points d'infiltration,

6. de déterminer la performance thermique de l'ensemble de l'enveloppe du bâtiment et de localiser les zones de transfert de chaleur relativement élevé.

Les essais et les contrôles ont été effectués sur un immeuble de 100 appartements (Cedar Creek), comptant sept étages, situé à Waterloo, en Ontario. Les températures de part et d'autre de l'assemblage mural, à huit endroits, ont fait l'objet de contrôles sur une période de trois mois, soit du 1er décembre 2005 au 28 février 2006. En outre, les chercheurs ont mené des essais avec des ventilateurs à débit contrôlé afin de quantifier les fuites d'air pour tout le bâtiment et ont utilisé un système d'imagerie thermique pour localiser les zones où les transferts de chaleur étaient relativement élevés. Enfin, une modélisation énergétique informatisée a permis d'estimer les charges de chauffage et de climatisation de l'immeuble de même que sa consommation d'énergie annuelle, en tenant compte des infiltrations et de la masse thermique, et de comparer divers assemblages muraux aux murs à coffrages isolants.

L'ensemble du mur à coffrages isolants, comprenant le parement extérieur en stucco et le revêtement intérieur en plaques de plâtre, possède une résistance thermique (ou valeur R) de 3,9 m^2K/W (22,1 pi^2•h•°F/Btu). Le béton n'assure que 2,2 % de la résistance thermique globale, alors que ce pourcentage atteint 91,8 % pour les deux couches de polystyrène expansé, le reste (6,0 %) étant attribuable aux autres composants (stucco, plaques de plâtre, lames d'air intérieures et extérieures). Les murs à coffrages isolants ne créent pas de ponts thermiques complets, de sorte que la résistance thermique est pratiquement continue sur l'ensemble du mur.

Par comparaison, le Code modèle national de l'énergie pour les bâtiments exige que la valeur R d'un mur en élévation pour un immeuble du Sud de l'Ontario chauffé au gaz naturel soit d'au moins 1,76 m^2K/W (10 pi^2•h•°F/Btu). La résistance thermique de ce mur est donc deux fois supérieure à ce qui serait considéré comme normal pour un immeuble du Sud de l'Ontario chauffé au gaz naturel.

Les données recueillies ont confirmé que la densité de stockage du béton n'augmente pas la valeur R globale du mur en régime permanent. En régime transitoire, les données montrent que le béton joue un rôle important pour protéger le bâtiment contre les fluctuations de la température de l'air extérieur à partir de la surface intérieure du mur. Bien que la chaleur ne soit jamais passée du béton au bâtiment, le béton a quand même emmagasiné la chaleur perdue par l'intérieur et a diffusé l'énergie emmagasinée chaque fois que la température de l'air extérieur baissait. La température du béton a chuté lentement en raison de sa faible diffusivité thermique, ce qui a souvent permis de créer un tampon contre les baisses de température durant la nuit.

Les résultats obtenus lors des essais réalisés au moyen de ventilateurs à débit contrôlé ont révélé que le bâtiment était exceptionnellement étanche, puisque son indice normalisé d'étanchéité à l'air (à 75 Pa) a été établi à seulement 1,25 L/s/m^2. Ce serait le bas de l'échelle si l'on en croit une étude de la SCHL qui a porté sur 11 immeubles répartis aux quatre coins du Canada et qui a fait ressortir des indices globaux dans une fourchette allant de 0,9 à 10,3 L/s/$m^2{}_{75}$. Les résultats de cet essai laissent entrevoir que les charges de chauffage et de climatisation de calcul des locaux et la puissance associée du système de chauffage et de climatisation du bâtiment pourraient être fondées sur un taux d'infiltration d'air qui est jusqu'à 60 % inférieur à celui des constructions standards.

L'étude thermographique a permis de repérer les endroits où se produisaient des ponts thermiques dans l'enveloppe du bâtiment. On a ainsi pu confirmer la présence d'importants ponts thermiques à la hauteur des points de pénétration dans les murs, ménagés pour le passage des conduits du condensateur rattaché aux installations de chauffage, de ventilation et de climatisation, des orifices de ventilation de 50 mm (2 po), du bâti d'attente des fenêtres et des portes-fenêtres ainsi que des balcons. Par conséquent, il serait envisageable de rehausser la performance thermique de l'immeuble en réalisant avec soin les points de pénétration des murs, comme les balcons, en sélectionnant des composants d'enveloppe non muraux à rendement élevé (cadre des fenêtres et des portes) et en choisissant de l'équipement mécanique qui ne nécessite pas le perçage des murs extérieurs, ou du moins ne requièrent que des ouvertures minimales (tels que les condensateurs muraux).

Des simulations paramétriques ont montré que la réduction des infiltrations d'air que permettent les murs à coffrages isolants a abaissé considérablement les charges de chauffage et de climatisation et a fait réaliser des économies d'énergie annuelles de 574 584 MJ ainsi que des économies d'argent de 5 879 $ pour ce bâtiment. Les simulations ont aussi montré que les différences étaient négligeables au chapitre de la performance énergétique entre un mur construit avec des coffrages isolants et un assemblage mural à faible masse offrant la même résistance thermique et le même taux d'infiltration. Par conséquent, la modélisation n'a pas révélé d'augmentation de la valeur R réelle des murs à coffrages isolants attribuable à la masse thermique.

Malgré l'aptitude à la construction des coffrages isolants, l'avantage le plus intéressant qui distingue vraiment ce type d'assemblage est la possibilité de réduire considérablement les infiltrations d'air dans l'enveloppe du bâtiment sans devoir mettre en œuvre un programme d'étanchéisation rigoureux. En outre, la stabilité de la température à l'intérieur du mur indique que les assemblages réalisés avec des coffrages isolants procurent aussi un confort thermique intéressant pour les occupants de l'immeuble.

La portée de cette étude se limitait à exercer un suivi du bâtiment pendant une période de trois mois durant la saison de chauffage et à évaluer les éléments des murs opaques. Il est donc recommandé que l'ensemble du bâtiment (zones opaques des murs, cadres des fenêtres et balcons) fasse l'objet d'un contrôle étalé sur une période de 12 mois (idéalement du 1er janvier au 31 décembre). Il est de plus recommandé que les factures d'énergie mensuelles soient analysées durant cette période afin de déterminer la performance énergétique globale de l'immeuble et de tenter d'établir des corrélations entre le climat, les murs à coffrages isolants et la consommation d'énergie des installations de chauffage et de climatisation.

Les chercheurs responsables de cette étude n'ont pu mettre en place des mécanismes de contrôle évolués dans ce bâtiment étant donné qu'il était continuellement occupé. Il serait par conséquent recommandé de procéder à un suivi similaire sur un bâtiment réalisé à partir de coffrages isolants qui présente de longues périodes d'inoccupation, tel un immeuble de bureaux typique. Contrairement au bâtiment résidentiel utilisé pour l'étude en question, qui était continuellement occupé, ce genre d'immeuble pourrait servir à déterminer l'incidence des diverses stratégies de réglage de la température du point de consigne et à comprendre comment tirer avantage de la masse thermique des coffrages isolants.

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Integra Spec
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1. INTRODUCTION

1.1 Insulating Concrete Forms

Insulating concrete forms (ICF) have been used in residential and commercial construction since the early to mid 1990's. Proponents claim that ICF walls offer four advantages over traditional wood/steel stud or block back-ups used:

- high thermal resistance (nominal R20+ with minimal thermal bridging)
- airtight construction
- additional thermal mass that reduces heating and cooling loads, and
- constructability (competitive pricing and ease of construction).

While ICF building systems are gaining in popularity, there is little quantitative performance monitoring data, particularly for commercial/institutional buildings, to substantiate the performance claims.

1.2 Project Objectives

The objectives of this study are to assess:

1. the nominal and the effective thermal resistance of the ICF wall component,
2. the air-tightness of the building envelope and identify areas of infiltration, and
3. the thermal performance of the entire building envelope and identify areas of relatively high heat transfer.

1.3 Cedar Creek Apartment Building

The building selected for evaluation was the Cedar Creek Apartment building constructed and owned by Jamesway Construction Group located on Old Albert Road, Waterloo, Ontario. This is a seven-storey building with 100 apartment suites having a total floor area of 8,140 m^2 and an interior building volume of approximately 22,630 m^3. Ventilation for the building is provided by rooftop mounted make-up air unit delivered to the corridors. Air is exhausted via in-suite bathroom and kitchen hood exhaust fans. Heating and cooling is provided by in-suite fan coil units. A central boiler generates hot water for the fan coil heating coils and each fan coil contains a thru-wall condenser to provide cooling. The following two photos show the Cedar Creek apartment building when the ICF walls were being constructed and when the building was nearing completion.

Figure 1: ICF walls being constructed at Cedar Creek apartments.

Figure 2: Cedar Creek near completion.

2. MONITORING SYSTEM

The Cedar Creek Apartment building has been instrumented with 68 resistance temperature detector (RTD) sensors in the walls, under balconies and in the framing of the balcony doors to record the transient behaviour of the wall system and associated wall penetrations.

2.1 Sensors

The primary temperature sensor selected for this project is a 3-wire 1,000 Ohm platinum RTD embedded in a 2½" x ¼" stainless steel sheath. The three-wire design offers the advantage of measuring the resistance of the RTD and wiring, thus compensating for the wire resistance. Figure 3 shows one of the RTDs installed at the wall-ceiling intersection.

Figure 3: An installed RTD temperature sensor.

There are 68 of these RTD sensors installed throughout the building, in 16 different locations, with 4 sensors installed at each location. In addition, to ensure that data would not be lost due to a malfunctioning sensor(s) from the most significant measurement location, a back-up set of sensors was installed in the 4th floor South Wall location. Figure 4 shows a cross-sectional wall schematic indicating where the sensors are positioned. The sensors are mounted at the following locations:

1. On the exterior surface of the outer layer of insulation;
2. At the interface between the outer layer of insulation and the concrete;
3. At the interface between the inner layer of insulation and the concrete; and
4. On the interior surface of the inner layer of insulation.

The sensors at locations 1 and 4 are mounted on the surface of the insulation and covered by the gypsum board and the stucco finish for protection and to mitigate convective heat transfer.

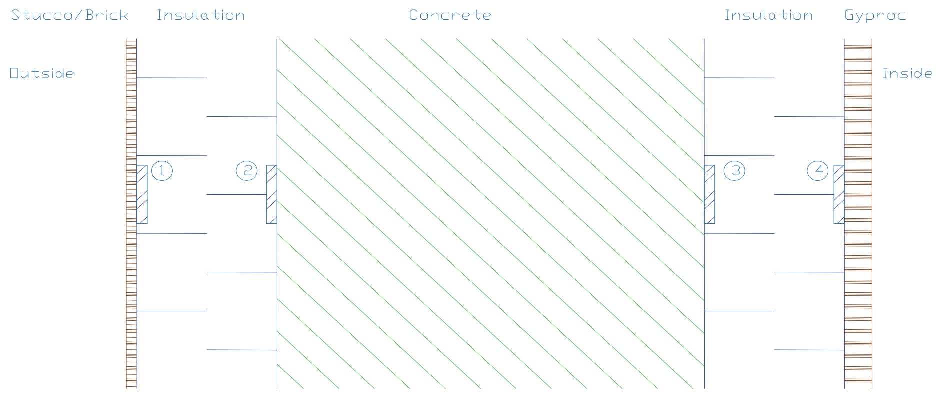

Figure 4: Wall section schematic showing the sensor locations.

The following is a listing of sensor locations:

1. 1st floor wall N (1N)
2. 1st floor wall S (1S)
3. 4th floor wall N (4N)
4. 4th floor wall E (4E)
5. 4th floor wall S (x2) (4S, 4S2)
6. 4th floor wall W (4W)
7. 4th floor window N
8. 4th floor window E
9. 4th floor window S
10. 4th floor window W
11. 4th floor balcony N
12. 4th floor balcony E
13. 4th floor balcony S
14. 4th floor balcony W
15. 7th floor wall N (7N)
16. 7th floor wall S (7S)

The scope of this report is limited to the sensors mounted in the wall locations (9 of the 17 locations). The remaining sensors (windows and balconies) may be monitored in a future study.

In addition to the sensors mounted in the walls, there were 8 independent dataloggers mounted behind the thermostats in the monitored suites to collect the indoor air temperature of these suites. The datalogger selected for this task was a SmartButton, manufactured by ACR Systems Inc. These sensors are 17 mm in diameter and 6 mm in height, as shown in Figure 5, and contain a silicon temperature sensor, lithium battery, and 2 kB of memory, capable of storing up to 2,048 readings. The temperature range is -40 to 85°C, and the accuracy is +/- 1.0°C from -30 to 45°C. They were set up to collect the temperature readings every hour.

Figure 5: SmartButton datalogger.

2.2 Data

A Campbell Scientific CR10X datalogger was mounted in an enclosure and installed in the electrical room on the 7th floor. From December 1, 2005 to February 28, 2006 data was collected from the 36 sensors on a regular 15 minute interval and stored to the datalogger's onboard memory. Enermodal made bi-weekly visits to the building to download data from the datalogger. While on site, the data was checked to verify that the monitoring system was functioning properly.

The SmartButton dataloggers were set up to collect data hourly starting on December 1, 2005, and end on February 24, 2006 (when the memory was full). The sensors were installed in November 2005, repositioned behind the thermostats on December 2, 2005, and retrieved from the building on March 2, 2006.

Ambient air temperature data was retrieved from the University of Waterloo weather station. This station is located on the campus of the University of Waterloo, which is less than two kilometres away from the apartment building. Data is recorded on a 15 minute interval and was downloaded directly from the weather station's internet website: http://weather.uwaterloo.ca/data.htm.

3. THEORETICAL THERMAL PERFORMANCE

There are three material properties related to the thermal performance of the ICF wall that are important to address. The first is the volumetric heat capacity, which is a measure of a material's ability to store thermal energy. It is simply the product of the material's density (r) and specific heat (c_p). Materials having the best energy storage potential have a volumetric heat capacity greater than 1 MJ/m^{3}K.

