DID PURSUING LEED MAKE THE CIRS BUILDING MORE ENERGY EFFICIENT?

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ABSTRACT

It has been found repeatedly that LEED-certified buildings are often not performing as predicted with respect to energy efficiency. The discrepancies between the energy consumption of the proposed design energy model and the occupied building can be either due to the building's actual usage being different from model assumptions, or design, construction and commissioning deficiencies. This question is being explored for the Centre for Interactive Research on Sustainability (CIRS) on the campus of the University of British Columbia, with respect to overall energy performance as well as the performance of sub-systems. CIRS is a LEED Platinum-certified building equipped with various energy efficiency measures, such as increased envelope R-values, ground-coupled heat pumps and high-performance lighting system. In order to assess the actual performance of the building, energy models of the as-built design and the matching baseline have been developed using the measured performance parameters of sub-systems and actual operation of the building. The results show that the overall saving in reality is similar to the one submitted and subsequently accepted for certification. However, the savings by end-use are different.

INTRODUCTION

There are various certification programs to promote more sustainable buildings. Leadership in Energy and Environmental Design (LEED) is a popular building rating system in North America. As part of the LEED Optimize Energy Performance credits, energy performance improvements relative to standard market practice are measured in the form of %-improvement over a fictitious building that is designed just to meet minimum code requirements (e.g. ASHRAE 90.1 or MNECB), referred to as the baseline. Numerous studies have found that the proposed energy consumption of LEED-certified buildings is often different from the utility data (Diamond et al., 2006; Turner and Frankel, 2008; Newsham et al., 2009).

Diamond et al. (2006) performed a meta-analysis of a sample of 21 first generation LEED-certified commercial buildings. They showed that on average projected energy consumption of these buildings is similar to the measured data. However, there is a significant variation around the average. Similar results were obtained by Turner and Frankel (2008) who studied 121 LEED-certified buildings.

Newsham et al. (2009) also studied energy modeling results and actual utility bills of a sample of LEED-certified buildings. They showed that the actual consumption does not have any correlation with the LEED certification level. However, on average LEED-certified buildings used less energy than conventional buildings. This finding was contested by Scofield (2009) who suggested a different definition of average energy use intensity (EUI) and including the source energy consumption to better reflect the collective greenhouse gas emissions of the sample.

The discrepancy between the building energy modeling predictions and the utility data is often referred to the energy *performance gap* or *credibility gap* (de Wilde, 2014; Menezes et al., 2012). The performance gap can be either due to design, construction or commissioning deficiencies of the building (Branco et al., 2004) or because of differences in operational parameters such as occupancy (Masoso and Grobler, 2010) or equipment left on over-night (Webber et al., 2006).

In order to assess the performance of a building after construction several measurement and verification protocols have been suggested in the literature. The International Performance Measurement and Verification Protocol (IPMVP) (EVO, 2012) suggests to first correct the design model with measured data of at least one year of operation. Then, the baseline model should also be updated to reflect the actual operation of the building. The difference between the predictions of these two models represents the actual saving of the building.

ASHRAE guideline 14 (ASHRAE, 2002) is the adoption of IPMVP for calculation of energy savings in retrofitting projects. Burman et al. (2014) also suggested to use IPMVP to evaluate the performance of the buildings under the Energy Performance of Buildings Directive (EPBD) of the European Parliament. According to the EPBD, the energy performance of building must be evaluated under a set of standard operating conditions. Burman et al. (2014) suggested calibrating the building energy model and then reverting certain model input parameters back to the EPBD standardized settings.

In this work, a methodology similar to the IPMVP is used to study the actual saving of a LEED Platinum-certified building relative to the baseline.

METHODOLOGY

The proposed plan in this work consists of the following steps:

1. Review the building energy models created for LEED Optimize Energy Performance credits. If

the mechanical systems are complex, there are often so-called *modeling workarounds* to overcome modeling software limitations. In order to verify the modeling approach and avoid software limitations, the building is re-modelled using a different software tool.

