Measuring a Building's Vital Signs: Cold Climate Case Studies—Green on the Grand, Waterloo, Ontario

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BACKGROUND

The Vital Signs Curriculum Materials Project examines the physical performance of buildings, their energy use and their impact on occupant well being. The goal of Vital Signs is to encourage the next generation of architects to create energy efficient and environmentally responsible buildings. The U.S. based project is supported by The Energy Foundation, Pacific Gas & Electric, The National Science Foundation, The Nathan Cummings Foundation, The Educational Foundation of America, The U.S. Department of Energy and the Society of Building Science Educators. It is operated from of the Center for Environmental Design at the University of California at Berkeley.

The Vital Signs Project feels that architects must be targeted for education about energy and environmental issues. Energy issues ought to be considered and balanced with other aspects of the architectural design process at the earliest point of the project.

THE VITAL SIGNS METHOD FOR BUILDING PERFORMANCE EVALUATION

The main challenge of the Vital Signs Project is to restore an appreciation and understanding of the physical environment. Consideration of appropriate building design according to bioclimatic concerns should become one of the basic notions that governs the design process. Building performance, both from energy and occupant comfort points of view, needs to be brought to the forefront of architectural concerns. Understanding energy issues must be a key part of architectural education.

Such studies cannot be accomplished without adequate field work. Data must be collected to verify assumptions and hypothesized performance criteria. The Vital Signs Project requires that students engage the building to assess its performance. This approach integrates abstract conceptualization with reflective learning, concrete experience and experimentation.

As part of the Vital Signs Project, twelve teaching "Resource Packages" have been developed by architecture faculty in the U.S. and Canada. These units address physical building performance issues such as energy use, the experiential quality of buildings and occupant well being. The specific topics include: whole building energy use, the dynamics of solar shading devices, natural ventilation, occupant thermal comfort, thermal mass, health in the built environment, indoor illuminance, and glazing performance.

The protocols for field evaluation fall into three levels. The first level is based on document based research, occupant interviews and observation. It does not require any equipment. The second level involves minimal equipment for data collection and uses simple site experiments to understand building processes and performance. The third level requires a significant equipment component and involves data collection and analysis over a period of time.

COLD CLIMATE PERFORMANCE: UNIVERSITY OF WATERLOO STUDENT CASE STUDIES

School of Architecture at the University of Waterloo, through the course Arch 366: Energy in Design, worked with the Vital Signs Project during the Winter 1998 term. As the result of a Request for Proposals in the Spring of 1997, the school was one of 9 in the United States and Canada to be awarded the loan of a "Toolkit." The toolkit included approximately $US35,000 of data collection equipment. The equipment sets include small microprocessor data acquisition systems that can measure temperature, humidity and light levels over time (Hobos); an infrared thermometer to measure surface temperature: photometers to determine luminance and illuminance levels; a sling psychrometer to measure humidity; an anemometer to calculate wind speed; carbon dioxide, ozone and VOC monitors to make preliminary evaluations of indoor air quality; a digital camera for web documentation; and a laptop computer for field use.

Students at the University of Waterloo used Vital Signs protocol and equipment/testing devices to carry out a series of four detailed building case studies which were entered into the 1998 Student Cast Study Competition. Students employed all three levels of evaluation protocols. Their building performance evaluations fell under three primary categories: thermal performance, lighting and air quality. Specific areas of focus were dependent upon the building type and its design intentions.

Within the confines of equipment sharing, course work and the curriculum, data collection was limited to a one-month period. In spite of time limitations, this did provide a relevant discrete picture of building performance during a certain time of year. In this case, data was collected during the month of March which allowed for an assessment of cold climate building performance. In order to create a more complete picture, the students created daylighting models to allow for visualization of the year-round solar and lighting characteristics. These models were tested through the use of a heliodon.

Four buildings were selected by the students to be evaluated. Case studies were specifically chosen which had shown initiatives in cold climate passive and sustainable design principles. As little or no post occupancy information was available for these buildings, the students were interested in finding out whether the applied principles were working as planned and whether or not the buildings were able to achieve a comfort level comparable to buildings which did not use passive heating and daylighting.