The second property is thermal diffusivity (a). This is the ratio of the material's thermal conductivity to its volumetric heat capacity, and is a measure of the material's ability to conduct thermal energy relative to its ability to store thermal energy. Hence, materials with a high thermal diffusivity will respond relatively quickly to thermal changes and reach a new thermal equilibrium state in a short amount of time.

The final property is the thermal resistance, or R value, of the wall assembly. This is a measure of the wall's ability to resist the flow of heat.

The ICF wall tested in this study is comprised of three key layers: an exterior layer of insulation, a layer of concrete, and an interior layer of insulation. Both layers of insulation are made of expanded polystyrene. The properties of the insulation and concrete are listed in Table 1.

Table 1: Thermal properties of insulation and concrete.

Property	**Units**	**Expanded Polystyrene**	**Concrete**
Thickness	mm	66.675	152.4
Density	kg/m^3	16.0	2,350
Thermal Conductivity	W/mK	0.037	1.4
Specific Heat	J/m^{3}K	1,210	880
Volumetric Heat Capacity	J/m^{3}K	19,360	2,068,000
Thermal Diffusivity	m^2/s	1.91e-6	6.77e-7
Thermal Resistance	m^{2}K/W	1.8	0.1

As shown in Table 1, the insulation has a low volumetric heat capacity and a high thermal diffusivity, which means that the insulation has a low capacity to store thermal energy and responds quickly to external temperature changes. Conversely, the concrete has a high volumetric heat capacity and a low thermal diffusivity, making it a good thermal storage medium that responds slowly to external temperature changes.

The ICF forms have numerous plastic spanners used to connect the layers of insulation prior to the placement of the concrete. The plastic spanners used in the Nudura ICF system do not fully penetrate either layer of insulation (ICF form systems by other manufacturers are similar in this regard). Hence, the only thermal bridges through the wall assembly are windows, doors, balconies, exhaust ducts, and condensers.

Using conventional calculations, the thermal resistance of the ICF wall assembly is determined to be RSI-3.7 (R-21), as shown in Table 2, below.

Table 2 : Thermal resistance of the Nudura ICF assembly.

Wall Component	**Nominal Thickness (mm)**	**Thermal Conductivity (W/m K)**	**Thermal Resistance (m^2K/W)**
Outer Insulation (Expanded Polystyrene)	66.7	0.037	1.8
Concrete (2350 kg/m^3)	152.4	1.4	0.1
Inner Insulation (Expanded Polystyrene)	66.7	0.037	1.8
Total Assembly	**285.8**	**-**	**3.7**

Thermal conductivity values are for a mean temperature of 24°C.
Reference: ASHRAE Fundamentals Handbook 2005.

The thermal resistance of the overall wall assembly, including the stucco exterior, and gypsum board on the interior, as well as the exterior and interior film coefficients is 3.9 m^2K/W. Figure 6 presents a screenshot of the assembly performance window from NRCan's EE4 version 1.50b7 building energy modelling software program.

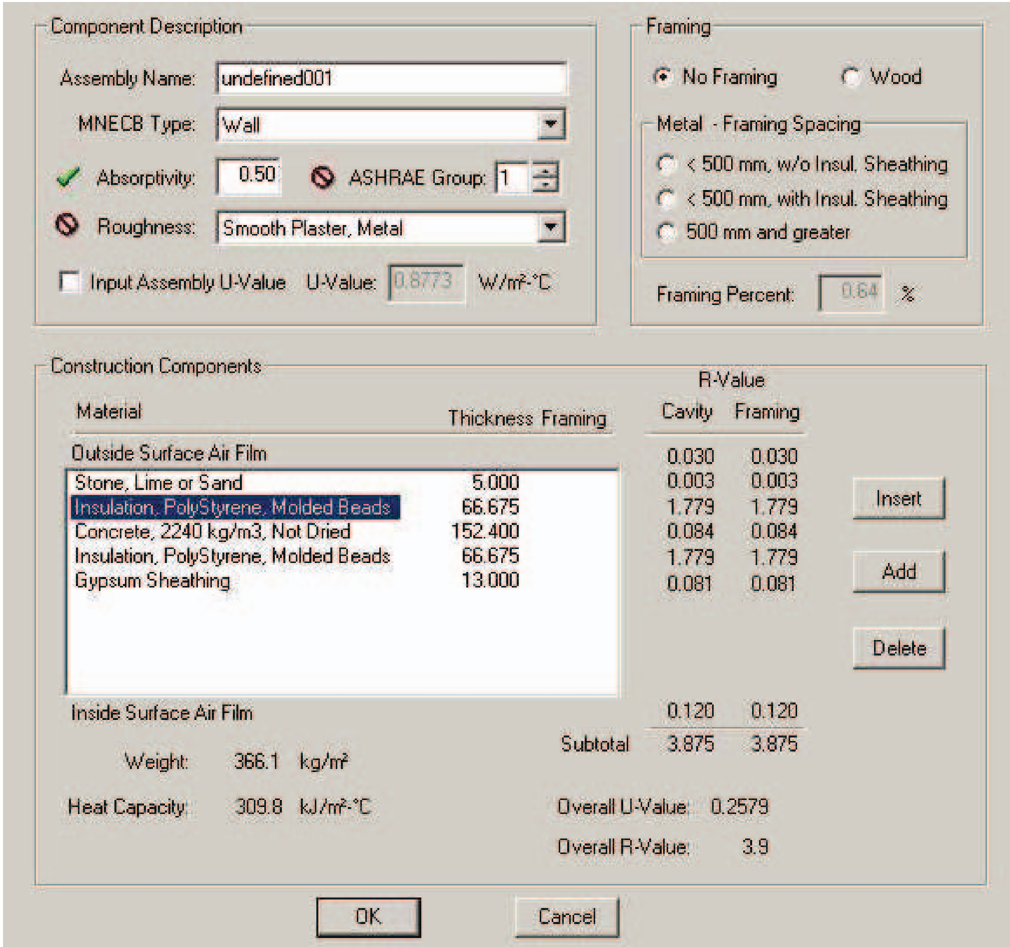

Figure 6: EE4 screenshot of the R value of the wall assembly.

Using the above material properties and appropriate environmental conditions, it is possible to estimate the temperature profile across the wall for steady-state conditions. At steady-state, the energy entering the wall must equal the energy leaving the wall. Consequently, two equations can be developed for the temperature at the exterior surface of the wall, T1'. First, the energy entering the wall is equal to the heat gained from the building interior,

$$E_{in} = (IAT - T1') / \Sigma R_t$$

where,

$$\Sigma R_t = 1/h_i + R_{gyproc} + R_{insulation} + R_{concrete} + R_{insulation} + R_{stucco}$$

Second, the energy leaving the wall is equal to the heat lost via convection from the outer surface of the wall to the ambient environment, or,

$E_{out} = h_o(T1' - OAT)$

The following assumptions are made in order to solve for T1':

1. IAT = 20°C
2. OAT = -3.5°C
3. h_i = 8.3 W/m^2
4. h_o = 33.3 W/m^2
5. One-dimensional heat transfer.
6. Contact resistance between wall layers is negligible.

$E_{in} = (20 - T1') / 3.9$

$E_{out} = 33.3 (T1' - (-3.5))$

Setting $E_{in} = E_{out}$ and solving, T1' = -3.3°C and $E_{in} = E_{out}$ = 6.0 W/m^2

Since the heat flux is constant through the wall, it is possible to calculate the temperature at any point in the wall (refer to Figure 4 for locations). Hence,

T4 = 18.5°C,
T3 = 7.8°C,
T2 = 7.3°C, and
T1 = -3.3°C

With regards to transient performance, the insulation and concrete behave very differently, as we would expect given the different thermal diffusivities. The time constant (t) for a material is the time that it takes for a material to complete 63.2% of the dynamic or transient portion of its response to a change in its thermal environment. It may be defined by a first-order differential equation, analogous to an electrical RC circuit,

$t = R r c_p x$

where,

R is the thermal resistance (m^{2}K/W),
r is the density (kg/m^3),
c_p is the specific heat (J/kgK), and
x is the thickness of the material (m)

This is a significant simplification to the actual transient process, but is useful for interpreting the graphs of the monitored data and drawing conclusions about the wall performance. Using the data from Table 1, the time constant for the outer layer of insulation is,

$t \quad = (1.8\ m^2K/W)(16\ kg/m^3)(1210\ J/kgK)(0.066675\ m)$
$\quad = 2323.5\ s = 38.7\ min = 0.65\ hr$

Similarly, the time constant for the concrete is,

$t \quad = (0.1\ m^2K/W)(2350\ kg/m^3)(880\ J/kgK)(0.1524\ m)$
$\quad = 31{,}516.3\ s = 525.3\ min = 8.75\ hr$

Consequently, we would expect the outer layer of insulation to respond relatively quickly (within an hour) to changes in the OAT. On the other hand, since the time constant of the concrete is close to a third of a day, we would not expect the concrete to respond to temperature fluctuations spanning only a few hours.

4. DATA ANALYSIS

For the scope of this monitoring project, the sensors installed at the 9 wall locations (1N, 1S, 4N, 4E, 4S, 4s2, 4W, 7N, and 7S) were connected to the datalogger and monitored for a three-month period, from December 1, 2005 to February 28, 2006. In addition, the SmartButtons collected indoor air temperature data from December 1, 2005 to February 24, 2006.

4.1 Completeness of Data

The RTD temperature data set is 96.6% complete, with data missing for January 19, 20, and 21, 2006. The SmartButton data set is 100% complete. And, the weather data set is 98.3% complete.

4.2 Data Irregularities

The data was checked for any irregular data points before it was analyzed. Sensor #1 (refer to Figure 4 for locations) at the back-up for the 4th floor South wall was damaged when the stucco was applied to the exterior of the building. Consequently, data from this sensor was not collected.

It was observed that sensor #3 at the back-up for the 4th floor South wall (4S2) location yielded erroneous data from 1415 on December 17, 2005 (Day 351) to 1400 on December 18, 2005 (Day 352).

Data recorded for location 4 on the 4th floor south was faulty for a short period in December 2005. It is not known why this event happened. For the purposes of analysis, the data for this period was replaced with data from the adjacent back-up sensor.

Data recorded for location 4 on the north side of the 7th floor was found to be abnormally high on December 7, 2005 from 0930 to 1230. The temperature spiked to a high of 36.2°C, while the IAT varied between 19°C and 22°C.

Readings recorded for location 3 for the spare set of sensors on the south side of the 4th floor were abnormal from 1415 on December 17, 2005 to 1345 on December 18, 2005. The reason for the faulty data is unknown.

No data irregularities were observed in the data collected by the SmartButtons or in the ambient air temperature data from the University of Waterloo weather station.

4.3 Data Trends

General Observations

The average OAT was -3.6°C for the entire monitoring period, and ranged from 8.4°C down to -20.9°C. The average OAT for each month is shown in Table 3.

Table 3: Monthly average OAT and concrete temperatures.

		Average Concrete Temperature (°C)								
Month	**OAT**	**1N**	**1S**	**4N**	**4E**	**4S**	**4W**	**7N**	**7S**	**4S2**
Dec	-4.34	8.44	10.54	9.22	8.61	8.96	9.86	11.01	10.85	8.68
Jan	-1.01	10.01	12.09	10.04	9.80	10.97	11.42	11.86	12.30	11.10
Feb	-5.27	8.80	11.67	8.98	8.92	10.43	10.01	10.32	11.86	10.60

Where,

OAT = Outdoor air temperature
1N = 1st floor wall N
1S = 1st floor wall S
4N = 4th floor wall N
4E = 4th floor wall E
4S, 4S2 = 4th floor wall S
4W = 4th floor wall W
7N = 7th floor wall N
7S = 7th floor wall S

The IAT was maintained at approximately 19.4°C, with very little variation between the suites, and regardless of the occupied status of the suite—only two of the eight suites were occupied over the monitoring period. The temperature at location 4 tracked closely with the IAT, but was generally less than 2°C lower than the IAT.

The temperatures on either side of the concrete (at locations 2 and 3) were relatively stable over the three months, varying only by approximately ±3.5°C from the average.

It was also observed that the temperature at the interior surface of the concrete (location 3) was never higher than the temperature on the interior surface of the insulation (location 4). Hence, the heat flow never reversed direction such that the concrete could transfer/supply heat to the interior of the building.

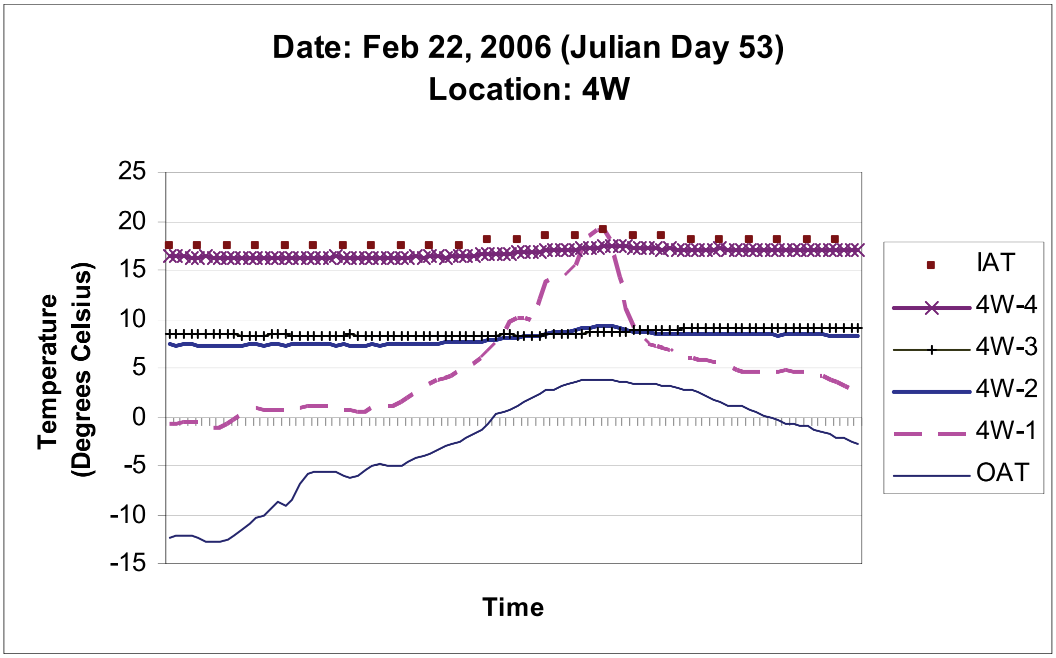

Figure 7: Wall response to solar insolation.

