Integrated Process for Multi-Model Simulation

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Many high profile projects in recent years have illustrated the benefits of simulation technologies to aid in the design and conceptualization process for buildings. Structures, airflow, thermal aspects, and illumination can all be modeled and tested long before a building is ever constructed. The ability to simulate a single aspect may be appropriate for some projects, but to achieve an integrated building a comprehensive approach to building performance simulation is of critical importance.

Sensor information and data acquisition equipment are usually the tools utilized to investigate the performance of existing buildings. Computational models are also used to investigate the performance of buildings as well as proposed designs. In addition, computational models provide the means to allow the exploration of different alternatives and investigate the consequences of these solutions. Integrating both approaches has the potential to yield a better understanding of the building performance and provide a robust system to building retrofit design.

This paper illustrates a study that utilizes multi-models to investigate and retrofit the energy performance of an office building. Sensor data output that accounts for actual building performance was used in the computational models to increase their accuracy. In addition, this data was used as a base line to calibrate the computational models and ensure their accuracy. Once a computational model was constructed and calibrated to fit the current building performance, it is then used to investigate different alternatives of the building. Interdependency between different computational models was accounted for to provide comprehensive solutions.

METHOD

A number of computerized application tools have been developed to analyze energy conservation in existing buildings. These tools often simulate the energy performance of buildings using an embedded simulation engine as part of the overall analytical process. These tools thus require a quick, easy and robust method of obtaining a description of the building for these simulations that accurately reproduce metered building energy consumption. This has in the past been accomplished by developing a starting guess description and then manually refining it by adjusting the parameters that constitute the building simulation description until the simulated energy performance matches actual measured data. The tuning process is generally iterative, with individual building description parameters repeatedly selected and adjusted by a user-determined amount until the difference between simulated and measured performance is acceptably small (Carroll, 1989). The accuracy of this type of manual technique is dependent on the expertise of the user. Other methods automated this process by developing numerical methods to match the building simulation to measured utility data, (Carroll, 1993). These methods were developed for one simulation engine that have no interdependency with other models. As user interest becomes more comprehensive, different simulation models need to be evaluated. Due to the interdependency of some of these simulation models, accurate information of the building description needs to be used to provide a good measure of the building performance. This paper provides a description of a method that supplements sensor information about the building as input for the simulation to reach a quick match with actual building performance. A description of which the method uses is described through a case study.

Physical and computational modeling can inform each other and provide robust models for prediction. Actual building data can be extracted using sensors that can be used to inform several computational models. In addition, this information can be used to validate the computational models. Once a model is validated, it will produce a base representation of the actual building performance, which can be used to conduct several iterations of design alternatives, figure 1. Interdependency between some computational models is of critical importance. For example, lighting and thermal analysis are inter-related because of the solar aspect among other things. The output from one model can be the input to another. Our method utilized sensor data to cross check the information from one computational model before it was used in the other model, figure 2. In addition, the use of

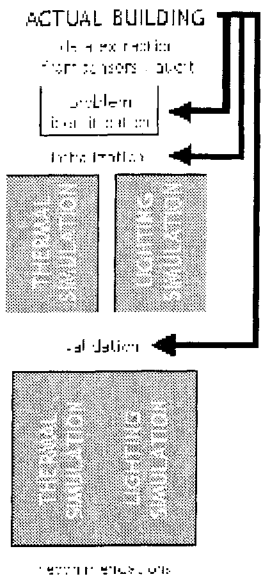

Figure 1 - Diagram of integrated process

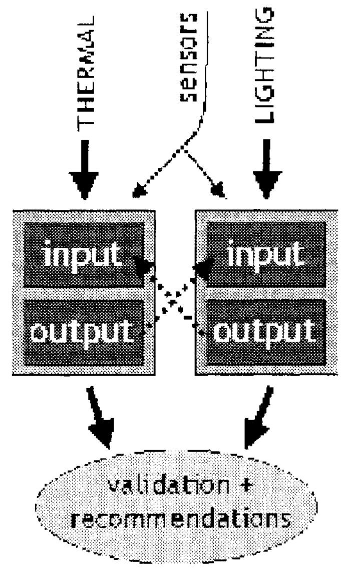

Figure 2 - Detail of data cross-over process

sensor data reduced or eliminated the dependency on default data which can produce larger errors in predictions (Shaviv, 1991); (Shaviv,1992).