One building will be included within this paper: Greening on the Grand, the first C-2000 Office Building, in Waterloo, Ontario, designed by the architectural firm of Snider, Reichard and March. This case study was awarded an honorable mention in the Undergraduate category in the 1998 Vital Signs Student Case Study Competition.

Greening on the Grand: Canada's First C-2000 Office Building. Snider, Reichard and March Architects

Student Case Study Team: Kevin Leskiw, Laurie Evans MacLeod, Carla Weinberg, Angie Mendes and Costas Catsaros

This low rise office complex was designed to maximize daylighting and also uses various sustainable and low energy practices. The principal focus of this case study focuses on the effectiveness of the daylighting strategy. In order to maximize daylight, the building envelope is 30 percent glazed and has uniformly distributed windows on all orientations. A high performance selective spectrum low-e glass was used in lieu of solar shading devices. The students conducted an occupant survey to examine comfort levels for the various orientations and also looked at issues of glare that result from winter sun penetration at this latitude. They were fortunate to have the cooperation of Enermodal Engineering who is a tenant of Greening on the Grand and who was involved with the energy design of the building.

Green on the Grand is Canada's first C-2000 (Commercial-2000) Office Building. C-2000 is a program developed by the Natural Resources Canada (NRCAN) and follows in the footsteps of the R-2000 (Residential-2000) building program. C-2000 requires the use of energy efficient building systems during the design, construction, and operation of advanced commercial office buildings. Requirements also include an annual energy consumption that is less than 50 percent of that specified by the American Society of Heating Ventilating and Air Conditioning Engineers (ASHRAE) standard 90.1, a benchmark for energy performance of large buildings. It also requires a high level of performance in indoor air quality (IAQ), and lighting, while reducing environmental impacts and maximizing the ease of adaptation for future changes and ease of maintenance and operations.

Fig. 1. South face of building.

Green on the Grand conformed to these strict requirements, and wherever possible exceeded them. Building size, lot orientation and the use of passive solar heating and daylighting all played a role in determining the form of Green on the Grand. The two-story building has a floor area of 2,180 m^2 (23,456.8 sq. ft) and the architectural style was chosen to be compatible with the neighboring buildings. The building is oriented so as to maximize its exposure to the midday/afternoon sun while also providing views north and east to the Grand River. The building shape is two offset rectangles, which maximizes the building's surface area to the total window area. Overlapping areas are kept to a minimum and provide the stairwell, elevator and washroom facilities. In addition, a steep roof was chosen over a traditional flat roof to allow for dormer windows and to extend the life span of the roof. The positioning of outside reflective surfaces and the placement of ample south-facing windows will provide the maximum solar gain. Low reflecting objects, such as shrubs, below south-facing windows will diffuse the summer sun and well placed deciduous trees will block the summer sun and allow the winter sun to penetrate into the building. They will also act as a windbreak, substantially decreasing infiltration and minimizing conductive heat flow. Double stud wall sections and engineered wood products are used as opposed to the typical steel construction. More flexibility in layout and lower embodied energy are the result. It allowed the architect to explore large volumes while still being financially viable and within the energy constraints.

This study detailed how well Green on the Grand met its goals of passive and sustainable design. In addition to investigating the effectiveness of the Green on the Grand with respect to its passive design and sustainability design objectives, two hypotheses were established and were also investigated in the report.

Fig. 2. Detail of exterior of building

Hypothesis 1: An office building can achieve a significant energy reduction through the successful use of advanced envelope construction and mechanical systems without affecting the occupant attitude or changing the quality of the work environment.

The designers objectives were to achieve a building that minimized the embodied energy, was built with materials that contained no CFCs or HCFCs and would significantly reduce waste during construction. In addition, the designers hoped to achieve a 40% reduction in total energy and water required to operate the building, as compared to a traditional commercial building of similar size built to ASHRAE 90.1 standards. These aggressive design objectives were structured to reduce energy, without changing the occupant attitude. Occupant survey results, building methods, and mechanical systems are the main focus, however site planning, building massing, building plan, and building openings are considered in determining the success of these objectives.