Figure 7 illustrates how the ICF wall responds to solar insolation. Throughout the morning, the OAT steadily increased from -12°C to 4°C at 14:30. At the same time the temperature of the exterior wall surface rose as a result of the rising OAT and solar radiation. At 14:30, the temperature on the outside surface of the wall (4W-1) actually surpassed the temperature on the interior wall surface (4W-4). The graph also shows that the temperature on the outside surface of the concrete (4W-2) matched or surpassed the temperature on the inner surface of the concrete (4W-3) from 13:00 to 15:45. This means that some solar energy was being absorbed by the concrete for this period. However, the temperature at 4W-3 only increased by 0.7°C over the course of the day. Hence, heat from the solar load on the exterior of the building is never transferred into the building. While this would reduce heat loss, the overall impact would not be significant.

Furthermore, because the temperature drop across the layer of insulation on the interior of the building (4W4 – 4W-3) is relatively constant over the course of the day, the heat loss from the building interior also varies little.

The temperature on the inside surface of the wall assembly (4W-4) and the IAT did increase slightly over the course of the afternoon, but returned to the same temperatures they exhibited in the morning hours of the day. The elevated IAT temperatures are attributed to the solar heat gain through the windows and the balcony door.

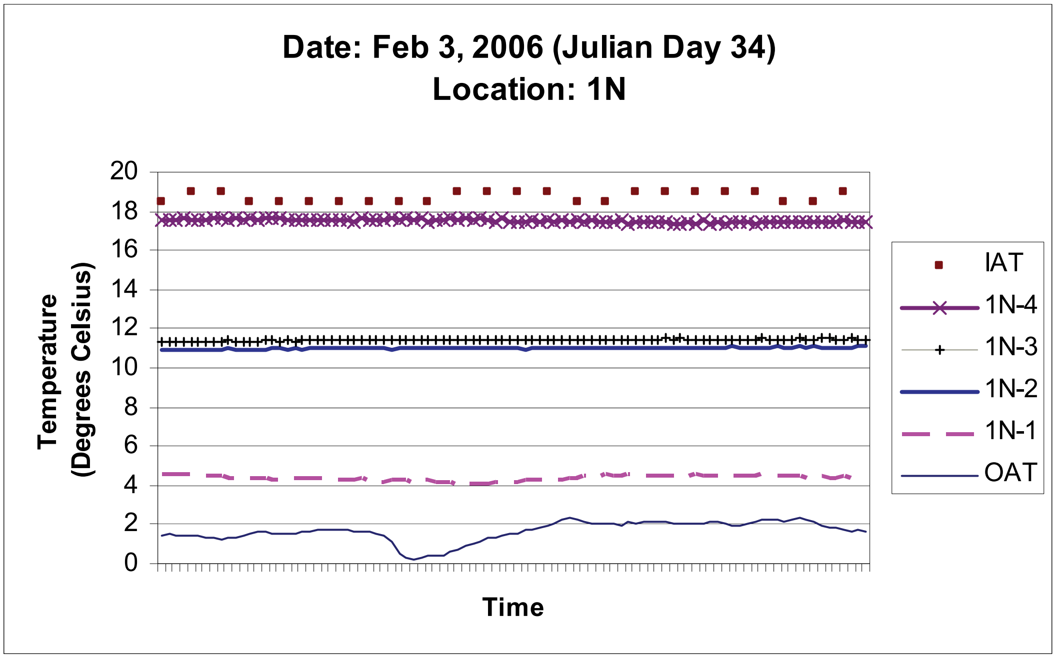

Figure 8: Quasi steady-state wall performance.

Figure 8 illustrates the wall conditions at location 1N over the course of February 3, 2006 when the wall was observed to be at a quasi steady state condition for the entire day. The temperature difference across the inner (1N-4 to 1N-3) and outer (1N-2 to 1N-1) layers of insulation was approximately 6.3°C. By comparison, there was only a difference of 0.4°C across the concrete (1N-3 to 1N-2). This confirms that the concrete does not contribute significantly to the overall thermal resistance of the wall when steady-state conditions are reached.

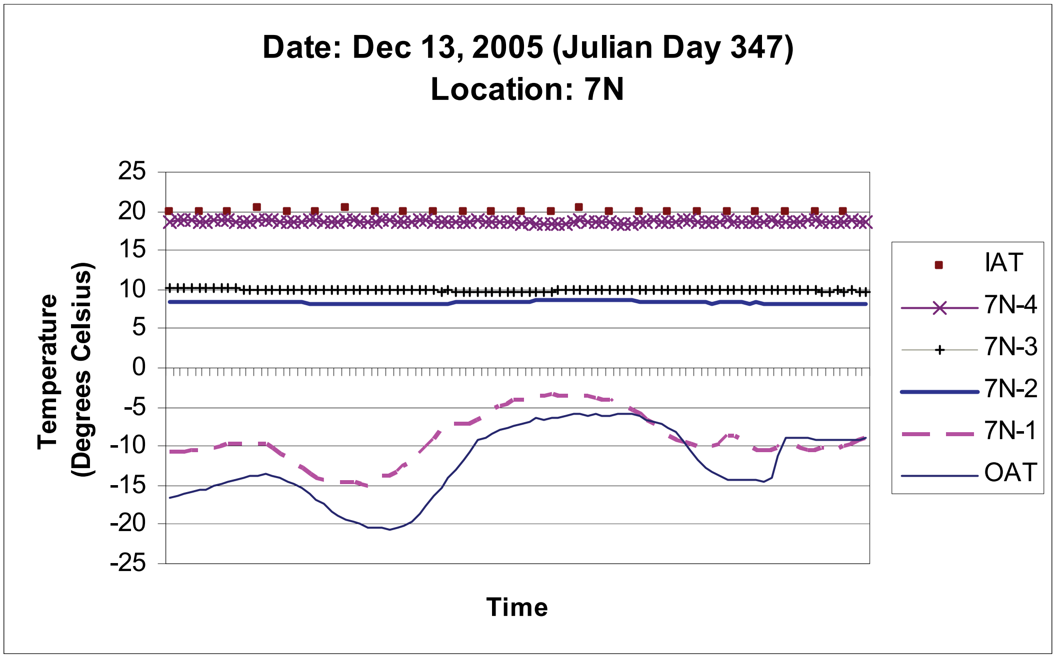

Figure 9: Example of how the wall isolates the interior from the exterior.

Figure 9 illustrates the wall conditions at location 7N for a day with significant fluctuations in the OAT. Not surprisingly, the temperature at 7N-1 trends closely with the OAT, however, the temperature at the inner locations, as well as the IAT hold constant throughout the day. The temperature at outer surface of the concrete (7N-2) lags behind the temperature at the exterior surface of the wall assembly (7N-1) by 45 minutes to an hour. And the temperature at the inner surface of the concrete (7N-3) lags behind the temperature at the outer surface of the concrete (7N-2) by about six hours.

The inner surface of the concrete (7N-3) is isolated from outdoors temperature changes by both the insulation levels on the exterior of the wall and the capacitance of the concrete. The level of isolation is so large that what happens outdoors has almost no impact on the interior concrete temperature and therefore no significant impact on the heat flow through the wall from the interior in the short term (i.e. daily or even weekly).

Wall Orientation

Comparing the total heat loss from location 4 and location 3 for each wall orientation on the 4th floor, it was found that the greatest heat loss occurred on the South side, followed by the West, North and East. Upon close examination of this trend, it was also observed that the magnitude of the heat loss corresponded with the magnitude of the IAT. Consequently, solar orientation does not seem to play a significant role in the amount of heat loss from the interior of the building (i.e., the sun does not appear to warm up the wall and thereby reduce heat loss).

Building Height (Floor 1 vs. Floor 4 vs. Floor 7)

A clear significant difference between the performances of the ICF wall at the various building heights was not observed.

Exterior Finish (Brick vs. Stucco)

A clear significant difference between the performances of the ICF wall covered with brick versus the ICF wall covered with stucco was not observed.

(Quasi) Steady State Conditions

Over periods of extended cold temperatures (lasting several days), the heat flow from the building interior to the concrete and from the concrete to the exterior, were practically balanced. During these conditions, the concrete added very little to the overall wall thermal resistance, as expected.

Unsteady State Conditions

During unsteady state conditions, such as when the sun comes up and heats the outer wall surface, or when there are sudden temperature drops, the inside surface generally remained at a constant temperature. The biggest temperature fluctuations in the wall are on the exterior side of the concrete.

On sunny days, especially on the south side, the heat flow from the inside surface to the concrete exceeded the heat flow from the concrete to the exterior surface. This is due to the very slow thermal response of the concrete so that as the temperature difference between the outside air and the concrete decreased, the temperature difference between the inside air and the concrete remained constant. Therefore, solar gains in the wall assembly had no benefit to heat loss from the interior to the wall.

After periods of near steady state conditions, as the OAT dropped the concrete buffered the inside of the building from a temperature drop—as shown by the greater heat loss on the exterior side of the concrete relative to the heat loss on the interior side of the concrete. Thus, due to the high volumetric heat capacity of the concrete, heat that was stored within the concrete during the near steady state conditions was released to the exterior as the OAT dropped. This buffering effect means that the inside of the building did not experience the full effect of the temperature difference between the inside and outside air temperatures.

The data indicate that peak, or near peak, space heating load conditions may not be experienced often, and therefore, the heating system may not have to operate as often as it might otherwise be required to. However, since it is possible that the peak space heating load could be reached by a slow transition through a near steady state condition (i.e., after more than one day at the design heating temperature), the boiler should be sized for the peak space heating load.

Finally, the data indicates that the concrete dampens out the hourly temperature swings and buffers the building interior (to the inside surface of the concrete) from the building exterior, contributing to a comfortable building environment.

5. AIR INFILTRATION

On Tuesday August 30, 2005, Enermodal carried out airtightness testing of the new Cedar Creek Apartment building located on Old Albert Street, Waterloo, Ontario. The building was in the final stages of construction in order to be ready for occupancy on Thursday September 1, 2005. Contractors were installing hardware, plumbing fixtures, carpet, painting, and caulking. Not all caulking, weather-stripping, fire-stop or mechanical penetrations were complete and sealed, as they were when the building was completed.

The purpose of the testing was to assess the airtightness of the overall building envelope. The building was prepared generally as per the intent of the CGSB 149.10 where all intentional openings are sealed to determine the leakage characteristics of the constructed building envelope.

The team assembled on site at 11:00 a.m. to prepare the building for the test. The following areas were sealed prior to testing:

- 2” ventilation holes located below the thru-wall condenser in each suite.
- Pre-drilled holes for door hardware on exterior sliding doors.
- Ventilation grilles without dampers (E.g., front office, boiler room).
- Plumbing stacks to simulate sealed traps in all fixtures.
- Exhaust vents/grilles in various locations that did not have backdraft dampers as they are expected to operate continuously.
- Pipes and transfer grille in the elevator lobby in the underground parking.
- Several entry doors where weather-stripping was not yet installed. (E.g., penthouse elevator room, boiler room front door)
- Two thru the wall condensers had back panels that had to be taped in place.

Further, the following measures were taken:

- All suite windows and balcony doors were closed and locked.
- Central supply air system shut down.
- All suite doors and stairwell doors were propped open.

Three blower doors were used – two in ground floor exit doors and one in the man-door leading to the roof. A multi-point test was conducted where the building was depressurized from 50 Pa to 20 Pa in approximately equal increments. Testing ran from about 8:30 p.m. to 9:30 p.m. The outdoor temperature was 20.6^{0}C, indoor was 22^{0}C, winds were calm, and it was dry.

5.1 Identification of Air Leakage Locations

With the building depressurized to 50 Pa., a walk through examination of the building undertaken to identify air leakage locations. The following is a list of the leakage locations and a qualitative assessment of the leakage:

Location	Leakage Appraisal	Suites Affected	Comment
Through-the-wall condenser			
3/4" dia. hole at base of unit (See Figure 1 below)	Large	All	Could be sealed with a plastic insert
Opening for refrigerant line leading to cooling coil (See Figure 2 below)	Large	All	Could still be caulked and sealed
Gap between the condenser and the wall opening	Medium	Few	All building caulking should be checked
Sliding patio door (See Figure 3 below)	Medium	All	Consider doors with better weather seals in future
Window and door RFO	Small	Few	All building caulking should be checked
Sliding windows	Small	Few	
Range hood, bath fan	Small	Few	
Front vestibule pot lights (See Figure 4 below)	Large	Three	Could seal the vestibule ceiling space to prevent air movement between the inside and outside of the vestibule.
Sprinkler riser in garbage room (See Figure 5 below)	Large	One	Seal around riser

Front office AC sleeve (See Figure 6 below)	Large	One	Caulk around the sleeve.
Light switch next to double exterior doors in garbage room	Small	One	
Around duct work penetrating exterior wall in SE corner of garbage room	Small	Two	All building caulking should be checked

Figure 10: Uncovered knock-out in the condenser cabinet.

Figure 11: Unsealed opening for condenser refrigerant line.

Figure 12: Poor seal along the bottom (and top) of the sliding doors.

Figure 13: Pot light in the vestibule provides pathway to outside.

Figure 14: Missing seal around sprinkler riser in garbage room allows unwanted floor-to-floor air movement.

Figure 15: Unsealed front office AC sleeve.

The access panel for the condenser units in rooms 314 and 404 were not installed due to damage to these units. For the purposes of testing, the panels were temporarily affixed using duct tape. However, at the end of the testing these panels were found partially off.

5.2 Interpretation of Findings

The collected data was subsequently analyzed, and the following results were obtained:

- The Normalized Air Leakage Index was calculated to be 1.25 L/s/m^2 @ 75 Pa. A CMHC study of 11 buildings across Canada, found overall indexes in the range of 0.9 to 10.3 L/s/m$^2{}_{75}$, with an average of 3.19 L/s/m$^2{}_{75}$. Other references suggest that typical buildings have a Normalized Air Leakage Index in the range of 2 to 20 L/s/m$^2{}_{75}$.
- The exponent n was 0.62 and the R^2 was 0.97. While the correlation coefficient (R^2) was lower than the ideal of 0.99, the exponent n does show that this is a valid test result.