Actual building data, construction documents, building usage and energy bills were used to analyze an office building. This analysis took the shape of analyzing sensor information that was placed in the building, constructing a computational model of the building and calibrating it using the actual building information. Suggestions for improvements were made through consultations and meetings with building representatives. Sensors for temperature, lighting and humidity were placed in key places throughout the building and site measurements for equipment, lighting and register air speed were made. Two simulation models were constructed to establish the base for the investigations. These models included thermal and lighting and were constructed to fit the present building through the input of the spatial, construction, equipment, lighting, occupants and mechanical system properties of the building. The models were checked against actual building performance (utility buildings and lighting levels). The thermal model used Power DOE and the lighting model used Lightscape. Based on the output of the computational models, data was analyzed to check the overall performance of the building and provide diagnosis to improve the efficiency of the building.

CASE STUDY PROFILE

The Sleeping Bear Dunes National Lakeshore Park headquarters building is located in northern Michigan in Empire, 25miles west of Traverse City. It is open seven days a week with the exception of federal holidays during the winter months. Summer hours are 9:00 a.m. - 6:00 p.m.; the remainder of year the building is open 9:00 a.m. - 4:00 p.m. It consists of an entry hall, exhibition area, auditorium, a conference room, individual office spaces, and two open office areas. The total floor area is about 11,500 sq.ft, see figure 3. The majority of the lighting system is fluorescent fixtures with three and four fluorescent tubes. The exception is the exhibition area, which includes 59 track light units (75-watt flood lamp). These track lighting fixtures are on whenever the building is open. The building is composed of eight thermal zones that are served by direct expansion units for heating and cooling. The heating is gas and the cooling is electrical provided by units located on the roof of the building.

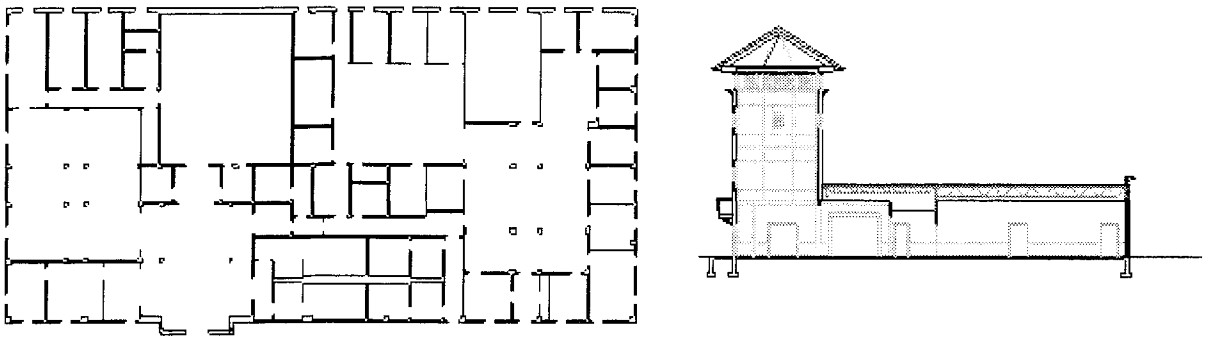

Figure 3 - Plan and section of the existing office building

MEASUREMENT

The data used to initiate the computer simulations was acquired in a number of ways from the existing building. This provided for the ability to create a validated base case condition for the simulations. Once these base case models were calibrated with the actual building, alternatives could be tested in order to provide tested recommendations. The calibration factor for the energy analysis was the consumption of gas and electricity, which was provided by gas and electricity utility bills.