Green on the Grand uses a structural support system of wood. This reduces the cost and minimizes the embodied energy of the building and allows for more insulation and less thermal bridging at floor intersections, as compared to steel-stud construction. To improve the durability of the structure and dimensional stability, engineered wood products such as laminated strand lumber (LSL) and laminated veneer lumber (LVL) were chosen. An exterior insulated finishing system (EIFS) adds to the thermal performance of the building. The wall cavities were filled with blown-in cellulose insulation made from 100% recycled newspapers, 216 mm (8.5 inches) for the first-story walls and 140 mm (5.5 inches) for the second-story walls. The exterior of the wall is covered with 50 mm (2.0 inches) of expanded polystyrene insulation (EXPS) that is coated with stucco to provide a finish. EIFS provides a layer of insulation over all studs and other thermal bridges. EIFS, however, are not durable systems. They are extremely susceptible to damage at ground level. This type of system is also very susceptible to moisture penetration. Once cracking has occurred on the outer stucco layer, water has a path to the interior cellulose insulation and oriented strand board (OSB). Maintenance of this wall type is very important. In addition the underside of the slab-on-grade first floor is insulated with 50 mm (2.0 inches) EXPS to reduce heat loss and improve thermal comfort. The basement walls are covered with a polyethylene sheet for waterproofing; this eliminates the use of tar, a source of soil contamination. 75 mm (3.0 inches) of rigid fiberglass is both a drainage layer and insulation.

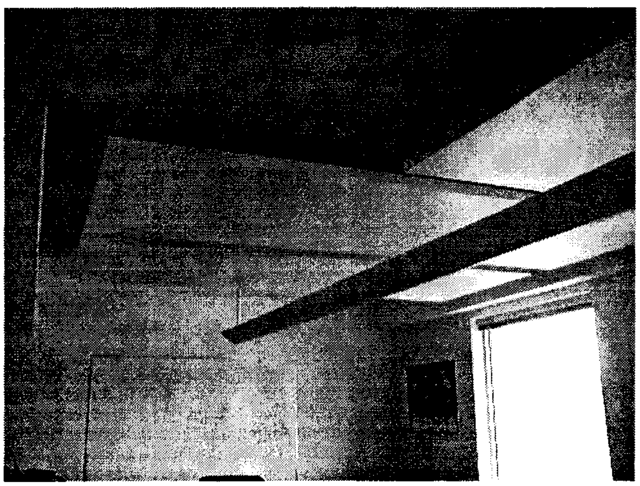

Fig. 3 View of ceiling showing radiant heating panels

The roof at Green on the Grand has sections that are steeply pitched and sections that are shallow in pitch. Steeply pitched sections are constructed from 450-mm (17.7 inch) wood I-joists, while premanufactured wood trusses support shallow pitched areas. The roof is finished with high-grade, fiberglass-reinforced shingles for a long life expectancy.

Green on the Grand offers all of its occupants 100 percent fresh outdoor air. The air is first heated or cooled and then vented through the building. The ventilation system is independent of the heating and cooling system. The main components of the ventilation system are two heat exchangers, two fans, and a heating/cooling coil. This unit provides a continuous flow of air at a comfortable temperature and humidity. The fresh air is circulated via a displacement system, reducing fan energy.

The Green on the Grand set a design objective for a reduction in water consumption of 30 percent as compared to a typical office building. This objective is obtained through the use of collected rainwater for landscape watering; the elimination of a cooling tower; and the use of low water-consumption bathroom fixtures and dishwashers.

The philosophy of the Green on the Grand design was to create a building as energy efficient as possible, and as environmentally friendly as possible. Natural gas is used as the fuel for the system and is therefore CFC/HCFC free. Space heating and cooling is provided through water-based radiators located in each tenant area. Radiant heating and cooling offers three main advantages over traditional forced-air heating: it uses less motor energy; water is a more efficient heat transfer medium than air; and, more even and comfortable warmth can be provided with more effective zonal control.