The normalized air leakage index of 1.25 L/s/m^2 shows that the overall building is airtight, due in large part to the continuity of the ICF wall assembly. Moreover, this is considered to be a worst case scenario, as the building construction was not yet completely finished. For example, the caulking was only about 80 percent complete, door hardware was still being installed, and the condensers were still being commissioned.

These results suggest that the design heating and cooling loads and subsequent sizing of the building's heating and cooling system may be based upon an air infiltration rate that is up to 60% lower than standard construction.

Since air leakage in an ICF building is practically limited to penetrations in the building envelope, the following recommendations, stemming from this study's observations, should be observed when designing an ICF building:

- Minimize the number of penetrations through the building envelope.

- Carefully detail building penetrations and assembly intersections, indicating the air barrier and sealing.

- Specify air sealing requirements for equipment and services that must penetrate the building envelope, such as pipes, electrical conduit, and louvers and grilles.

- Specify windows and doors with superior weather seals.

- For mechanical equipment that must penetrate the building envelope, specify equipment that has a well insulated and airtight cabinet.

6. THERMOGRAPHY

On Tuesday February 7, 2006, John Kokko and Troy Greene of Enermodal Engineering Ltd. and Wes Dettwiler of WCD Technical Solutions Inc. conducted an infrared thermographic survey of the Cedar Creek Apartment building. Testing was conducted on this night, after being deferred several times, because the low outdoor air temperature and consequent temperature difference between the indoor and outdoor temperatures facilitated the investigation.

The investigation commenced at approximately 9:30 pm and lasted for two hours. Testing was done at night to ensure that solar heating of the building exterior did not lead to false identification of areas of high heat loss. The weather conditions during the investigation were: light winds, light snow flurries, and ambient air temperature of -6°C to -7°C.

The purpose of the testing was to qualitatively assess thermal integrity of the building envelope. Particular attention was paid to areas of potential thermal bridging, including joints, wall-floor intersections, wall-roof intersection, windows, balcony doors, and thru-wall condensers.

Mr. Dettwiler used a Thermoteknix VisIR Ti-200 digital thermal imaging camera. This real-time thermal imaging camera is capable of simultaneous visual and infrared images plus voice recording. Consequently, digital and infrared images were recorded at each location examined along with our observations.

The following areas were surveyed:

- Suite 110 (exterior wall, thru-wall condenser, balcony door, bedroom window),
- Suite 710 (exterior wall, thru-wall condenser, balcony door, bedroom window),
- Roof (including the parapet, the mechanical penthouse, and the roof access stairwell),
- Underground parking lot, and
- Building exterior

6.1 Identification of Thermal Bridge Locations

<u>Thru-Wall Condenser Unit:</u>

In Suite 110, cold air was felt blowing through the electrical punch out near the bottom of the condenser unit, and around the refrigerant line at the top of the cabinet. The thermograph in Figure 16 shows that the temperature on the inside surface of the cabinet varies from 10°C down to 0°C at the bottom (the very dark areas). This shows that the condenser unit is a significant thermal bridge. Unnecessary and unused penetrations through the condenser cabinet could be sealed and insulated.

Figure 16: Suite 110 condenser unit.

<u>Vent (2 inch dia. opening under the condenser unit in each suite):</u>

In Suite 110, cold air was felt entering through the vent. Although this cold air enters into a small utility closet in the suite, there is a grille located near the bottom of the door for the closet, which allows the cold air to spill out into the living room. In addition, the concrete floor in front of the vent was cold (5°C to 7°C) relative to the other interior surfaces of the room (>10°C), as a result of the cold air (at -6°C) from the vent. Refer to Figure 17.

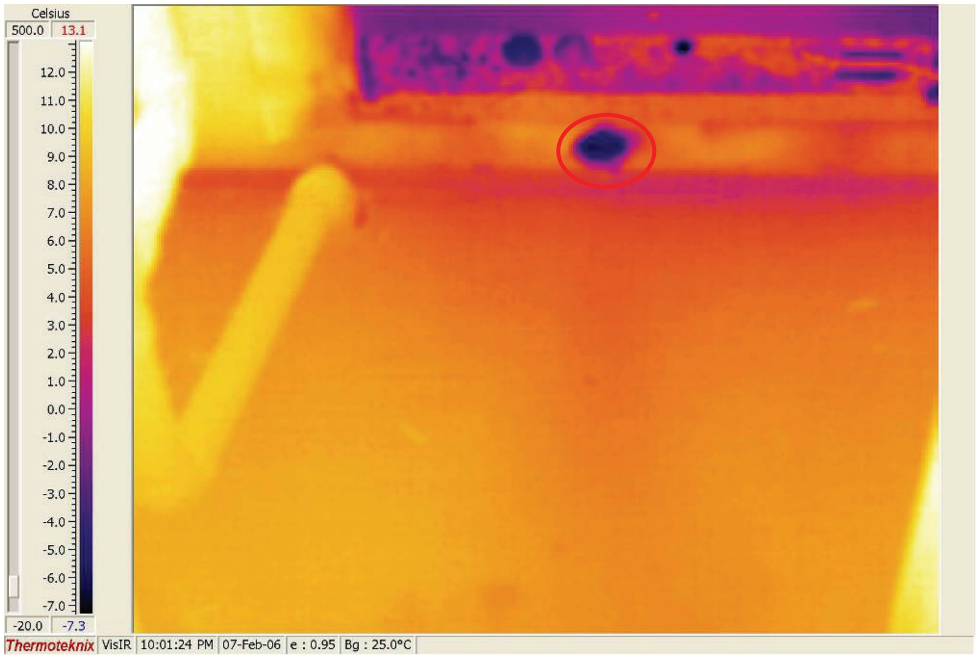

Figure 17: Two-inch vent under the condenser unit in Suite 110.

In Suite 710, air appeared to be exiting through the vent and the concrete floor was close to room temperature. This is most likely caused by stack effect within the building. Figure 18 below shows that the temperature of the floor in front of the condenser unit was even, between 13°C in the very corner increasing to more than 25°C air at the interior side of the closet.

Since ventilation is provided via a central make up air unit, the purpose of this vent should be verified, and if deemed unnecessary, be sealed and filled with insulation. Alternately, there may be an opportunity to downsize the central corridor make-up air unit.

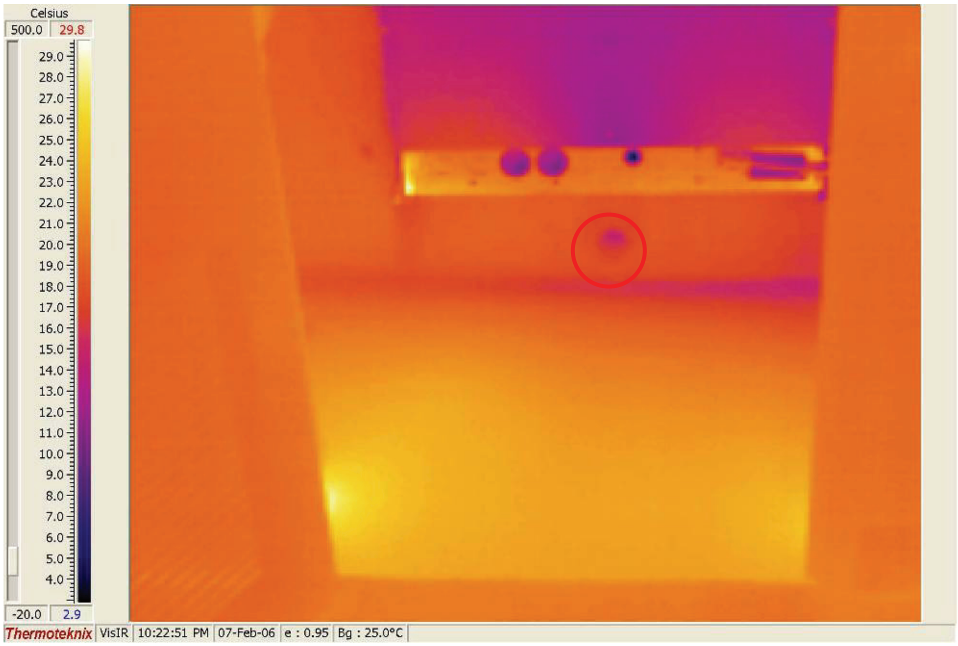

Figure 18: Two-inch vent under the condenser unit in Suite 710.

<u>Wall-Ceiling Intersection:</u>

Thermal bridging was observed at the wall-ceiling intersection as shown in Figure 19, where the temperature at the corner was 14°C, while the walls were more than 17°C and the ceiling was at approximately 16°C. From the construction detail of the wall-ceiling intersection shown in Figure 20, there is a thermal path from the ceiling to the concrete within the ICF wall. Although, there is some additional heat loss at this location, it would not likely have a significant impact on the overall building heating load. There may be some concern of condensation at this location if there is high humidity in the suite.

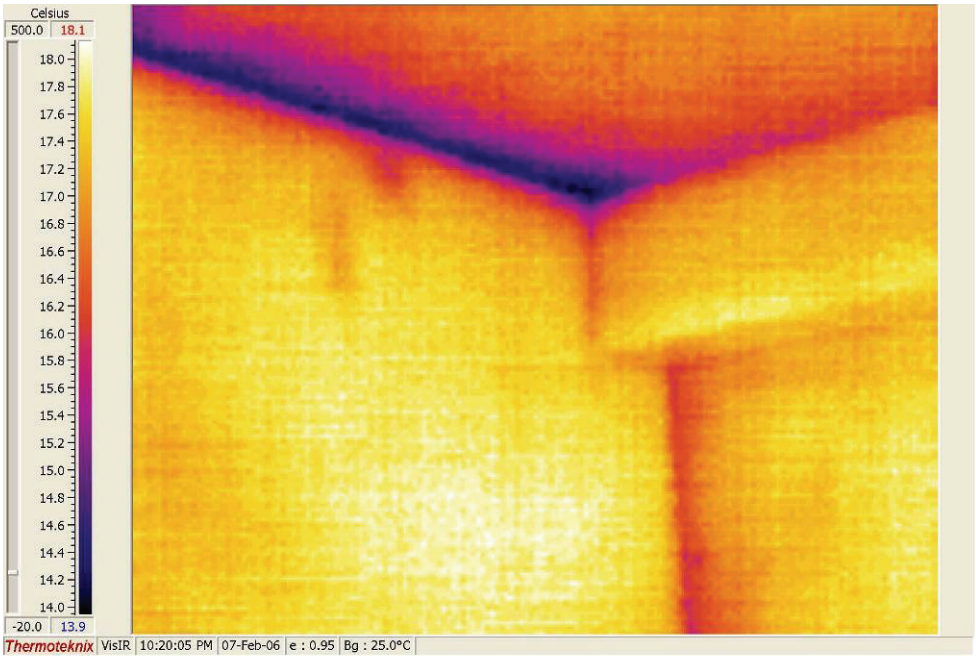

Figure 19: Thermograph of the wall-ceiling intersection in Suite 710.

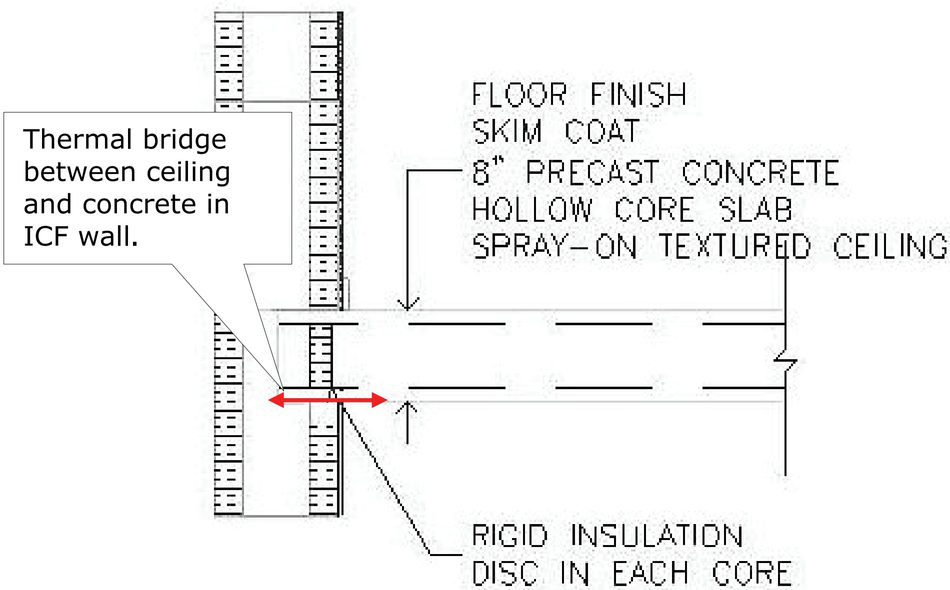

Figure 20: Wall-ceiling construction detail.

<u>Windows:</u>

Condensation was observed on the bedroom window in Suite 710. This indicates that warm moist air is leaking out past the window slider seals. Condensation doesn't occur on the 1st floor because the building pressure is negative relative to the outside, so cold dry air from the outside is drawn in.

The window buck construction was uninsulated on the lower floors, but was modified during construction so that those on the upper floors were insulated with rigid expanded polystyrene. However, thermographs of the windows in Suites 110 and 710, Figure 21 and Figure 22 respectively, did not reveal any significant differences.