Five sensors were placed in the building for a 3-week period to assess the internal conditions of the building. They were placed in key locations that represent different zonal conditions. These sensors are miniature, reusable data recorders for logging relative humidity, temperature, and light intensity. In addition to utilizing this data to calibrate the computational simulation model explained later, this data was used to make observations about temperature gradients between the zones. For example, 5-7 degrees were observed in relation to variation of temperatures within the spaces, see figure 4. Although the thermostat setting was similar, variation of about 5 degrees Fahrenheit was observed between the different locations where the internal office spaces shows temperature profiles larger than the other sensors. This variation indicated that the mechanical systems were not capable of maintaining constant temperatures within acceptable throttling range. During a site visit to the building additional data was acquired for energy and lighting. An equipment and lighting audit was conducted to estimate the equipment and lighting power usage. A power Harmonics Analyzer was used to determine the individual equipment wattage usage. A light meter was used to determine the lighting levels in the spaces.

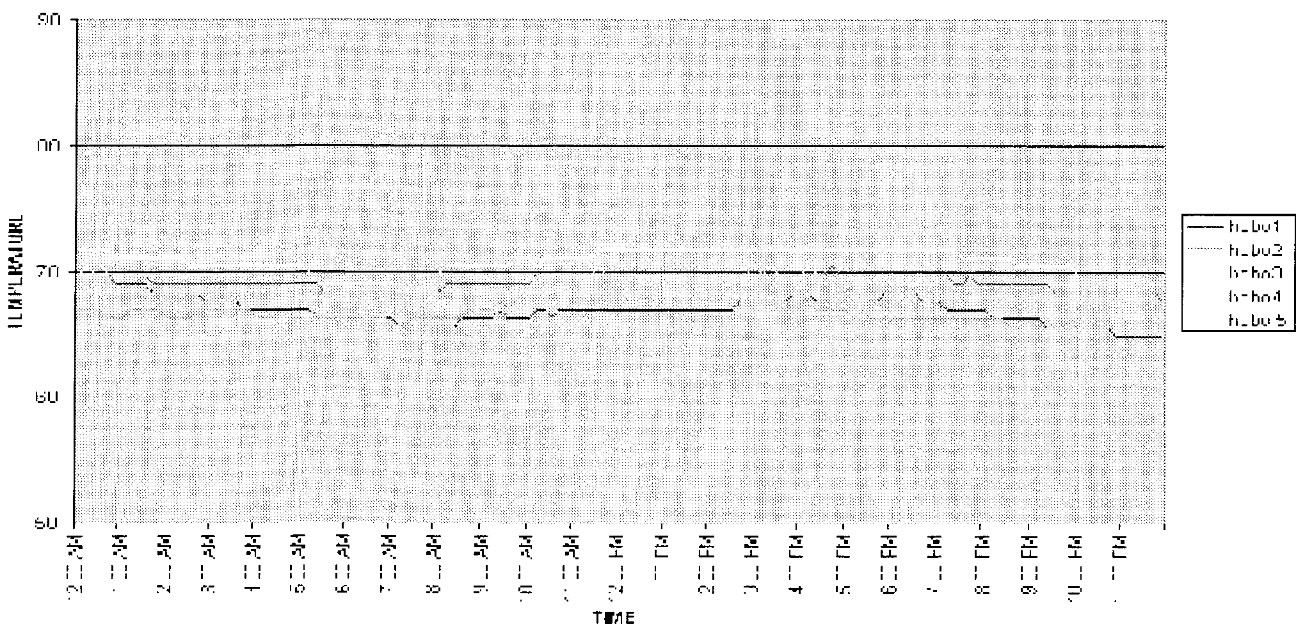

Figure 4 - Chart of 5 sensor readings for one day

THERMAL MODELING

A computational model was constructed to facilitate robust predictions to increase the energy efficiency of the building. This simulation allowed for the estimation of the energy consumption of the building, components, and its distribution. The model was constructed using Power DOE. Data from construction drawings, building audits and sensor information was used to construct the model.