Green on the Grand uses natural evaporative cooling to cool the occupants. Any air conditioning system requires a method for rejecting heat to the outside. Normally, cooling towers are used for this purpose using large amounts of water and fan energy. The Green on the Grand building uses a manmade pond located in front of the building. The pond is approximately 20 meters x 10 meters (65.62 feet x 32.81 feet) and is an average of 0.9 m (3.0 feet) deep. When the chiller is operating, untreated pond water is filtered and circulated through the chiller condenser. The hot water is then ejected into the pond for evaporation and cooling.

Since actual operating costs were not obtained, results from an energy simulation were used to determine the effectiveness of the energy and water consumption targets. The simulation results were supplied by Enermodal Engineering. The total energy costs were estimated to be 42% of a typical new office building. This includes space heating and cooling, water heating, lighting and electrical demand, pumps, fans, and water and sewer costs.

From the data collected by the HOBOs, which were located throughout the study area it was found that indoor temperatures were within the comfort zone during office hours. Outdoor temperatures during this time were representative of a mild winter.

Hypothesis 2: A comfortable working atmosphere based on the maximization of natural daylighting can be achieved regardless of window positioning and distribution according to the cardinal axes, but not without the use of exterior shading devices. To test these hypotheses this investigation employed a case study approach. Both quantitative and qualitative methods of collecting data were used. These included: A daylighting survey of building occupants; The building's thermal performance and light conditions were recorded for a two week period in March (this was achieved by programming a set of temperature, relative humidity and light dataloggers (Hobos), which were located at various locations in the study area); interviews with the designers, architect and energy engineers, were conducted; photography and field notes; and the construction of a daylighting model for analysis of light penetration in different seasons, using a heliodon.

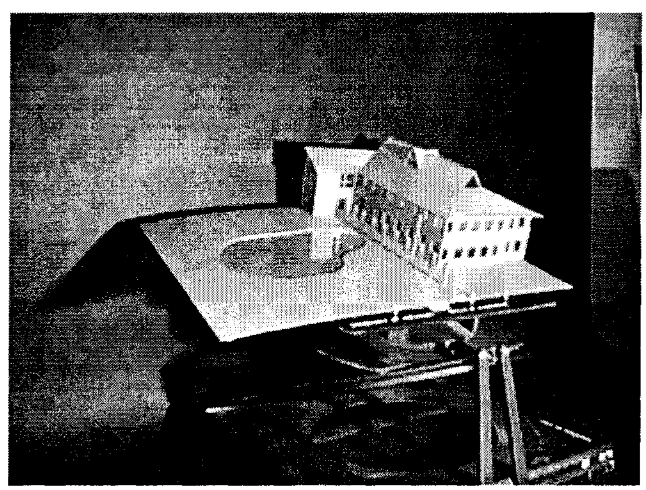

Fig. 4. View of model on heliodon.

The main features of the Green on the Grand windows are: low heat loss, high transmission of daylight, low solar heat gain, triple glazing (a feature now becoming common in Canadian construction) with two low-e coatings, argon gas in the two cavities between the panes, and silicone edge-spacers are used throughout. This produces a total U-value that is under 1.0 W/m2C. In addition, the outer pane of glass is spectrally-selective, maintaining a high visible light transmission (listed at 0.53) and significantly minimizes solar heat gain (solar heat gain coefficient, SHGC, of 0.28). Ultimately, the glazing luminous efficacy, or visible transmission-to-SHGC ratio, is 1.9—almost the highest attainable value. The window frames are constructed from pultruded fiberglass lineals and filled with polystyrene insulation. The frames, constructed of fiberglass, are environmentally advantageous since there is a low embodied energy, provide maximum insulating factors and their manufacture results in few noxious emissions. To touch briefly upon glazed areas such as entrances, they have been thermally broken with structural aluminum frames, providing maximum strength with a minimum of framing. The thermal break has a 50 mm thickness, ten times that found in conventional commercial aluminum windows.