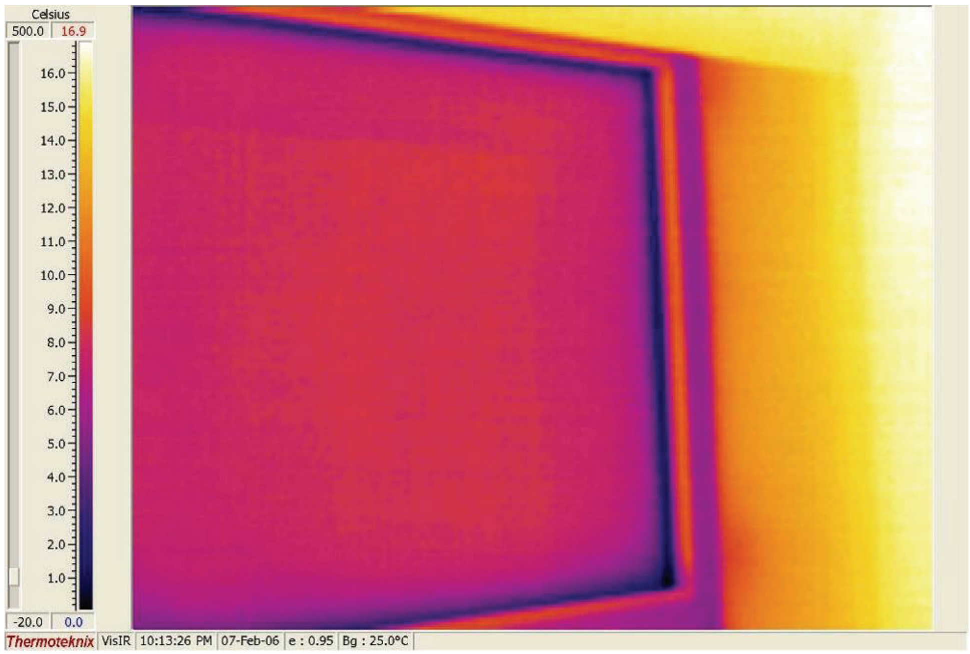

Figure 21: Bedroom window in Suite 110.

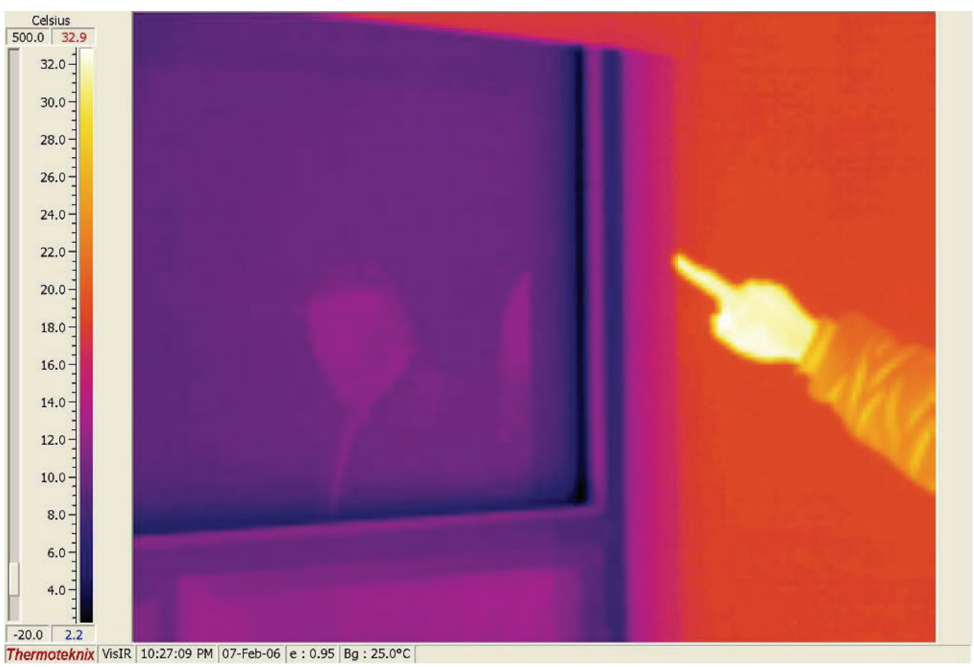

Figure 22: Bedroom window in Suite 710.

Balcony Sliding Door:

Scans of the balcony door indicate that the door frame has low a thermal resistance relative to that of the glass. This is shown in Figure 23 by the dark band at the edge of the door, where the temperature is approximately 8°C, while the temperature of the inner glass surface is 10°C to 12°C.

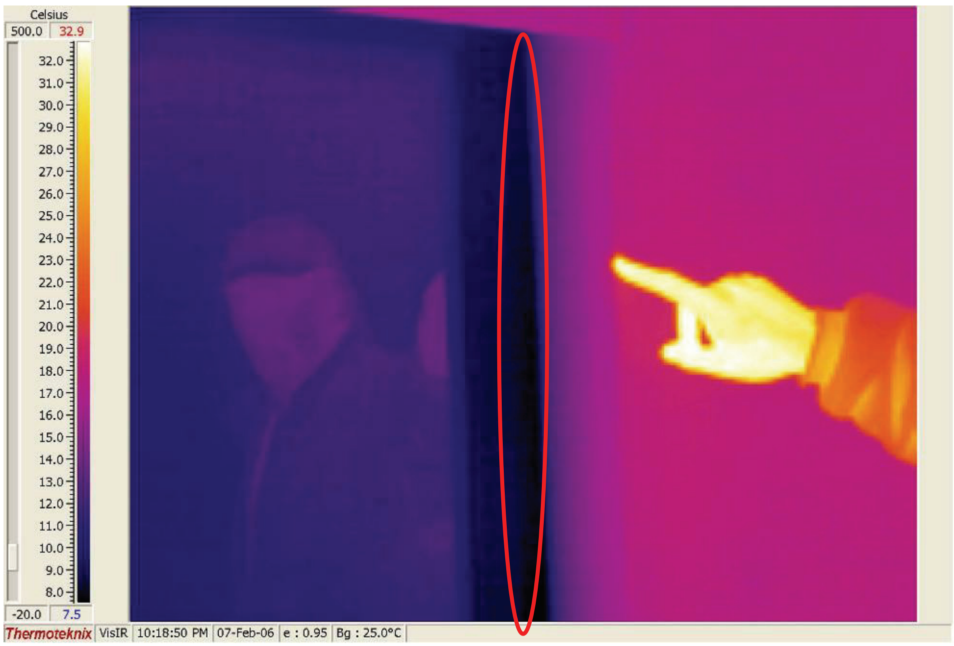

Figure 23: Balcony door in Suite 710.

Balcony:

Heat loss through the floor slab and balcony was visible on the night of the testing. Snow had accumulated on the balcony, but was mostly melted away from the area immediately in front of the balcony door. The thermograph in Figure 24 shows that the temperature of the balcony near building (in front of the balcony door and at the intersection of the balcony and the exterior wall), was approximately 5 degrees warmer than the areas further away from the building.

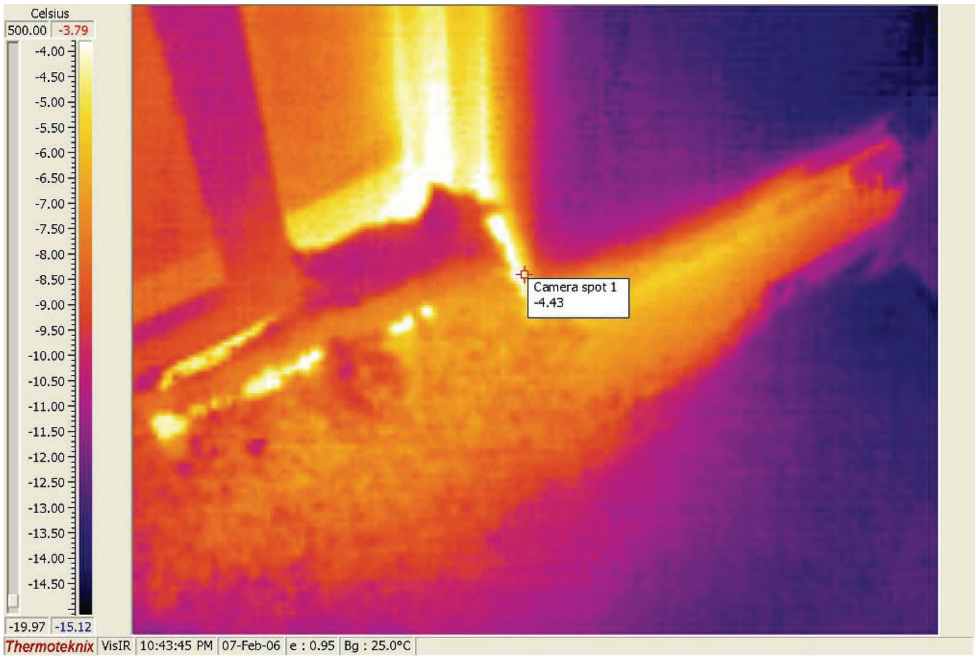

Figure 24: Close-up of heat loss through the balcony (Suite 710).

The construction detail shown in Figure 25 shows that there is a thermal break directly between the core slab and the balcony, and a thermal bridge between the concrete core slab and the balcony passing through the concrete in the ICF wall. In reality, this thermal bridge only exists on either side of the balcony and does not exist over the entire width of the balcony because the balcony is cambered (i.e., there is a slight curve in the balcony) creating a gap between the balcony and the ICF wall. This gap was filled with spray foam during construction.

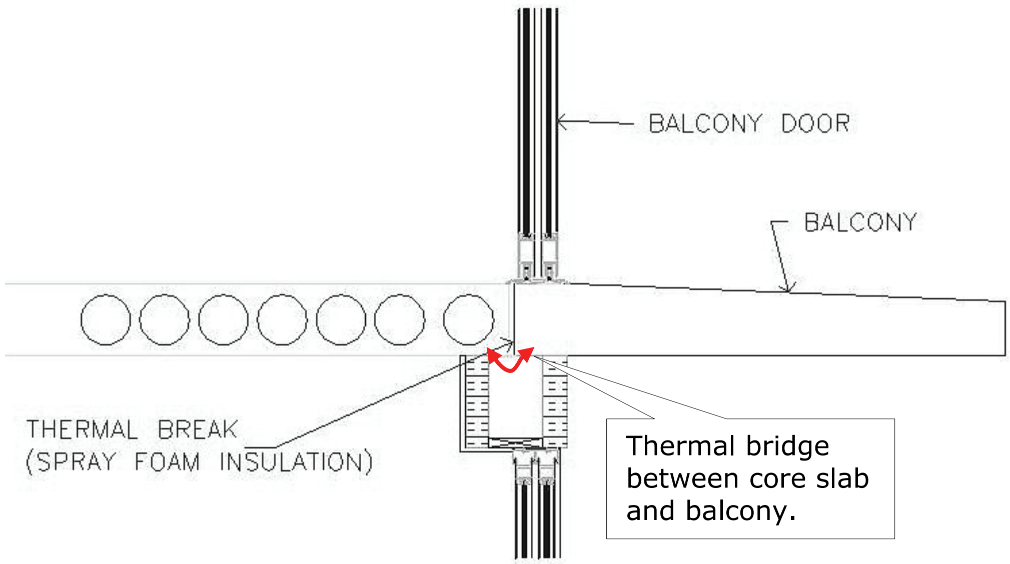

Figure 25: Wall-balcony construction detail.

The heat loss by the balcony was also visible in a thermograph of the west side of the building taken from the ground. Figure 26 shows a yellow band at the balcony-wall intersection under each balcony. This band is approximately -8°C, whereas the other building surfaces are less than -15°C. Consequently, the gap between the balcony and the ICF wall could be better insulated.

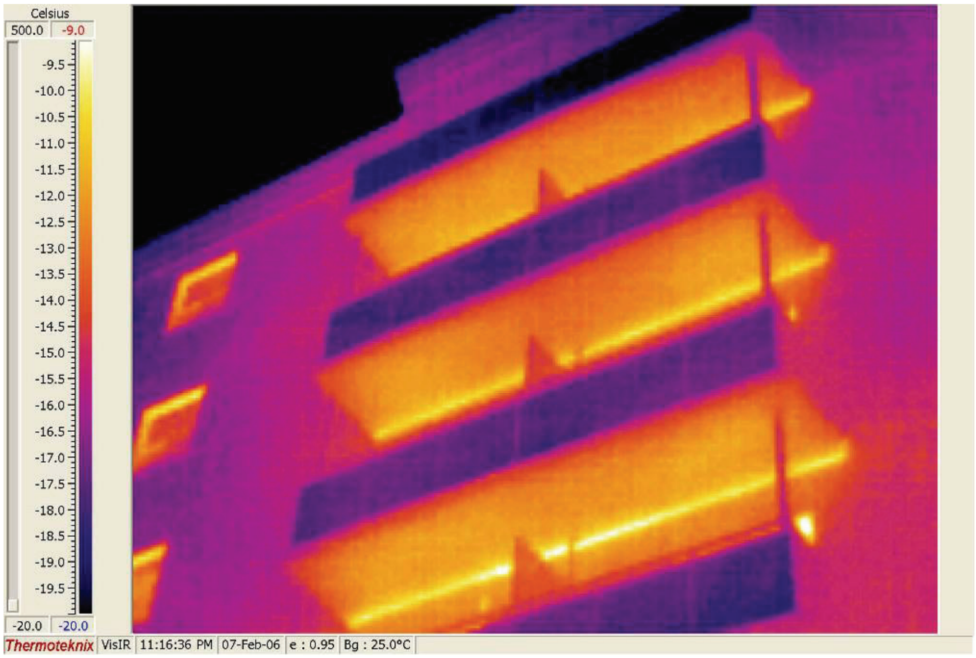

Figure 26: Thermograph of west side of building.

Roof:

Overall, the roof appeared to be well insulated. There were some areas of higher heat loss, particularly at the intersections of the roof and parapet and the roof and parapet bracing as shown in Figure 27. The thermal bridges that exist at the roof-wall intersection are indicated on the construction detail provided in Figure 28. In terms of the overall building heat loss, these are not significant.