To validate this model, actual building consumption output of both electric and gas were compared with the consumption predicted by the model. The model constructed showed remarkable fit between its prediction and the actual consumption of the building. Figure 5 shows the actual average consumption of the building and the predicted model. The figure shows similar yearly profiles with close range of variation with a 4% average error. Figure 6 shows yearly actual and predicted electrical consumption. Numbers also show agreement between the two. Figure 7 shows actual gas consumption with predicted consumption. Although the overall profile is similar, the simulated model provides gas consumption overproduction from October-December, which can be related to weather conditions and building operation. This overproduction does not affect the validity of the model knowing that the profile is similar and the model is used to account for energy distribution.

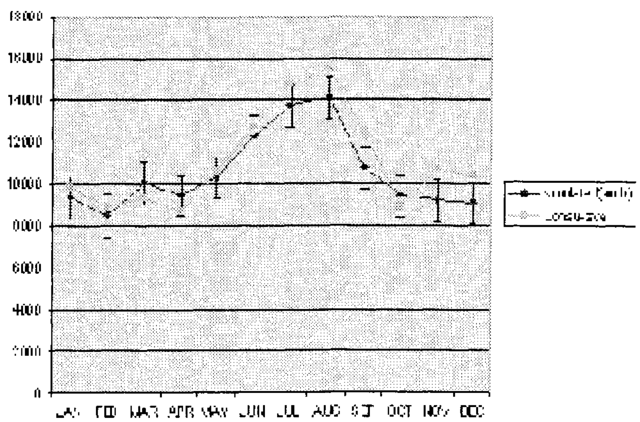

Figure 5 - Actual average consumption of the building and the predicted model

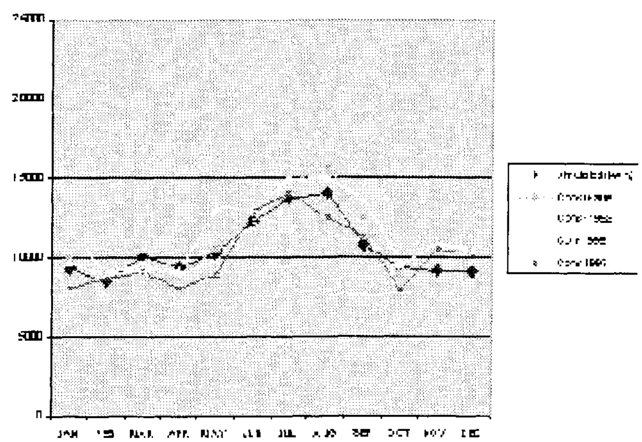

Figure 6 - Yearly actual and predicted electrical consumption

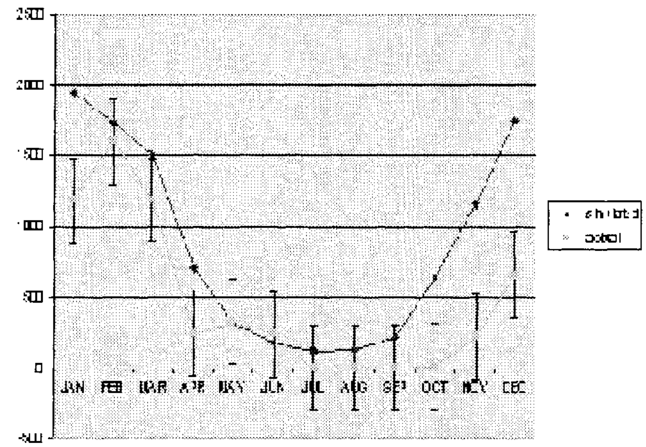

Figure 7 - Actual gas consumption against predicted simulation

LIGHTING ANALYSIS

A related investigation to the energy analysis was the lighting both natural day lighting and artificial lighting. To further test the analysis made regarding the energy, a computational lighting model was constructed. The model was constructed using Lightscape which uses radiosity to simulate how light energy is actually distributed in space, as reflected and absorbed by every surface. Many forms of data were collected for the lighting simulation that included data from construction drawings, light meter readings collected during the site visit, photographs from the actual building, and sensor data that recorded the schedule and lighting levels over the course of two weeks.