2. The operational parameters of the building such as temperature set-points, operating schedules, occupancy, infiltration and non-regulated loads are adjusted in the design model.
3. Other input parameters in the design model that are different due to design, construction, commissioning and equipment deficiencies are adjusted. The objective is for the final model to predict within acceptable error limits of (for this work) ASHRAE guideline 14. Following the recommendations of Raftery et al. (2011), modification history is tracked using a version control software, Git. The operational parameters are grouped together into different Git *branches*. Using this strategy, one can simply update the baseline model (represented by a git branch) by the *merge* process.
4. The baseline model is adjusted to represent the actual operation of the building.
5. Finally, the actual overall savings and savings by end-use are calculated.

The above steps are graphically shown in Figure 1.

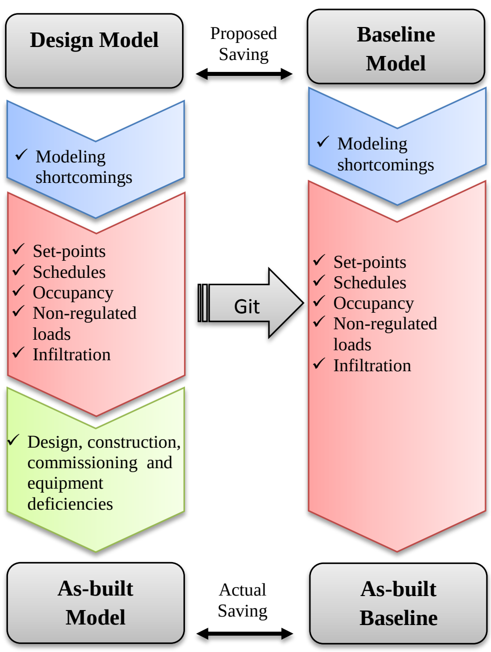

Figure 1: Proposed methodology for measurement and verification of LEED-certified buildings.

Case Study Building

The Center for Interactive Research on Sustainability (CIRS) is a multi-purpose university building with office spaces for faculty members, staff and students, classrooms, a 475-seat auditorium and a small Café. It also has a solar aquatic facility for rainwater reclamation and waste water treatment.

Figure 2: Front view of CIRS building (Image taken from www.cirs.ubc.ca with permission).

This building is LEED Platinum-certified and equipped with various energy efficiency measures. The building envelope R-value is significantly increased over the minimum code requirement and it has double and triple glazing windows. The building has a high efficiency lighting system with low light power density. The building has one air-handling unit for office spaces and one dedicated to the auditorium. The air-handling units are variable air volume with high-efficiency fans. The office spaces have under-floor air distribution system with additional heat supplied by perimeter radiators. The office spaces have narrow floor plans to facilitate cross flow natural ventilation when windows are open on both sides. In case more than 30% of the windows in an office wing are open, that wing goes into natural ventilation mode and the under-floor air distribution system shuts off. This results in increased pressure in the air-handling unit supply duct. The variable frequency drives of the supply fans have pressure set-points to reduce the fan speed when the demand for mechanical ventilation is reduced.

The atrium has hydronic radiant floor heating system with natural ventilation. The auditorium has a demand-controlled ventilation system with CO_2 sensors.

The heating system is all-electric. It has ground-coupled heat pumps with extensive heat recovery. Fume hoods from an adjacent building are the main source of wast heat recovery. The hot water loop is connected to the air-handling units' heating coils, perimeter radiators, radiant slabs and unit heaters. Unit heaters provide heating for stairs, washrooms, storage and mechanical rooms. The surplus heat is transferred to the adjacent building.

The ground-coupled heat pumps are also used for cooling. The chilled water loop is connected to the auditorium air-handling unit cooling coil and fan-coil units (FCU). The FCUs are used in the transformer rooms for air conditioning. There are three water-to-air heat pumps for cooling the main electrical room, server room and the café food preparation area.

The building uses arrays of solar cells to generate renewable electricity and also provide shading. There are also solar hot water panels on the roof for domestic hot water.

As part of the LEED Optimize Energy Performance (EAc1) credits, two energy models were made for this building: Baseline and Design models. The baseline follows the Model National Energy Code of Canada for Buildings (MNECB, 1997). The design model is based on the actual proposed design. The operational parameters of the building such as occupancy, plug loads, cooling loads, heating and cooling set-points and lighting schedules are kept consistent between the baseline and design models. Table 1 summarizes the input parameters used in these two models. As shown in this table, the building envelope is significantly improved over the baseline. Table 2 and 3 provide a brief over-view of the air-side and water-side mechanical systems.