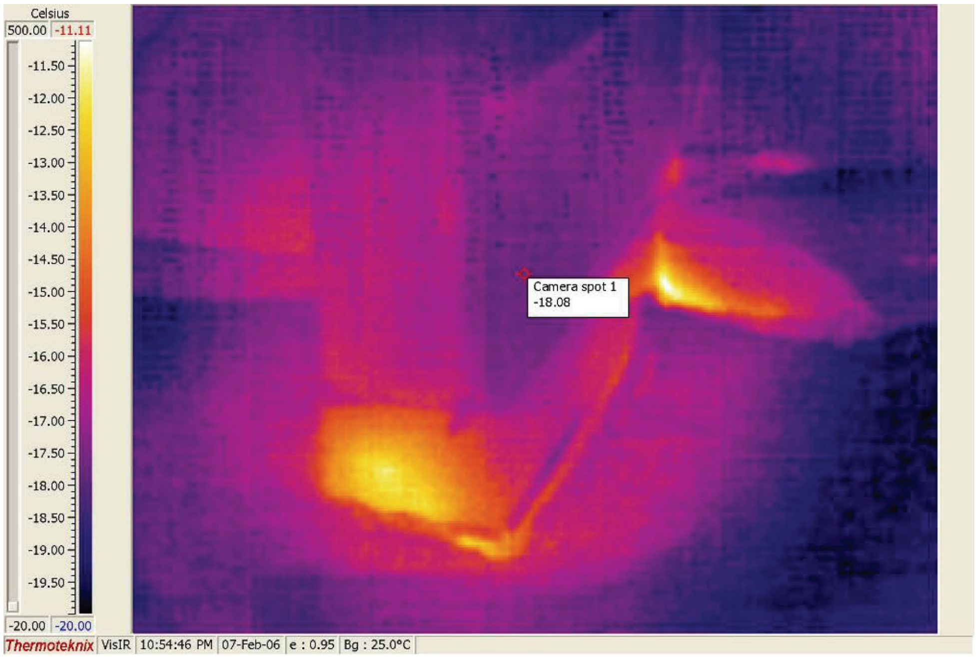

Figure 27: Thermograph of the parapet bracing.

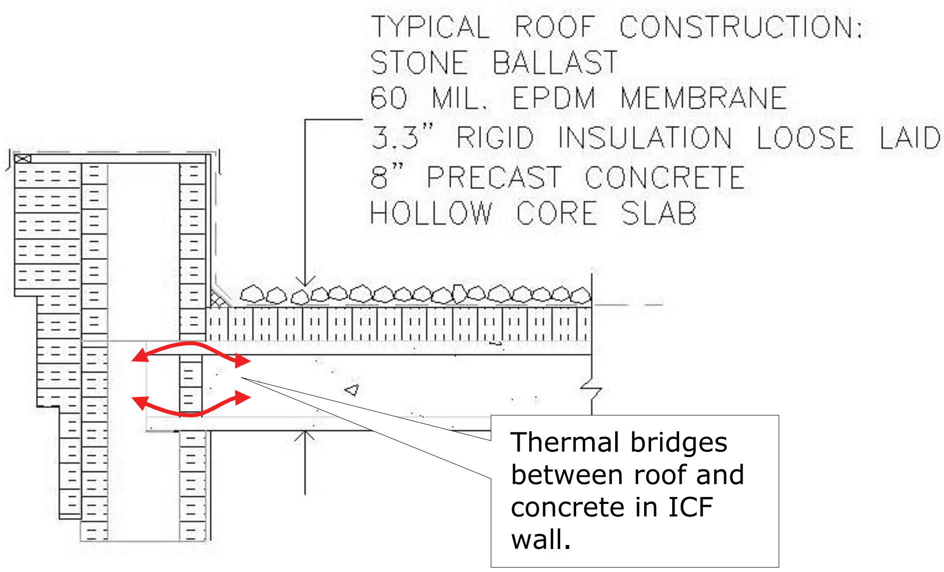

Figure 28: Wall-roof construction detail.

The stairwell enclosure above the roof of the building was observed to have relatively high heat loss. The thermograph, Figure 29, shows that the temperature of the areas near the roof of the enclosure is 7 degrees warmer than the lower portions of the wall. It appears that warm air is leaking out of this intersection, indicating that this joint may not be sealed properly.

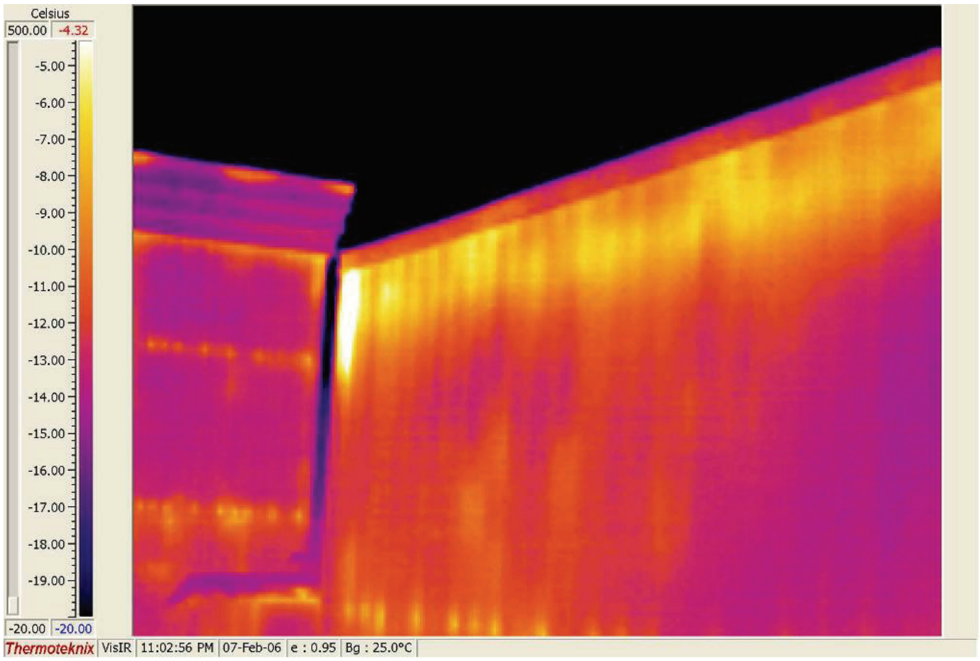

Figure 29: Stairwell wall-roof intersection.

<u>Building Exterior:</u>

As expected, the thermographs of the building exterior indicate that the opaque building components (walls and roof) are the coldest, while vents, grilles, condensers, windows and doors, and balconies are all several degrees warmer. Hence, improving the design and/or component selection will reduce the overall heat loss from the building.

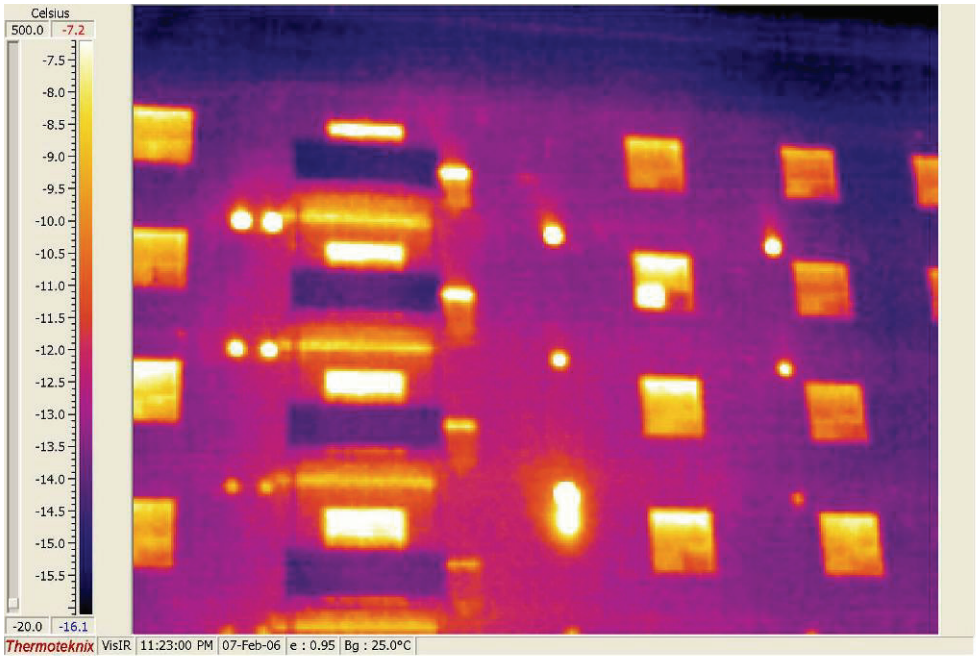

Figure 30: Thermograph of the south face of the building.

Underground Parking Garage:

Thermographic scans of the parking garage indicated that the surface temperature was relatively consistent over the entire envelope. Figure 31, below, shows some electrical cables passing through a hole in the concrete wall (separating the conditioned parking area from the unconditioned parking area) without any sealing. All unsealed openings allow unwanted air infiltration and a direct connection between the conditioned building interior and the exterior environment.

Figure 31: Unsealed opening for electrical cables.

6.2 Interpretation of Findings

No thermal bridging through the ICF wall was observed. This is due to the design of the ICF system in which the plastic spanners do not fully penetrate either layer of insulation. In addition, the exterior layer of insulation is not breached at wall-floor intersections. The thermal bridging identified was limited to the penetrations through the envelope and at assembly intersections, including: balconies, through-wall condenser units, the 2 inch vent under each condenser unit, the window and balcony door frames, and the roof-wall intersection over the east stairwell.

Since the findings indicate that the greatest heat loss is through penetrations in the building shell, the following considerations should be observed when designing an ICF building:

- Detail the envelope penetrations and intersections for air tightness.
- Select mechanical systems with minimal envelope penetrations.
- Select well insulated/sealed equipment if it must penetrate the envelope.
- Install insulated motorized dampers on kitchen and bath exhaust ducts.
- In addition to providing a thermal break between the interior core slab floor and the exterior balcony slab, insulate and seal between the balcony slab and the ICF wall.

7. ENERGY MODELLING

The Cedar Creek apartment building was simulated using the eQUEST v.3.5 software. eQUEST incorporates a building creation wizard and the DOE-2 simulation engine to perform an hourly simulation of the described building for a one-year time period. DOE-2 has a complex algorithm that allows it to account for the thermal capacity of building materials, which has been tested and verified.

The Cedar Creek building was modelled in eQUEST with the following parameters:

ICF wall construction:

1st Floor:
3.5" face brick
1" air gap
2 5/8" expanded polystyrene
6" concrete (density is 2350 kg/m^3)
2 5/8" expanded polystyrene
1/2" gyproc

Floors 2 - 7:
1/4" stucco
2 5/8" expanded polystyrene
6" concrete (density is 2350 kg/m^3)
2 5/8" expanded polystyrene
1/2" gyproc

Roof Construction:

Stone ballast
EPDM membrane
R-20 expanded polystyrene
Concrete slab

Windows and Balcony Doors:

1", double 1/4" panes, low-e, argon fill, with an aluminum spacer, and fibreglass frames

HVAC:

A rooftop make-up air unit is used to pressurize the corridors with tempered fresh air. Each suite has a standard efficiency DX fan coil unit with a hot water heating coil.

Plant:

A near-condensing boiler (86% thermal efficiency) provides hot water for the building.

Utility Rates:

Waterloo North Hydro supplies the building with electricity at $0.0632/kWh for the first 750 kWh, and $0.0682/kWh for each additional kWh. Natural gas is supplied to the building by Kitchener Public Utilities according to the following schedule:

Block (Therms)		Total Gas Charges ($/Therm)
First	500	1.18
Next	1,643	1.13
Next	44,299	1.10
Next	96,458	1.08
All Over	142,900	1.07

Other:

Typical operating schedules, water use, lighting densities, and ventilation quantities were used in the model.

Infiltration:

With regards to infiltration, eQUEST requires the number of air changes per hour for a 10 mile per hour wind blowing on the building. This is easily converted from other units of quantifying air infiltration. The results of the infiltration testing were 1.25 L/s/m^2 at 75 Pa. The average normalized air leakage index for 12 buildings reported by CMHC was 3.19 L/s/m^2 at 75 Pa. Converting these rates into ACH with a 10 mph wind blowing across the building gave 0.269 ACH for the Cedar Creek building, and 0.691 ACH for the typical building.

eQUEST was used to run parametric simulations to quantify the annual energy savings that may be attributed to the reduced infiltration and the increased thermal mass associated with the ICF wall construction. Consequently, the following three models were simulated:

Model #1: CEDAR CREEK BUILDING - REFERENCE

This model simulates the actual performance of the Cedar Creek apartment building. It is based upon the actual building construction and measured infiltration, as outlined above. Accordingly, this model will be used to compare the other two models against.

Model #2: TYPICAL INFILTRATION

This model is identical to Model #1, except the infiltration rate has been adjusted to that of a typical MURB. As previously noted, based upon a limited number of MURBs tested, the average infiltration rate was 0.691 ACH (with a 16 km/hr (10 mph) wind blowing on the building). Consequently, the simulation results of this model are compared against those of Model #1 to investigate the impact of infiltration upon the building's energy performance.

Model #3: NO CONCRETE

This model is identical to Model #1, except that the concrete layer of the ICF wall assembly has been replaced by a 6.35 mm layer of expanded polystyrene. The thickness of this insulation was selected so that the R-value of the wall assembly matched that of Model #1. Consequently, the simulation results of this model are compared against those of Model #1 to investigate the impact of the thermal mass of the concrete within the ICF wall assembly.

7.1 Simulation Results and Findings

The results of the three models are presented below in Table 4:

Table 4: eQUEST simulation results.

	Model #1	Model #2	Model #3
Cooling Load (kW)	197	234	202
Heating Load (kW)	164	383	161
Electricity (MJ)	1,698,113	1,692,415	1,702,649
Natural Gas (MJ)	5,466,351	6,046,631	5,468,250
Total (MJ)	7,164,463	7,739,047	7,170,899
Electricity Cost	$44,114	$43,967	$44,233
Natural Gas Cost	$57,732	$63,758	$57,753
Total Cost	$101,846	$107,725	$101,986

Reducing Infiltration:

Comparing the simulation results of Models #1 and #2, refer to Table 4, it is observed that the 60% reduction in air infiltration associated with the ICF wall construction lowered the building's peak heating and cooling loads by 57% and 16% respectively, giving rise to annual energy savings of 574,584 MJ (= 7,739,047 MJ – 7,164,463 MJ) and cost savings of $5,879 (= $107,725 - $101,846). Consequently, the tighter envelope provided by the building's ICF wall construction yields significant energy and energy cost savings.