The light modeling of the building actually used many programs in its creation. Initially 2D drawings were constructed using Autocad that were based on the paper drawings provided by the Park Service. The 2D plans were then extruded and made 3D using a modeling program, in this case 3D Studio MAX. A computer model of the geometry was then exported to Lightscape, which on its own is not able to model geometry. Using the artificial lighting interface provided with Lightscape, the florescent fixtures could be placed in the building to create the base case conditions. Because of many uncontrollable factors such as maintenance and fixture "wear and tear" the calibration was actually done in reverse. Rather than specify the output of the lights, the model was modified until the computer output matched the actual light level readings from the site visit. The spaces that were modeled do not currently have any windows to the exterior, so once the artificial light levels were matched, the model was considered calibrated.

The light readings of the actual spaces were about 45 footcandles at the work surface height. This value is lower than would be necessary for reading small text with low contrast where 80 - 150 FC is suggested. The other problem as determined from the site inspection was the spaces appeared dark from a qualitative perspective, without a connection to the exterior. This observation led to the desire to use a natural

/ passive solar agenda in which the introduction of natural light would supplement the low light levels, provide additional heating in winter, and provide a connection to the external environment.

BUILDING CONSUMPTION AND ANALYSIS

In making the analysis, this study relies on several outcomes. The total building peak load components for both heating and cooling shows that the major elements that have the largest contribution are infiltration and skin conduction (wall and roof), figure 8. In addition, based on the simulation output and examination of the building performance, it is evident that the heating load is higher than the cooling load. Heating load accounts for 68% vs cooling load, which is 32%, figure 9. When examining the heating load components, infiltration and wall conduction are the major elements in heat loss. This suggests that the building is dominated by external loads rather than internal loads. Infiltration can be improved by increasing the tightness of the building. Wall improvement can also be achieved by increasing the R-value of the walls but can be difficult to achieve due to the cost involved with adding a layer of insulation. Windows utilize minor consumption due to their small area and good quality.

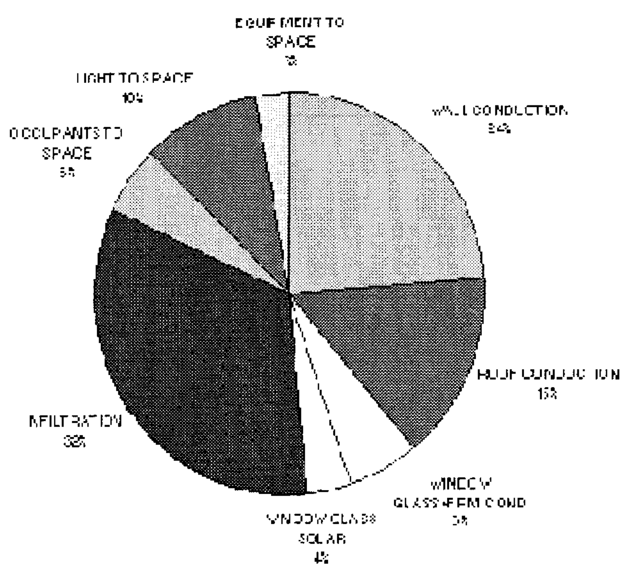

Figure 8 - Total building peak load components (kBtu/h)

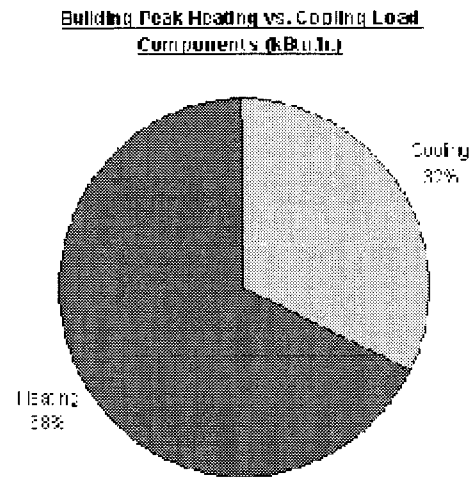

Figure 9 - Building peak heating vs. cooling load components (kBtu/h)