Table 1: Summary of inputs for baseline and design energy models.

	Baseline Model	**Design Model**
R-values (Km^2/W)		
Walls above grade insulation	1.94	3.52
Walls below grade insulation	1.58	3.52
Roof Insulation	1.76	6.69
Occupancy		
Offices	20 m^2/person	
Auditorium	475 people	
Café	5 m^2/person	
Atrium	51 m^2/person	
Plug Load Power Density (W/m^2)		
Offices	7	
Auditorium	5	
Café	20	
Atrium	1	
Cooling Process Loads (kW)		
Main Electrical Room	19	
Transformer Rooms	1	
Data / Security Room	11	
Lighting Power Density (W/m^2)		
Offices	19.4	6.9
Auditorium	17.1	11.2
Café	14.0	8.1
Atrium	7.5	8.8
Storage	7.5	2.0

Table 2: Air-side mechanical systems

Baseline Model	**Design Model**
AHU-1	
Multi-zone VAV Heating $T_{SA} = 43°C$ No cooling $\eta_{Supply\ Fan} = 55\%$ $\eta_{Return\ Fan} = 30\%$	VAV with under-floor air distribution and perimeter radiators Heating $T_{SA} = 19°C$ No cooling $\eta_{Supply\ Fan} = 63\%$ $\eta_{Return\ Fan} = 63\%$
Zones Assigned:	
Serving: Offices, Café and Atrium	Serving: Offices and Café. Atrium has radiant heating with natural ventilation
AHU-2	
Constant Air Volume with 31.5 CFM/person outside air Heating $T_{SA} = 24°C$ Cooling $T_{SA} = 13°C$ $\eta_{Supply\ Fan} = 50\%$ $\eta_{Return\ Fan} = 25\%$	Variable Air Volume with demand controlled ventilation with CO_2 sensors Heating $T_{SA} = 26°C$ Cooling $T_{SA} = 18°C$ $\eta_{Supply\ Fan} = 63\%$ $\eta_{Return\ Fan} = 63\%$
Zones Assigned:	
Auditorium	Auditorium

Table 3: Water-side mechanical systems

Baseline Model	**Design Model**
Heating:	
Autosized Electric Boiler η = 100% HW Loop ΔT = 16°C Constant Speed Pumps	Ground-coupled heat pumps with extensive fume hoods and exhaust heat recovery COP = 3.58 HW Loop ΔT = 11°C Variable Speed Pumps
Cooling:	
Reciprocating chiller with cooling tower COP = 3.8 CHW Loop ΔT = 6°C Constant Speed Pumps	Ground-coupled heat pumps and fume hoods exhaust for heat rejection COP = 4.14 CHW Loop ΔT = 6°C Variable Speed Pumps
Domestic Hot Water:	
Electric boiler	From HW loop with solar hot water preheating
Process Flow Rate:	
5.7 liter/min	1.9 liter/min

The above inputs were used in the DOE 2.2 simulation engine by a consulting company to calculate the annual energy consumption of the baseline and design buildings. The RETScreen software package was used

to estimate the energy savings of Photovoltaics and Solar Water Heating (SWH) system. The results for annual energy production of the PVs and SWH were 4 kWh/m^2 and 3 kWh/m^2 respectively.
Table 4 compares the energy consumption by end-use of the design and baseline models. The results are also depicted in Figure 3. The total non-regulated energy savings of this building over the baseline is 68%. LEED credit system for optimize energy performance is based on the total non-regulated cost savings. Since the electricity cost for this building is constant at \$0.0429/kWh; the annual energy cost savings over the baseline is also 68%.

Table 4: Annual energy consumption by end-use results for LEED optimized energy performance credits.