Design intentions claim that, window sizing was decided upon by balancing between the need for light and the need to keep hot/cold air outside, as necessary. It is stated from design (Enermodal) computer simulations that a window-to-wall ratio of 30% was most optimum and regardless of siting and orientation, windows are distributed evenly on each side of the building to provide light to all perimeter rooms. An issue of contention does arise, in the fact that for reasons of energy efficiency, most windows are fixed. Indeed, only ten percent of the windows are operable and the justification for their existence is for the provision of air in the event of a power failure. Through the tenant survey, it was found that this was one of the drawbacks to the building, but in general, was found to be justifiable.

One of the design objectives stated that the Green on the Grand project wished to demonstrate that offices could be effectively lit while consuming only a fraction of normal electrical requirement. Daylighting, energy-efficient light fixtures, and task lighting were three methods used to meet this demand. Daylighting is the most efficient source of building lighting, but at the same time it proposes several design problems. Among them is the fact that with the number of windows necessary to accomplish a significant amount of daylighting, perimeter spaces may become overlit while conversely, spaces without windows are too dim and uncomfortable. A solution seems to have been arrived at with the placement of windows in relation to the office space. Windows are placed high on the wall, allowing natural light to penetrate deep into the office space. At the same time, two methods of interior shading are employed, dependent upon the tenant: translucent fabric roller-blinds that admit diffuse light and horizontal blinds that have upside-down slats (concave up), thus directing light up into the back of the room.

There are also several issues that must be discussed in relation to the whole decision of equal distribution of windows and the use of interior light shading rather than exterior solar shading. First, both the architect and the consulting engineers (Enermodal Engineering, the tenant) decided that the windows were of such high quality and allowed so little radiant heat transmission, that the necessity of exterior solar shading was deemed unnecessary. Enermodal specializes in window design but were surprised that computer test runs revealed the high quality of the window. There was also the economic fact that the combination of conventional window and exterior solar shading would have been more expensive than the windows that were used. The superior performance of the windows, according to the architect, seems to have also justified the equal distribution of the windows, even though it was admitted by the architect as well as observed that currently, there is a problem with excessive light penetration from the West facade. However, natural exterior shading will eventually come into being through the growth of a row of trees set in front of that facade and there is currently an open colonnade that provides very marginal shading to only the first floor. Ultimately, the even distribution allows for flexible design of the perimeter spaces and therefore, it becomes an issue of light control from within the building as opposed to exterior control.

Large dormer windows located on the steeply pitched roof allow a great amount of ambient light to enter into interior spaces. However, due to their positions on the roof, determined by the overall exterior appearance of the building, they create difficult spaces within because rooflines and walls must be greatly manipulated in order to allow the light to enter into the space. This is particularly apparent in the case of the Enermodal office. This is, however, just an example of how exterior design dictates over interior space, or rather, form following function.

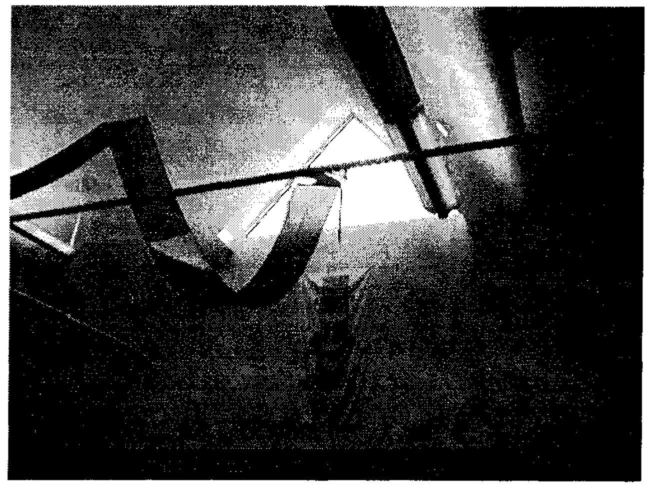

Fig. 5. View of dormer window.