Shifting the attention to cooling, lights constitute the major components of the overall cooling (30%), while roof and wall conduction constitutes 27%. The building is one story where heat gain is conducted through the roof and the lights. Evaluating the external components of the building loads vs the internal components reveal that the building internal load accounts for 57% of the total loads. This internal cooling load shows that 53% is due to lighting. Different lighting strategies need to be recommended to overcome this problem. Lighting is also a concern by employees due to the fact that lighting levels are not sufficient.

To try to focus the diagnostics of the building thermal and lighting loads, individual building zones and spaces were evaluated by zone peak loads for both heating and cooling. The entrance zone and open office spaces zone showed the highest loads. In the entrance zone, lighting and roof conduction contribute the most to the heating and cooling loads. For the open office spaces zone, wall conduction is the most critical load for heating, and lighting, windows and roof for cooling.

RECOMMENDATIONS

Based on the sensor data, lighting, and energy simulation output highlighted in the previous sections, a number of recommendations were proposed which included lighting (artificial and natural), alterations to the building skin, and revisions to the mechanical systems and ducting. To focus this discussion, many of the recommendations have been omitted, including only the lighting recommendations.

In the current building, lighting affects both the qualities of the environment and the energy efficiency in that it represents the highest cooling loads. Although the lighting is not the greatest contributor to the overall cooling and heating loads, the lighting levels and quality in the main open office were