	Baseline Model	**Design Model**
	(kWh/m^2/year)	
Space Cooling	9	7
Space Heating	92	14
Domestic Hot Water	9	3
Fans	17	7
Pumps	15	16
Lighting	37	16
Equipment	16	16
Photovoltaics	0	-4
Solar Hot Water	0	-3
Total	195	73
Total non-regulated	179	56
Non-regulated Savings	68%	

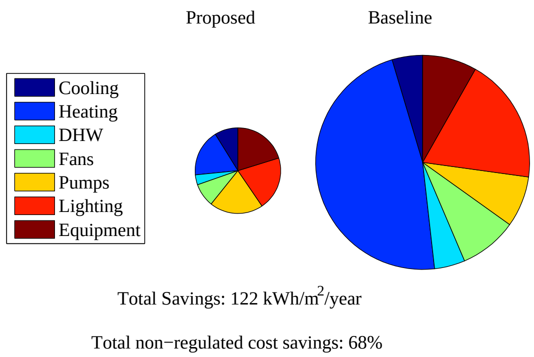

Figure 3: Details of annual energy consumption by end-use for LEED optimize energy performance credits.

The main projected energy savings in this building were in space heating and lighting end-use. The energy savings in the lighting system were due to having a more energy efficient lighting system and utilizing more daylighting. The savings in space heating are in part due to having ground-coupled heat pumps with extensive exhaust air heat recovery. This resulted in a penalty in increased pumping energy. Other factors in reducing the space heating energy are more insulation in envelope and demand-controlled ventilation in auditorium.

Modeling/Software Shortcomings

As described in the above sections, this building has a relatively complex HVAC system. In order to verify the LEED energy modeling results and avoid software limitations in modeling the HVAC system, a different software modeling tool is used. IES-Virtual Environment (2012) (IES-VE) was chosen due to a relatively greater flexibility in constructing and customizing the mechanical systems. Building as-built drawings, mechanical system documentations and the two DOE 2.2 models were used to extract necessary information for reproducing the baseline and design models in IES-VE. The results are shown in Figure 4 and 5.

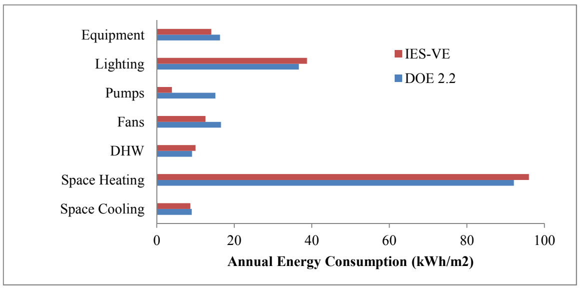

Figure 4: Comparison between DOE 2.2 and IES-VE in modeling the baseline building.

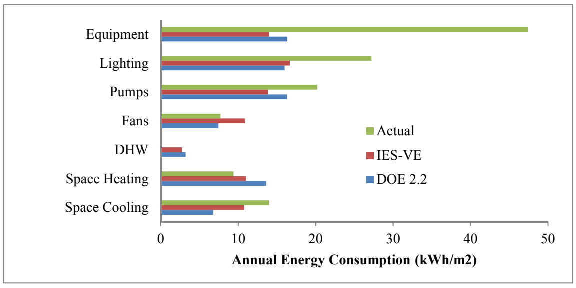

Figure 5: Comparison between DOE 2.2 and IES-VE in modeling the designed building.

The discrepancies between the two modeling results were investigated and the root-causes were mostly identified. The findings are summarized here:

- The fan-coil units were set to run continuously in the DOE 2.2 models. In the IES-VE model and the actual sequence of operations, it only turns on if there is a cooling demand. This resulted in a slightly higher fan energy consumption in the DOE 2.2 model compared to the IES-VE model. However, the fan energy end-use is dominated by air-handling units. It was also revealed that the total supply flow rate in one of the air-handling units was erroneously set to a low number in the DOE 2.2 model. This resulted in over-all lower fan energy prediction by the DOE 2.2 model.

- The outside air volume flow rates were not consistent between the DOE 2.2 baseline and design models at peak occupancy hours.
- IES-VE has a simplified model of pumps using specific pump power (W/(l/s)). This parameter was calculated using DOE 2.2 detailed simulation results for different water loops in an attempt to keep consistency between the two simulation tools. Nevertheless, the pump power predictions in IES-VE were lower.
- The minor discrepancies in equipment and lighting were in part due to the zoning being different between the two models. For example, in the DOE 2.2 models the small electrical rooms and stairs are grouped together.