In those areas that are artificially lit, energy efficient fixtures are used. Most fixtures have electronic dimmable ballasts and while providing the same level of light as a 40W fluorescent tube with magnetic ballast, they use 35 percent less electricity. A modulating dimming system controls electric light according to natural light intensity and motion sensors activate lights only when necessary. Task lighting is accomplished through the use of compact fluorescent and parabolically reflected halogen bulb, thus illuminating only small areas when necessary. Through all these modifications, a 70 percent savings has been calculated by the owners. The predicted annual utility cost derived from lighting was taken from $6534 Canadian for a typical new office to $1978 Canadian for the Green on the Grand. These savings will offset the initial increase in expenditure of the efficient fixtures over their life cycle.

At the beginning of this case study, the main points of initial question focused around the even distribution of windows, the lack of exterior solar shading and the inoperable nature of the majority of the windows. It is thought that the first of these questions was completely answered through the research and interviews conducted and even the second question was satisfactorily answered because solutions to the initial problem had already been considered. From survey results, it was noted that less than 20 percent of tenants found daylight to be the cause of significant glare. It is thought that this result could in large part be due to the still to be resolved west facade. In addition to the use of the survey, several HOBOs were placed in the study area. The light readings indicate a significant rise in ambient light during the sunny hours of a day. To further this study, a light model was constructed and placed on the heliodon. The model strongly illustrates the concentrated daylighting on the south facade during working hours.

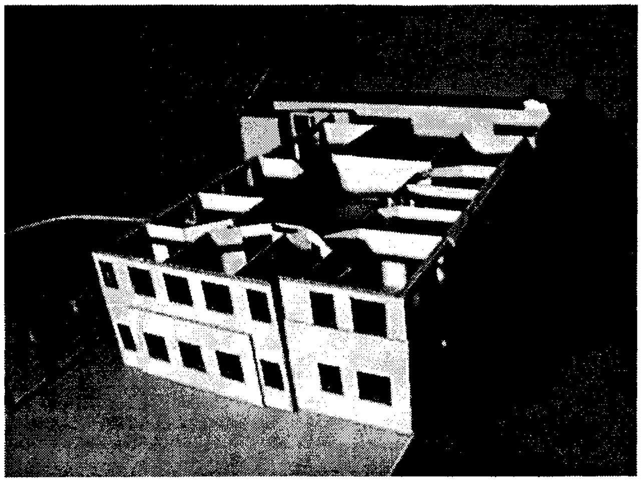

Fig. 6. View of model on heliodon with roof removed to show interior partitioning

The issue of operable windows still remains questionable. Ten percent is a low number, and though the C-2000 program bases its system around a sealed structure that is mechanically supplied with fresh air, it is still desirable for one to have the option of opening a window, if not for comfort, for safety. In the event of a power failure, it is not known whether one in ten operable windows will be sufficient for adequate air exchange. However; it must be stated that even though this was a concern for several tenants, there were other concerns that ranked higher in priority, such as noise propagation. Nonetheless, their overall attitude towards the building was very positive (80% satisfaction with overall lighting and just under 80 percent satisfaction with window size), possibly deeming this issue an acceptable drawback.

CONCLUSIONS OF THE STUDY

The results of the occupant survey indicated that 80 percent of occupants were satisfied with the lighting and less than 20 percent found a problem with glare in their work environment. Forty percent indicated that good ventilation was one of the most important features in a work place but only 50 percent were satisfied with the ventilation in this building. This was attributed to a lack of air conditioning in the summer.

Both the hydronic heating/cooling system and the low-velocity fresh air system proposed duct problems and created aesthetic issues. There is no ambient noise in the building, because both the hydronic and fresh air system are silent. Therefore there is a noise problem from the second floor to the first, even though there is acoustic tile, gypcrete, and flooring. Thirty percent of the tenants indicated a general dissatisfaction with the ventilation system and the ambient temperature. However, 25 percent were satisfied with the system. General comments from the occupant survey are that people would like more control over the temperature in their individual offices, and more operable windows but are happy with the lighting and ventilation through the winter months.

Hypothesis 1 - Conclusions

It was found that Green on the Grand generally succeeds in fulfilling its goal for a passive sustainable design without changing the occupant attitude. Green on the Grand uses a high level of engineering to achieve its goals and succeeds on almost every level. One area of difficulty is the summer cooling and seasonal transition periods. Thirty-three percent of the occupants indicated that they were dissatisfied with the temperature and ventilation, especially during the summer months. Occupants, however, did not indicate a problem with the winter months. This concurs with the HOBO results obtained, which did not leave the human comfort zone on mild winter days. It can be concluded that Green on the Grand met its goals, but did not provide adequate cooling for the summer months.