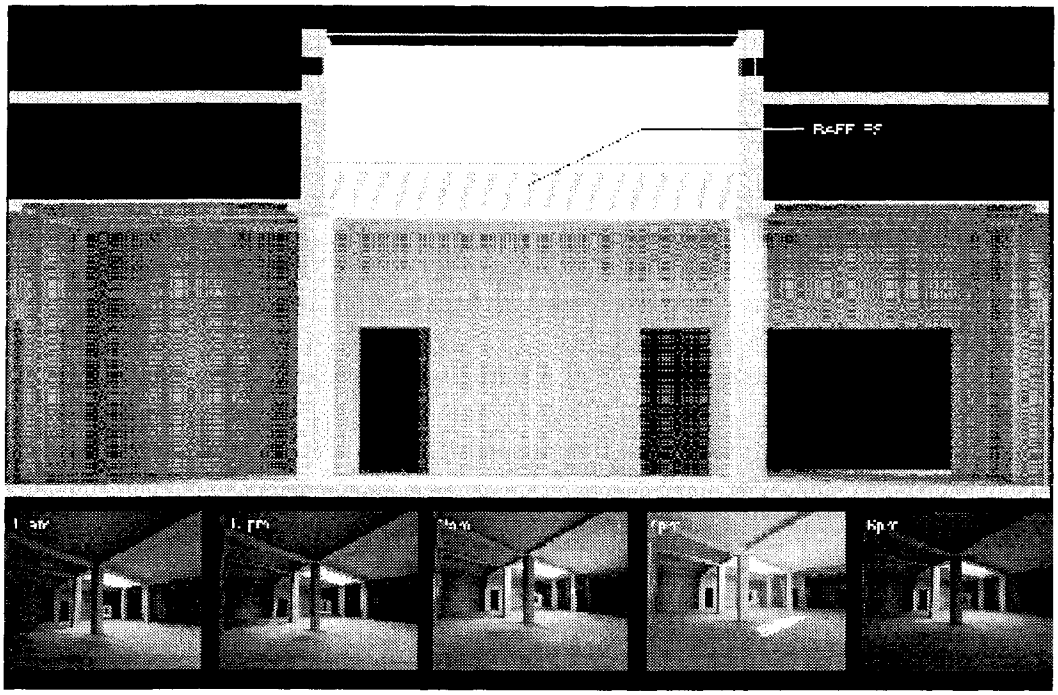

Figure 10 - Light studies for the proposed skylight

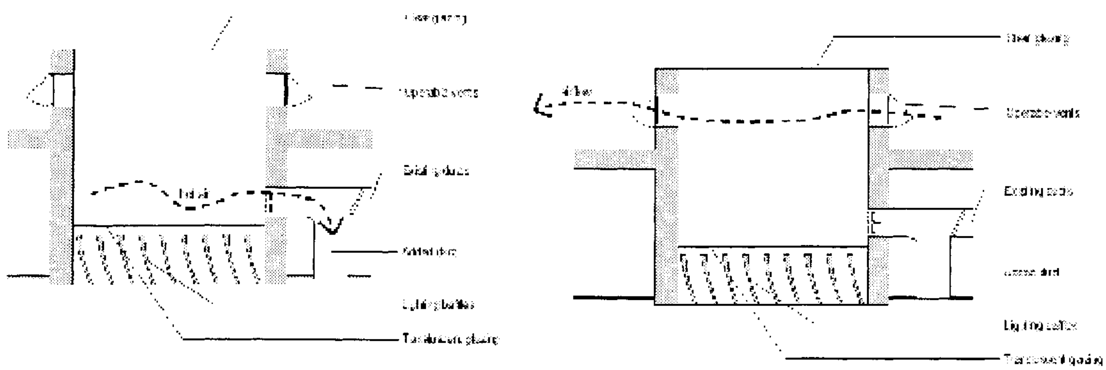

Figure 11 - Sections of skylight in winter (left) and summer (right)

investigated carefully because of the integrated nature of the problem. Our recommendation was to increase the lighting level by introducing natural lighting and reduce the demand on electric lighting. To do so, several alternatives were designed and evaluated using both lighting and thermal analysis. From the lighting perspective, the main areas of focus were the open offices because there is currently no access of natural daylight. The current level of lighting is an average of 45 footcandles. This value is low for the type of activities that occur in the spaces.

The main recommendation to increase the amount and quality of illumination for the open office spaces was the addition of skylights. The simulation tested a number of variations for the skylights and concluded with a 6' x 16' openings for each open office area that related to the proportion and scale of the spaces.

To avoid problems of overheating and glare from the skylights in summer, baffles were studies to reflect light into the space and prevent the sun from directly penetrating into the work areas. The baffle shape prevents high altitude sun from entering the space, figure 10. To reduce direct heat gains two layers of glazing were incorporated that could be vented in summer through natural ventilation. Conversely, in the winter the heat captured by the skylight could be used to heat the space below through the use of small, efficient fans, figure 11. The skylight would provide increased levels of illumination, connection to the exterior, and provide an additional source of heat during the winter months.

These changes will influence the demand on electrical lighting. For example, sensors can be used to operate the fixtures depending on daylight levels. This enhancement will reduce the load based on electric lighting considerably (from13.15kbtu/h to 6.69kbtu/h). In addition, changing the ballast to 0.8 will further enhance energy saving. Because the building is used only during the day, the skylighting can be used to induce solar radiation during the winter that heats the area. Small fans can be used to direct this heat toward the occupants. In the summer time, the sides of the skylights can be opened to draw the excess heat to the outside by wind movement.

CONCLUSIONS

The process of integration discussed in this paper indicates reasonable level of accuracy, robustness and efficiency. It is important to note that our intent was not to validate any simulation model but to calibrate or tune it for the investigation of design alternatives. Utilizing the method we outlined, once sensor information was added to the simulation model the output matched with the utility billing. This indicates that sensor data can be very useful in building computational models to provide close representation of the performance of existing buildings. Making retrofit decisions based on only sensor data is limiting. In addition using an iterative process, with individual building description parameters repeatedly selected and changed is time consuming and requires experts to perform. A calibration of more than one simulation model can also be very difficult to achieve. Even when using the sensor information as input for more than one inter-dependent simulation, the relationships between these different models needs to be carefully investigated to provide meaningful results. An interoperable building simulation representation can provide the ground for solving multi-simulation dependencies that is needed for the development of integrated building simulation systems.

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