The above corrections were made to the DOE 2.2 models and the simulations were repeated. As a result, the annual cost savings reduced from 68% to 63%. The detailed results are shown in Figure 6. This corrected model will be the reference for discussion and conclusion section.

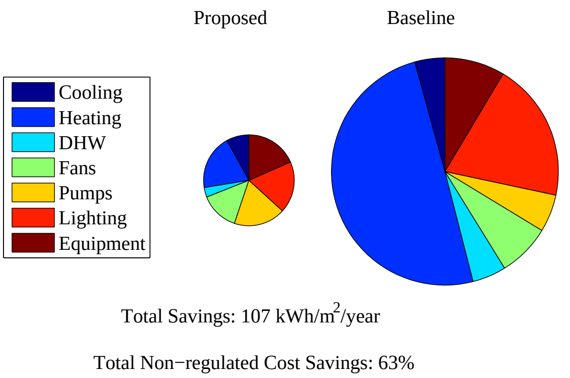

Figure 6: Annual energy consumption results by end-use after corrections.

As-Built Models

The actual annual electricity consumption of the building from April 2012 to March 2013 was 126 kWh/m^2/year. This value was higher than the design model prediction of 80 kWh/m^2. Therefore, there is a significant performance gap in this building. In a recent study by Salehi et al. (2015), IES-VE design and as-built models were used to find the performance gap sources in this building. This building is heavily instrumented, so most of the modeling input parameters could be measured. Table 5 and Figures 7 –10 summarize the changes between the design model and the as-built model. This process resulted in the following outcomes:

- For this particular simulation and measured data, using actual weather data, measured on the neighbouring site, compared to TMY did not significantly change the results.
- A significant fraction of the performance gap was due to the water treatment facility process load which was not included in the design model.
- Almost 40% of the performance gap was due to operational mismatch between the design model and actual plug load and lighting load. For example, the lighting in the common areas were always on whereas the design model presumed the lighting there would be largely switched off at night.
- The electricity transformers were not as efficient as expected resulting in energy loss and extra cooling load.
- The space heating energy was over-predicted by the design model. This was mainly due to assuming a significant outdoor air infiltration rate during winter months. The major source of outdoor air infiltration in this building was operable windows in office areas. As shown in Figure 10, this value was high in summer months and significantly low in the winter.

A similar adjustment process was repeated for the DOE 2.2 design model in this work. Using the measured input parameters of Table 5 and schedules (Figures 7–10) resulted in having an as-built model. As shown in an earlier study (Salehi et al., 2015), in this particular case using the actual, measured weather in the simulations did not have a significant effect; hence, the TMY weather data was used for obtaining the DOE 2.2 design model.

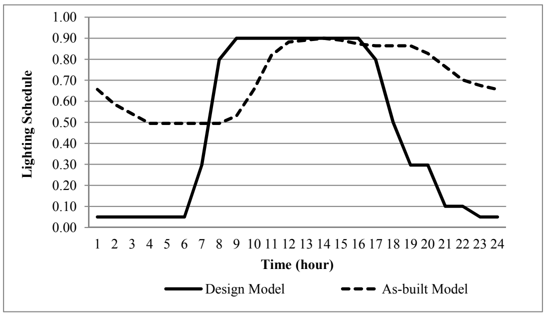

Figure 7: Weekdays lighting schedule for office and common areas.

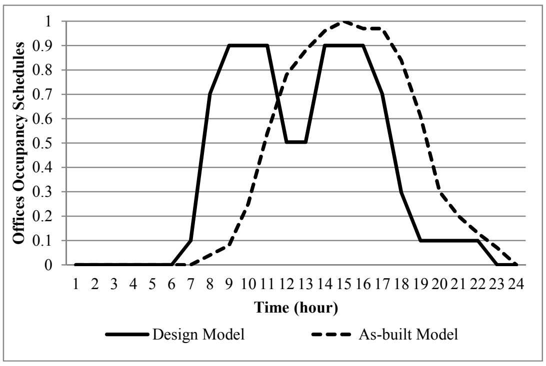

Figure 8: Occupancy profile for office spaces.