Increasing Thermal Mass:

By comparing the simulation results of Models #1 and #3, it is observed that the increased thermal mass offered by the ICF wall construction in this building showed an insignificant improvement when compared to a low-mass wall assembly having the same thermal resistance and infiltration. The annual energy savings and energy cost savings were determined to be 6,436 MJ (= 7,170,899 MJ – 7,164,463 MJ) and $140 (= $101,986 - $101,846).

The wall assembly used in Model #3 is a theoretical wall assembly, comprised only of polystyrene, having an extremely low thermal mass. Therefore, any other wall assemblies (such as stud in-fill) achieving the same level of infiltration and overall effective thermal resistance would be expected to yield similar results. Consequently, in terms of peak building loads and total annual energy demand, the increased thermal mass provided by the ICF wall construction in this multi-unit residential type building yielded very minimal savings. It is noted, however, that the ICF wall construction may have a greater impact upon the energy savings and the sizing of mechanical equipment for other building types, such as an office building, where energy saving control strategies may implemented during unoccupied hours (e.g., precooling the building using cooler night-time air).

8. CONCLUSIONS

Thermal Resistance

The overall ICF wall assembly, including the stucco exterior and gypsum board interior, has a thermal resistance (or R-value) of 3.9 m^2K/W (22.1 $hr.ft^2.F/BTU$). The ICF wall construction does not contain any full thermal bridges, so that the thermal resistance is practically continuous over the wall area. While the concrete only accounts for 2.6% of the overall thermal resistance, the two layers of expanded polystyrene insulation account for 92.3%.

By comparison, the Model National Energy Code for Buildings (MNECB) requires that the minimum R-value of an above-grade wall for a natural gas heated building in southern Ontario be at least 1.76 m^2K/W (10 $hr.ft^2.F/BTU$). Hence, thermal resistance for the ICF wall assembly is more than double that of what would be considered typical of natural gas heated buildings in Southern Ontario.

Thermal Buffering

During unsteady-state conditions, the data demonstrated that the concrete played a significant role in isolating fluctuations in the OAT from the interior wall surface. Furthermore, the heat loss from the interior of the wall assembly through to the concrete fluctuated slowly.

Heat never actually moved from the concrete back into the building. However, the volumetric heat capacity allows the concrete to store heat that is lost from the interior. When the outside air temperature drops, the heat that is stored in the concrete is slowly released, due to the concrete's low thermal diffusivity, reducing the heat loss from the building interior (i.e., maintaining a steady heat loss from interior into the wall despite increasing heat loss from wall to exterior). Because the temperature of the concrete drops slowly (i.e., has a long time constant), the building interior is buffered from overnight temperature drops.

Thermal Bridging

The thermographic investigation made it possible to identify areas of thermal bridging in the building envelope. The investigation confirmed that the significant thermal bridges were the through-wall penetrations, such as the condenser units, the 50 mm (2-inch) ventilation holes, the window and sliding door frames, and the balconies. Consequently, the thermal performance of the building may be improved by carefully detailing wall penetrations such as the balcony, selecting high performance non-wall envelope components (window and door frames), and selecting mechanical equipment that do not, or at least minimally, penetrate the exterior wall (e.g., through wall condenser units).

Air Tightness
The results of the airtightness test indicated that the building was exceptionally 'tight' with a normalized air leakage index (at 75 Pa) of only 1.25 L/s/m^2. Subsequently, with the reduced amount of infiltration, the peak and annual building heating and cooling loads have been shown to be lower than if the building had a typical air infiltration rate. This thermal improvement was achieved by carrying out an average air sealing program during construction. While the envelope was found to be "tight", the envelope penetrations were not. It is therefore recommended that the mechanical systems selected for these buildings require fewer penetrations. It is also recommended that insulated motorized dampers be installed on kitchen and bathroom exhaust ducts

HVAC System Sizing
The monitored data confirmed that the volumetric heat capacity of the concrete does not increase the overall R-value of the wall assembly under steady-state conditions. Air tightness testing revealed that the infiltration rate of this building was 60% lower than an average building. Since the thermal resistance of the ICF wall and the building infiltration were both better than typical construction, the design heating load is lower, and a smaller heating system would be selected than if the building had been constructed using a conventional wall construction assembly.

Modelled Performance
Parametric energy simulations showed that the reduced air infiltration provided by the ICF wall construction resulted in significantly lower heating and cooling loads and yielded an estimated annual energy savings of 574,584 MJ and cost savings of $5,879 for this building.

The simulations also showed that there were limited differences in energy performance for this building between the ICF construction and a low-mass wall assembly with the same the thermal resistance and infiltration. Hence, the modelling did not show that there is an increase in ICF wall's effective R-value due to thermal mass.

Observed Performance Characteristics of ICF
Notwithstanding constructability features of ICF, perhaps the single greatest benefit to the ICF construction is the ability to significantly reduce air infiltration through the building envelope without implementing a stringent sealing program.

The steady interior wall temperature indicates that the ICF construction also provided comfortable thermal conditions for the building's occupants.

The only observed limitation of the ICF construction is that the ability to recover heat from the concrete's thermal mass is reduced by the layer of insulation on the interior side. To do this, the concrete would have to be exposed to the interior. However, the concrete does provide buffering that reduces heat loss during swings in temperature and maintains higher interior temperature for greater thermal comfort.

9. RECOMMENDATIONS FOR FURTHER STUDY

The scope of this study was limited to monitoring the opaque wall areas of the building for a three month period in the heating season. Additional temperature sensors were installed at the window frames and balcony-wall intersections. Any future monitoring of this building should address the thermal performance of these envelope penetrations in order to provide a qualitative assessment of these penetrations and determine the impact upon the building's energy performance.

It is recommended that the full building (opaque wall areas, window frames, and balconies) be monitored for a full 12 month period (ideally from January 1 to December 31). It is further recommended that the monthly utility bills be analyzed over this monitoring period in order to assess the overall energy performance of the building and attempt to draw correlations between the weather, the ICF wall system, and the plant level energy consumption, and to verify the energy models.

One observation of this study is that advanced temperature control schemes could not be implemented in this building because of the continuous occupancy. It is therefore recommended that a typical office building (or other building having significant unoccupied periods) constructed using an ICF envelope assembly be similarly monitored.

Appendix A. Summaries of Modelling Inputs and Outputs

Model #1: Cedar Creek Building – Reference

Cedar Creek Wizard DOE-2.2-44c3 8/30/2006 11:53:30 BDL RUN 3

REPORT- LV-B Summary of Spaces WEATHER FILE- Toronto Ont CWEC

NUMBER OF SPACES 20 EXTERIOR 18 INTERIOR 2

SPACE	SPACE*FLOOR MULTIPLIER	SPACE TYPE	AZIM	LIGHTS (WATT / SQFT)	PEOPLE	EQUIP (WATT / SQFT)	INFILTRATION METHOD	ACH	AREA (SQFT)	VOLUME (CUFT)
Spaces on floor: EL1 Ground Flr										
EL1 West Perim Spc (G.W1)	1.0	EXT	90.0	1.10	2.8	0.23	AIR-CHANGE	0.27	832.7	7744.6
EL1 South Perim Spc (G.S2)	1.0	EXT	-0.1	1.10	17.6	0.23	AIR-CHANGE	0.27	5300.3	49292.9
EL1 East Perim Spc (G.E3)	1.0	EXT	-39.0	1.10	7.3	0.23	AIR-CHANGE	0.27	2201.8	20477.1
EL1 North Perim Spc (G.N4)	1.0	EXT	45.0	1.10	17.4	0.23	AIR-CHANGE	0.27	5237.4	48708.1
EL1 Core Spc (G.C5)	1.0	EXT	0.0	0.57	0.9	0.00	AIR-CHANGE	0.00	1390.6	12932.7
Spaces on floor: EL2 Ground Flr										
EL2 West Perim Spc (G.W1)	1.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.27	832.7	7494.7
EL2 South Perim Spc (G.S2)	1.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 East Perim Spc (G.E3)	1.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.27	817.3	7355.3
EL2 North Perim Spc (G.N4)	1.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 Core Spc (G.C5)	1.0	INT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
Spaces on floor: EL2 Mid Flrs										
EL2 West Perim Spc (M.W6)	4.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.27	832.7	7494.7
EL2 South Perim Spc (M.S7)	4.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 East Perim Spc (M.E8)	4.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.27	817.3	7355.3
EL2 North Perim Spc (M.N9)	4.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 Core Spc (M.C10)	4.0	INT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
Spaces on floor: EL2 Top Flr										
EL2 West Perim Spc (T.W11)	1.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.27	832.7	7494.7
EL2 South Perim Spc (T.S12)	1.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 East Perim Spc (T.E13)	1.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.27	817.3	7355.3
EL2 North Perim Spc (T.N14)	1.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.27	4878.8	43908.8
EL2 Core Spc (T.C15)	1.0	EXT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
BUILDING TOTALS					305.2				91575.1	828665.1

```
Cedar Creek Wizard                                                                     DOE-2.2-44c3   8/30/2006    11:53:30  BDL RUN  3

REPORT- LS-C BuiLding Peak Load Components                                                       WEATHER FILE- Toronto Ont CWEC
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*** BUILDING ***




                    FLOOR  AREA     91575  SQFT      8507   M2
                    VOLUME         828665  CUFT     23468   M3

                                                COOLING  LOAD                                  HEATING  LOAD
                                           ==========================                ==========================
    TIME                                          JUL  9  7PM                                JAN  1  1PM

    DRY-BULB TEMP                             80 F             27 C                   -1 F            -18 C
    WET-BULB TEMP                             71 F             22 C                   -2 F            -19 C
    TOT HORIZONTAL SOLAR RAD                  98 BTU/H.SQFT   308 W/M2                95 BTU/H.SQFT   299 W/M2
    WINDSPEED AT SPACE                      11.1 KTS          5.7 M/S               17.0 KTS          8.8 M/S
    CLOUD AMOUNT 0(CLEAR)-10                  2                                        5


                                    SENSIBLE          LATENT                                    SENSIBLE
                               (KBTU/H)    ( KW )  (KBTU/H)  ( KW )                        (KBTU/H)  ( KW )
                               --------    ------  --------  ------                        --------  --------

     WALL CONDUCTION            34.061      9.980     0.000   0.000                        -159.432   -46.714
     ROOF CONDUCTION            14.193      4.159     0.000   0.000                         -48.615   -14.244
     WINDOW GLASS+FRM COND      45.444     13.315     0.000   0.000                         -75.274   -22.055
     WINDOW GLASS SOLAR        110.268     32.308     0.000   0.000                         134.777    39.490
     DOOR CONDUCTION             0.000      0.000     0.000   0.000                           0.000     0.000
     INTERNAL SURFACE COND       0.000      0.000     0.000   0.000                           0.000     0.000
     UNDERGROUND SURF COND       0.000      0.000     0.000   0.000                           0.000     0.000
     OCCUPANTS TO SPACE         63.120     18.494    43.137  12.639                          38.449    11.266
     LIGHT     TO SPACE        237.061     69.459     0.000   0.000                          14.003     4.103
     EQUIPMENT TO SPACE         45.484     13.327     0.000   0.000                          14.745     4.320
     PROCESS   TO SPACE          0.000      0.000     0.000   0.000                           0.000     0.000
     INFILTRATION               22.214      6.509    57.802  16.936                        -479.152  -140.391
                               --------   -------   -------  ------                        --------  --------
     TOTAL                     571.847    167.551   100.938  29.575                        -560.498  -164.226
     TOTAL / AREA                0.006      0.020     0.001   0.003                          -0.006    -0.019

     TOTAL LOAD                672.785 KBTU/H      197.126  KW              -560.498 KBTU/H     -164.226  KW
     TOTAL LOAD / AREA           7.35  BTU/H.SQFT   23.171  W/M2               6.121 BTU/H.SQFT   19.303  W/M2
```

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*****************************************************************
*                                                               *
*  NOTE  1)THE ABOVE LOADS EXCLUDE OUTSIDE VENTILATION AIR      *
*  ----    LOADS                                                *
*        2)TIMES GIVEN IN STANDARD TIME FOR THE LOCATION        *
*          IN CONSIDERATION                                     *
*        3)THE ABOVE LOADS ARE CALCULATED ASSUMING A            *
*          CONSTANT INDOOR SPACE TEMPERATURE                    *
*                                                               *
*****************************************************************
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Cedar Creek Wizard DOE-2.2-44c3 8/30/2006 11:53:30 BDL RUN 3

REPORT- ES-D Energy Cost Summary WEATHER FILE- Toronto Ont CWEC

UTILITY-RATE	RESOURCE	METERS	METERED ENERGY UNITS/YR	TOTAL CHARGE ($)	VIRTUAL RATE ($/UNIT)	RATE USED ALL YEAR?
Custom Elec Rate	ELECTRICITY	EM1	471574. KWH	44114.	0.0935	YES
Custom Gas Rate	NATURAL-GAS	FM1	51811. THERM	57732.	1.1143	YES
				==========		
				101846.		