Hypothesis 2 - Conclusions

It is thought that the Green on the Grand does provide a suitable working environment, taking full advantage of natural daylighting through the use of equal window distribution, justified through superior window glazing construction and performance. Over 80 percent of the occupants were satisfied with the lighting in their work environment and over 75 percent were satisfied the size of windows used. Exterior shading was deemed unnecessary, although more attention to the problematic western facade could have been made.

Hypothesis 1 - Lessons Learned

The major lesson learned was that while technological advances can provide a cost savings in building operation they do not necessarily provide as great an improvement in occupant satisfaction. Although a building design may allow for a very high indoor air quality (IAQ) and ventilation rate it is apparent from the occupant survey that operable windows are desirable. This is human nature. In order to substantiate the findings from the occupant survey the results will need to be compared with other similar surveys conducted on typical office buildings. is that occupant comfort is of up most importance.

Hypothesis 2 - Lessons Learned

The major lesson learned is based around the creation of new supplements to current shading devices. This refers specifically to the invention of triple-glazed window systems, which offer excellent resistance to the transmission of radiant heat and still allow exceptional daylight transmission. Currently, it is thought that systems such as this still need to be used with more commonly used methods such as exterior solar shelves, in several situations. In this case, it would be in terms of the west facade. Perhaps in the future, such systems will become advanced enough to not need supplementation.

ASSESSING THE DATA COLLECTION DEVICES

Part of the purpose of this exercise was to assess the elements of the Vital Signs Toolkit in order to propose a University purchase and establishment of an Energy Lab. The items most in demand and which provided the majority of data in all case studies were the Hobo Dataloggers. The students were able to obtain accurate, relevant post occupancy performance information through the use of Hobo dataloggers that would not have been possible otherwise. The Hobos proved to be invaluable tools in providing data by which to test performance hypotheses. It was also helpful that the dataloggers could provide continuous output over a period of time (in this case one week). This allowed the students to place the equipment and return a week later to collect the data. Under normal teaching circumstances for a site visit observations would have typically been limited to a short period on a single day and the data limited to instantaneous readings from that particular period. With a larger quantity of equipment (or a smaller class size) readings could be taken for a much longer period of time which would provide a much more comprehensive analysis of the building performance.

The Green on the Grand group, with their specific emphasis on daylighting, also found the construction of a daylighting model with heliodon testing an invaluable means to extend the knowledge base beyond available term/class time and used this method to further investigate varying seasonal changes.

The course within which the case study was conducted introduces energy simulation software, such as Energy-10 and Solar 5.4, as an additional means to understand building performance and to compare design and post occupancy data. The Green on the Grand group was also able to access the energy software used by Enermodal Engineering in the detailed energy development of this building. This information is hot-linked to our web site.

Feedback from the students indicated that this type of hands on, interactive learning experience provided them with invaluable learning and was much preferred to the typical classroom format. All of the case studies are, and will continue to be, mounted at the Waterloo website as a means to further the Vital Signs Case Study Library, and to provide a more long lasting record for reference by future students and practitioners.

CREDITS

Much of the introductory information is excerpted from the Vital Signs Web Site. The key people involved at the Center for Environmental Design Research at the University of California at Berkeley with the development of the Vital Signs Project are: Cris Benton, Gail Brager, Bill Burke and Alison Kwok. More information, including the case study library, is available on the website at <http://www.berkeley.edu/cedr/vs/> or by contacting <vitalsigns@ced.berkeley.edu>.

Much of the material contained in this paper was generated through the research efforts of the Student Case Study Team of Kevin Leskiw, Laurie Evans MacLeod, Carla Weinberg, Angie Mendes and Costas Catsaros. The student case study projects are available for more complete viewing at the University of Waterloo Website located at <http://www.fes.uwaterloo.ca/Departments/Arch/>.