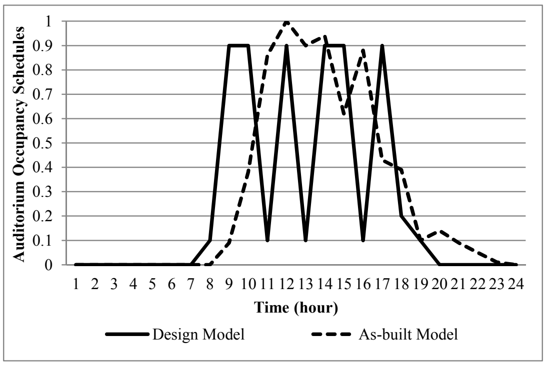

Figure 9: Occupancy profile for auditorium.

Table 5: Summary of differences between the design model and the as-built model.

Attribute	Design Model	As-Built Model
R-values (K m^2 / W)		
Walls above grade insulation	3.52	3.17
Walls below grade insulation	3.52	2.99
Office Window Frames	0.41	0.12
Occupancy		
Offices (m^2/person)	20	61*
Auditorium (People)	475	97
Café (m^2/person)	5	61*
Atrium (m^2/person)	51	61*
Plug Load Power Density (W/m^2)		
Offices	7	2
Auditorium	5	0
Cafe	20	67
Atrium	1	2
Cooling Process Loads (kW)		
Main Electrical Room	19	6
Transformer Rooms	1	8
Data / Security Room	11	1
Mechanical Systems		
HP Heating COP	3.58	4.77
HP Cooling COP	4.14	2.78
HW Loop ΔT	11°C	6°C
Electrical Rooms Cooling Set-point	30°C	25°C

* Offices, Café and Atrium occupancy are grouped together.

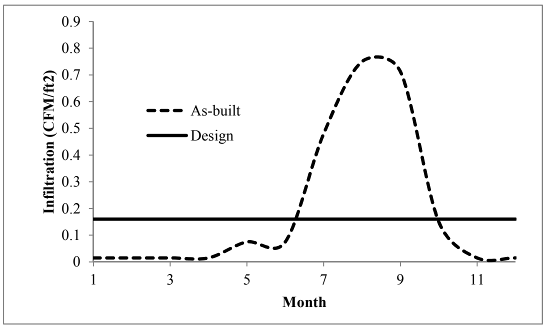

Figure 10: Monthly window infiltration rate of office spaces.

The prediction of the final as-built energy model is compared to the actual consumption by end-use in Table 6. The mean biased error (MBE) is -2% and the monthly coefficient of variation of the root mean square error ($CVRMSE_{monthly}$) is reduced to 5%; well within the acceptable limits of ASHRAE guideline 14 (ASHRAE, 2002). The change history is tracked using Git version control software.

Table 6: Comparison between the final as-built design model and measured data from April 2012 to March 2013

	As-built Design (kWh/m^2/year)	Actual
Space Cooling	9	14
Space Heating	9	9
Domestic Hot Water	3	N/A
Fans	10	8
Pumps	20	20
Lighting	29	27
Equipment	48	47
Photovoltaics[1]	-3	-3
Solar Hot Water[1]	-3	-3
Total	122	120

[1] The Photovoltaics were not properly installed in the studied time frame. A subsequent year data was used.

[2] There was not enough measurement points to accurately calculate the solar hot water production. Hence, the reported energy production is the same as the estimation for LEED.

The DOE 2.2 baseline energy model is also adjusted. This is done by using the actual plug load, equipment load, infiltration rate and occupancy in the baseline. For lighting, only the schedules are changed in the baseline model. Using the methodology proposed above, such changes can be easily obtained by the git merge process as shown in Figure 11. In this figure each branch is represented with a green box and the changes (git *commits*) are shown with bullet points. This figure also shows all the git merge processes. For example, the equipment load in the baseline model can be updated to the actual consumption by *merging* the "Equipment" branch into the "Baseline_Model" branch as shown in Figure 11.

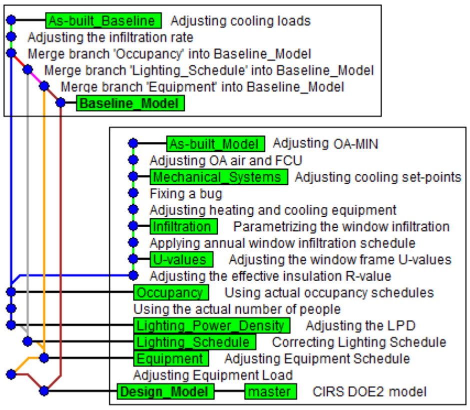

Figure 11: Using Git version control system. A green box represents a "branch" and a blue bullet point represents a git "commit".