ENERGY COST/GROSS BLDG AREA: 1.11
ENERGY COST/NET BLDG AREA: 1.11

Model #2: Typical Infiltration

Cedar Creek Wizard DOE-2.2-44c3 8/30/2006 12:01:02 BDL RUN 4

REPORT- LV-B Summary of Spaces WEATHER FILE- Toronto Ont CWEC

NUMBER OF SPACES 20 EXTERIOR 18 INTERIOR 2

SPACE	SPACE*FLOOR MULTIPLIER	SPACE TYPE	AZIM	LIGHTS (WATT / SQFT)	PEOPLE	EQUIP (WATT / SQFT)	INFILTRATION METHOD	ACH	AREA (SQFT)	VOLUME (CUFT)
Spaces on floor: EL1 Ground Flr										
EL1 West Perim Spc (G.W1)	1.0	EXT	90.0	1.10	2.8	0.23	AIR-CHANGE	0.69	832.7	7744.6
EL1 South Perim Spc (G.S2)	1.0	EXT	-0.1	1.10	17.6	0.23	AIR-CHANGE	0.69	5300.3	49292.9
EL1 East Perim Spc (G.E3)	1.0	EXT	-39.0	1.10	7.3	0.23	AIR-CHANGE	0.69	2201.8	20477.1
EL1 North Perim Spc (G.N4)	1.0	EXT	45.0	1.10	17.4	0.23	AIR-CHANGE	0.69	5237.4	48708.1
EL1 Core Spc (G.C5)	1.0	EXT	0.0	0.57	0.9	0.00	AIR-CHANGE	0.00	1390.6	12932.7
Spaces on floor: EL2 Ground Flr										
EL2 West Perim Spc (G.W1)	1.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.69	832.7	7494.7
EL2 South Perim Spc (G.S2)	1.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 East Perim Spc (G.E3)	1.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.69	817.3	7355.3
EL2 North Perim Spc (G.N4)	1.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 Core Spc (G.C5)	1.0	INT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
Spaces on floor: EL2 Mid Flrs										
EL2 West Perim Spc (M.W6)	4.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.69	832.7	7494.7
EL2 South Perim Spc (M.S7)	4.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 East Perim Spc (M.E8)	4.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.69	817.3	7355.3
EL2 North Perim Spc (M.N9)	4.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 Core Spc (M.C10)	4.0	INT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
Spaces on floor: EL2 Top Flr										
EL2 West Perim Spc (T.W11)	1.0	EXT	90.0	1.10	3.1	0.23	AIR-CHANGE	0.69	832.7	7494.7
EL2 South Perim Spc (T.S12)	1.0	EXT	-0.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 East Perim Spc (T.E13)	1.0	EXT	-90.0	1.10	3.0	0.23	AIR-CHANGE	0.69	817.3	7355.3
EL2 North Perim Spc (T.N14)	1.0	EXT	180.1	1.10	17.9	0.23	AIR-CHANGE	0.69	4878.8	43908.8
EL2 Core Spc (T.C15)	1.0	EXT	0.0	0.60	1.2	0.01	AIR-CHANGE	0.00	1361.2	12250.8
BUILDING TOTALS					305.2				91575.1	828665.1

```
Cedar Creek Wizard                                               DOE-2.2-44c3   8/30/2006    12:01:02  BDL RUN  4

REPORT- LS-C BuiLding Peak Load Components                                 WEATHER FILE- Toronto Ont CWEC
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*** BUILDING ***



                    FLOOR  AREA     91575  SQFT      8507   M2
                    VOLUME         828665  CUFT     23468   M3

                                          COOLING  LOAD                          HEATING  LOAD
                                     ==========================          ==========================
    TIME                                   JUL  9  7PM                         JAN  1  1PM

    DRY-BULB TEMP                       80 F            27 C              -1 F            -18 C
    WET-BULB TEMP                       71 F            22 C              -2 F            -19 C
    TOT HORIZONTAL SOLAR RAD            98 BTU/H.SQFT  308 W/M2           95 BTU/H.SQFT   299 W/M2
    WINDSPEED AT SPACE                11.1 KTS         5.7 M/S          17.0 KTS          8.8 M/S
    CLOUD AMOUNT 0(CLEAR)-10             2                                 5


                                 SENSIBLE          LATENT                             SENSIBLE
                            (KBTU/H)    ( KW )  (KBTU/H)  ( KW )                (KBTU/H)  ( KW )
                            --------    ------  --------  ------                --------  --------

     WALL CONDUCTION          34.061     9.980     0.000   0.000                -159.432   -46.714
     ROOF CONDUCTION          14.193     4.159     0.000   0.000                 -48.615   -14.244
     WINDOW GLASS+FRM COND    45.444    13.315     0.000   0.000                 -75.274   -22.055
     WINDOW GLASS SOLAR      110.268    32.308     0.000   0.000                 134.777    39.490
     DOOR CONDUCTION           0.000     0.000     0.000   0.000                   0.000     0.000
     INTERNAL SURFACE COND     0.000     0.000     0.000   0.000                   0.000     0.000
     UNDERGROUND SURF COND     0.000     0.000     0.000   0.000                   0.000     0.000
     OCCUPANTS TO SPACE       63.120    18.494    43.137  12.639                  38.449    11.266
     LIGHT     TO SPACE      237.061    69.459     0.000   0.000                  14.003     4.103
     EQUIPMENT TO SPACE       45.484    13.327     0.000   0.000                  14.745     4.320
     PROCESS   TO SPACE        0.000     0.000     0.000   0.000                   0.000     0.000
     INFILTRATION             56.855    16.658   147.935  43.345               -1226.321  -359.312
                            --------   -------   -------  ------                --------  --------
     TOTAL                   606.487   177.701   191.072  55.984               -1307.668  -383.147
     TOTAL / AREA              0.007     0.021     0.002   0.007                  -0.014    -0.045

     TOTAL LOAD              797.559 KBTU/H      233.685  KW          -1307.668 KBTU/H     -383.147  KW
     TOTAL LOAD / AREA         8.71  BTU/H.SQFT   27.468  W/M2           14.280 BTU/H.SQFT   45.036  W/M2
```

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*****************************************************************
*                                                               *
*  NOTE  1)THE ABOVE LOADS EXCLUDE OUTSIDE VENTILATION AIR      *
*  ----    LOADS                                                *
*        2)TIMES GIVEN IN STANDARD TIME FOR THE LOCATION        *
*          IN CONSIDERATION                                     *
*        3)THE ABOVE LOADS ARE CALCULATED ASSUMING A            *
*          CONSTANT INDOOR SPACE TEMPERATURE                    *
*                                                               *
*****************************************************************
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Cedar Creek Wizard                                                                 DOE-2.2-44c3   8/30/2006    12:01:02  BDL RUN  4

REPORT- ES-D Energy Cost Summary                                                            WEATHER FILE- Toronto Ont CWEC
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UTILITY-RATE	RESOURCE	METERS	METERED ENERGY UNITS/YR	TOTAL CHARGE ($)	VIRTUAL RATE ($/UNIT)	RATE USED ALL YEAR?
Custom Elec Rate	ELECTRICITY	EM1	469998. KWH	43967.	0.0935	YES
Custom Gas Rate	NATURAL-GAS	FM1	57311. THERM	63758.	1.1125	YES
				==========		
				107725.		

ENERGY COST/GROSS BLDG AREA: 1.18
ENERGY COST/NET BLDG AREA: 1.18

Model #3: No Concrete

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Cedar Creek Wizard                                              DOE-2.2-44c3   8/30/2006    12:04:30  BDL RUN  5

REPORT- LV-B Summary of Spaces                                            WEATHER FILE- Toronto Ont CWEC
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NUMBER OF SPACES   20          EXTERIOR   18     INTERIOR    2

                                                    LIGHTS         EQUIP
                             SPACE*FLOOR SPACE       (WATT /       (WATT / INFILTRATION           AREA        VOLUME
SPACE                         MULTIPLIER  TYPE   AZIM  SQFT ) PEOPLE  SQFT )       METHOD   ACH     (SQFT )       (CUFT )



Spaces on floor: EL1 Ground Flr

EL1 West Perim Spc (G.W1)            1.0   EXT   90.0    1.10    2.8    0.23   AIR-CHANGE  0.27       832.7        7744.6
EL1 South Perim Spc (G.S2)           1.0   EXT   -0.1    1.10   17.6    0.23   AIR-CHANGE  0.27      5300.3       49292.9
EL1 East Perim Spc (G.E3)            1.0   EXT  -39.0    1.10    7.3    0.23   AIR-CHANGE  0.27      2201.8       20477.1
EL1 North Perim Spc (G.N4)           1.0   EXT   45.0    1.10   17.4    0.23   AIR-CHANGE  0.27      5237.4       48708.1
EL1 Core Spc (G.C5)                  1.0   EXT    0.0    0.57    0.9    0.00   AIR-CHANGE  0.00      1390.6       12932.7

Spaces on floor: EL2 Ground Flr

EL2 West Perim Spc (G.W1)            1.0   EXT   90.0    1.10    3.1    0.23   AIR-CHANGE  0.27       832.7        7494.7
EL2 South Perim Spc (G.S2)           1.0   EXT   -0.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 East Perim Spc (G.E3)            1.0   EXT  -90.0    1.10    3.0    0.23   AIR-CHANGE  0.27       817.3        7355.3
EL2 North Perim Spc (G.N4)           1.0   EXT  180.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 Core Spc (G.C5)                  1.0   INT    0.0    0.60    1.2    0.01   AIR-CHANGE  0.00      1361.2       12250.8

Spaces on floor: EL2 Mid Flrs

EL2 West Perim Spc (M.W6)            4.0   EXT   90.0    1.10    3.1    0.23   AIR-CHANGE  0.27       832.7        7494.7
EL2 South Perim Spc (M.S7)           4.0   EXT   -0.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 East Perim Spc (M.E8)            4.0   EXT  -90.0    1.10    3.0    0.23   AIR-CHANGE  0.27       817.3        7355.3
EL2 North Perim Spc (M.N9)           4.0   EXT  180.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 Core Spc (M.C10)                 4.0   INT    0.0    0.60    1.2    0.01   AIR-CHANGE  0.00      1361.2       12250.8

Spaces on floor: EL2 Top Flr

EL2 West Perim Spc (T.W11)           1.0   EXT   90.0    1.10    3.1    0.23   AIR-CHANGE  0.27       832.7        7494.7
EL2 South Perim Spc (T.S12)          1.0   EXT   -0.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 East Perim Spc (T.E13)           1.0   EXT  -90.0    1.10    3.0    0.23   AIR-CHANGE  0.27       817.3        7355.3
EL2 North Perim Spc (T.N14)          1.0   EXT  180.1    1.10   17.9    0.23   AIR-CHANGE  0.27      4878.8       43908.8
EL2 Core Spc (T.C15)                 1.0   EXT    0.0    0.60    1.2    0.01   AIR-CHANGE  0.00      1361.2       12250.8
                                                               ------                               ---------    ----------
BUILDING TOTALS                                                 305.2                                 91575.1      828665.1
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Cedar Creek Wizard                                              DOE-2.2-44c3   8/30/2006    12:04:30  BDL RUN  5

REPORT- LS-C BuiLding Peak Load Components                                          WEATHER FILE- Toronto Ont CWEC
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*** BUILDING ***


                    FLOOR  AREA     91575  SQFT      8507   M2
                    VOLUME         828665  CUFT     23468   M3

                                             COOLING  LOAD                              HEATING  LOAD
                                        ==========================              ==========================
    TIME                                       JUL  9  7PM                              JAN  1  1PM

    DRY-BULB TEMP                          80 F            27 C                   -1 F            -18 C
    WET-BULB TEMP                          71 F            22 C                   -2 F            -19 C
    TOT HORIZONTAL SOLAR RAD               98 BTU/H.SQFT   308 W/M2               95 BTU/H.SQFT   299 W/M2
    WINDSPEED AT SPACE                   11.1 KTS          5.7 M/S              17.0 KTS          8.8 M/S
    CLOUD AMOUNT 0(CLEAR)-10                2                                      5


                                   SENSIBLE          LATENT                               SENSIBLE
                               (KBTU/H)    ( KW )  (KBTU/H)  ( KW )                  (KBTU/H)  ( KW )
                               --------    ------  --------  ------                  --------  --------

     WALL CONDUCTION            49.838    14.602     0.000   0.000                   -146.533   -42.934
     ROOF CONDUCTION            14.217     4.166     0.000   0.000                    -48.691   -14.267
     WINDOW GLASS+FRM COND      45.612    13.364     0.000   0.000                    -75.277   -22.056
     WINDOW GLASS SOLAR        112.019    32.822     0.000   0.000                    134.773    39.489
     DOOR CONDUCTION             0.000     0.000     0.000   0.000                      0.000     0.000
     INTERNAL SURFACE COND       0.000     0.000     0.000   0.000                      0.000     0.000
     UNDERGROUND SURF COND       0.000     0.000     0.000   0.000                      0.000     0.000
     OCCUPANTS TO SPACE         63.199    18.517    43.137  12.639                     38.421    11.257
     LIGHT     TO SPACE        237.323    69.536     0.000   0.000                     13.904     4.074
     EQUIPMENT TO SPACE         45.569    13.352     0.000   0.000                     14.766     4.326
     PROCESS   TO SPACE          0.000     0.000     0.000   0.000                      0.000     0.000
     INFILTRATION               22.215     6.509    57.804  16.937                   -479.170  -140.397
                               --------   -------   -------  ------                  --------  --------
     TOTAL                     589.993   172.868   100.941  29.576                   -547.807  -160.507
     TOTAL / AREA                0.006     0.020     0.001   0.003                     -0.006    -0.019

     TOTAL LOAD                690.934 KBTU/H      202.444  KW             -547.807 KBTU/H     -160.507  KW
     TOTAL LOAD / AREA           7.54  BTU/H.SQFT   23.796  W/M2              5.982 BTU/H.SQFT   18.866  W/M2
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*****************************************************************
*                                                               *
*  NOTE  1)THE ABOVE LOADS EXCLUDE OUTSIDE VENTILATION AIR      *
*  ----    LOADS                                                *
*        2)TIMES GIVEN IN STANDARD TIME FOR THE LOCATION        *
*          IN CONSIDERATION                                     *
*        3)THE ABOVE LOADS ARE CALCULATED ASSUMING A            *
*          CONSTANT INDOOR SPACE TEMPERATURE                    *
*                                                               *
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Cedar Creek Wizard DOE-2.2-44c3 8/30/2006 12:04:30 BDL RUN 5

REPORT- ES-D Energy Cost Summary WEATHER FILE- Toronto Ont CWEC

UTILITY-RATE	RESOURCE	METERS	METERED ENERGY UNITS/YR	TOTAL CHARGE ($)	VIRTUAL RATE ($/UNIT)	RATE USED ALL YEAR?
Custom Elec Rate	ELECTRICITY	EM1	472840. KWH	44233.	0.0935	YES
Custom Gas Rate	NATURAL-GAS	FM1	51829. THERM	57753.	1.1143	YES
				==========		
				101986.		

ENERGY COST/GROSS BLDG AREA: 1.11
ENERGY COST/NET BLDG AREA: 1.11

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