RESULTS AND DISCUSSION

Figure 12 shows the energy consumption of the as-built baseline and design models by end-use. The total energy and cost savings include the energy production by renewable sources. The Photovoltaics were not properly installed in the studied time frame. A different year was used and the actual measured production was used to calculate total savings. Since there were not enough measurement points to calculate the annual energy production of the solar hot water system, the estimation in the previous section (3 kWh/m^2/year) was used.

Comparison between Figure 12 and Figure 6 shows that lighting and equipment load has increased in the as-built models. However, the space heating energy is significantly reduced. All in all, the total energy saving slightly increased from 107 to 109 kWh/m^2/year. However, the total non-regulated energy consumption and energy cost savings reduced from 63% to 59%. This reduction is due to increased baseline energy consumption.

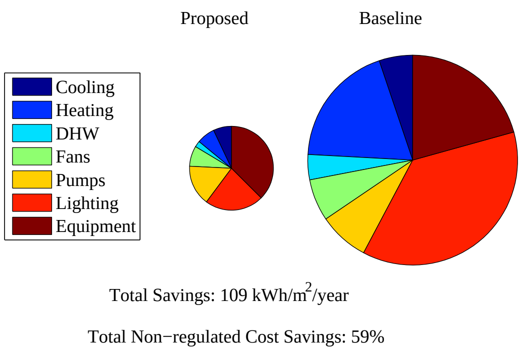

Figure 12: Final as-built models prediction of annual energy consumption by end-use.

Figure 13 shows the breakdown of the actual energy savings in this building compared to the proposed savings. This figure shows that the actual saving in space heating is significantly less than expected. This is due to over-prediction of space heating using a relatively high value for infiltration rate. On the other hand, the savings in the lighting electricity is substantially higher than the proposed values. This is the result of increased hours of consumption, especially in common areas.

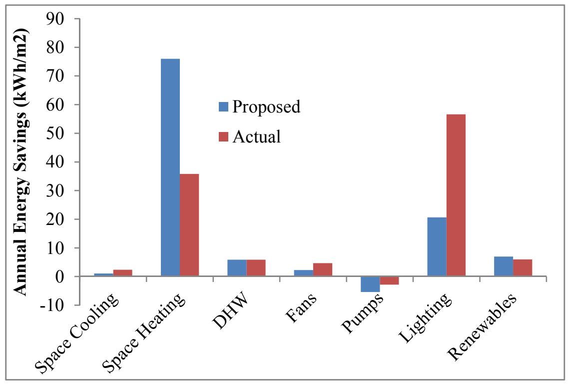

Figure 13: The actual annual energy savings by end-use compared to the proposed savings for LEED submission.

CONCLUSION

In this work, it was evaluated how the CIRS building performs relative to the LEED metrics, considering what was actually built and how it is actually operated. An energy model of the actual building design was built using the detailed measured data that is available for the building. The operational parameters such as plug load, infiltration rate and lighting schedules were also changed in the baseline model. The results show that, while energy savings under actual operation are similar to the projected savings, the nature of energy saving by end-use is different: while the main energy savings in the proposed design were from space heating, in reality substantially greater savings are realized through efficient lighting. However, the baseline building energy usage distribution did accurately identify the major energy consumers and direct the design team toward energy efficiency measures in the appropriate areas.

Ultimately, the most important result here is that, at least for the CIRS building, while the utility data suggest a substantially higher rate of energy consumption than was calculated by the design models built for LEED compliance, this energy "performance gap" is actually stemming more from an inappropriate comparison. A LEED design model is not intended to "predict" the overall energy performance of the building; the process is more intended to try to predict the relative energy savings that could result by including energy efficiency measures beyond what is required by local building codes. In this respect, this research suggests that the LEED process actually did a rather good job, given the limitations it was obviously subject to (not knowing future weather or occupancy, for example). Altogether, this suggests that pursuing LEED certification indeed *did* make the CIRS building more energy efficient.

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