Comparing Design and As-Built Simulations with Actual Measurements for a Large, Multi-Use University Building

Belgin Terim Cavka[1], M. Mahdi Salehi[1], Andrea Frisque[2], and Kendal Bushe[1]
[1]Mechanical Engineering Department, University of British Columbia, Vancouver, Canada
[2]Krieger SRM, Vancouver, Canada

Abstract

The Centre for Interactive Research on Sustainability (CIRS) at the University of British Columbia was designed with the intention of being a "Living Lab". The building is equipped with an Energy Monitoring System (EMS) and a Building Automation System (BAS). Data collection from over 3000 monitoring points (lighting, CO2, VOC, temperature, energy meters, many details of HVAC operations, window status sensors, solar PVs and transmitters, etc.) has been available since the building was fully occupied in 2012. The considerable volume of available data can be (and is being) directly used to optimize performance of the building's systems, and it is also used for validation and improvement of building simulations.

In this paper, we will describe some of the challenges we have had in processing the sheer volume of data, as well as challenges we have had with un-calibrated – or even incorrectly installed – sensors, some of which have come to light in part through our combined use of simulation and measurement in this project. After verification of the measured data, it is compared to data from whole building energy simulations from the design stage. A "performance gap" between simulation predictions and measured performance, which is frequently described in literature recently, is found the case of in CIRS as well. The reasons for this "performance gap" are investigated in this paper in some details.

1 Introduction

Overall energy consumption, largely dependent on non-renewable energy sources, became threatening for the environment in the last few decades, thus global focus on reduction of non-renewable energy consumption increased (Juan et al. 2010). Approximately 40% of world energy consumption is in buildings of varying types, such as residential, commercial, and public use (IEA 2010). Almost 80% of the building energy is due to the operational energy of the building over its lifespan (UNEP 2009). Thus, building services such as space heating, cooling and air handling, water heating, lighting, and utilities become important for reducing the environmental impact of the built environment (IEA 2010).

The necessity to reduce fossil fuel consumption and CO2 resulted in the voluntary certification programs such as LEED, and Living Building Challenge, and more stringent building regulations. While these rating systems cover a much wider range of building sustainability than building energy only, building energy is among the most significant. This is for example acknowledged in the large fraction of points in the LEED certification system that is allotted to operational building energy efficiency. Building certification systems have been an effective method to shift the construction market focus toward sustainability and "green buildings"; however, it does not necessarily result in rated buildings performing better or having reduced lifecycle environmental impact (WBCSD2009, Newsham et al. 2009, Fedoruk 2013).

During the design, predictions of the expected annual energy consumption of the building are calculated using whole building energy simulations; these simulations are used to develop designs with low expected energy consumptions. Unfortunately frequently these predictions are not met by the real building (Scofield, J.H., 2013; Newsham et al., 2009; Perez-Lombart et al., 2008; Turner C. and M. Frankel, 2008; Turner C., 2006; Torcellini et al., 2004). This discrepancy is commonly referred as the "performance gap".

In this paper the predicted performance and real measured performance of the Centre for Interactive Research on Sustainability (CIRS) building at the University of British Columbia is studied. CIRS is a sustainable building certified with LEED Platinum and a candidate for Living Building Challenge (LBC) certification (CIRS Building Manual, 2011, 2013).

2 Building

CIRS is a university building with administrative offices, study laboratories, meeting rooms, an auditorium, and a café. There is also a full tertiary water treatment plant in the building, which is consuming electricity. The building has a green roof, and a green wall façade. The building owner representative's overall goals for CIRS are to be a net-positive energy producer and a net-zero carbon building. It is designed with the intention of being a "Living Lab" (Robinson et al., 2013), with ongoing performance monitoring and activities to further improve performance. The building is equipped with an Energy Monitoring System (EMS) and a Building Management System (BMS). Data collection from over 3000 monitoring points (occupancy sensors, CO2, VOC, temperature of rooms, energy meters, many details of HVAC operations such as pump and fan temperature and flow details, window status sensors, solar PVs and transmitters, water reclamation and irrigation system details) has been available since the building has been fully occupied and operating in 2012.

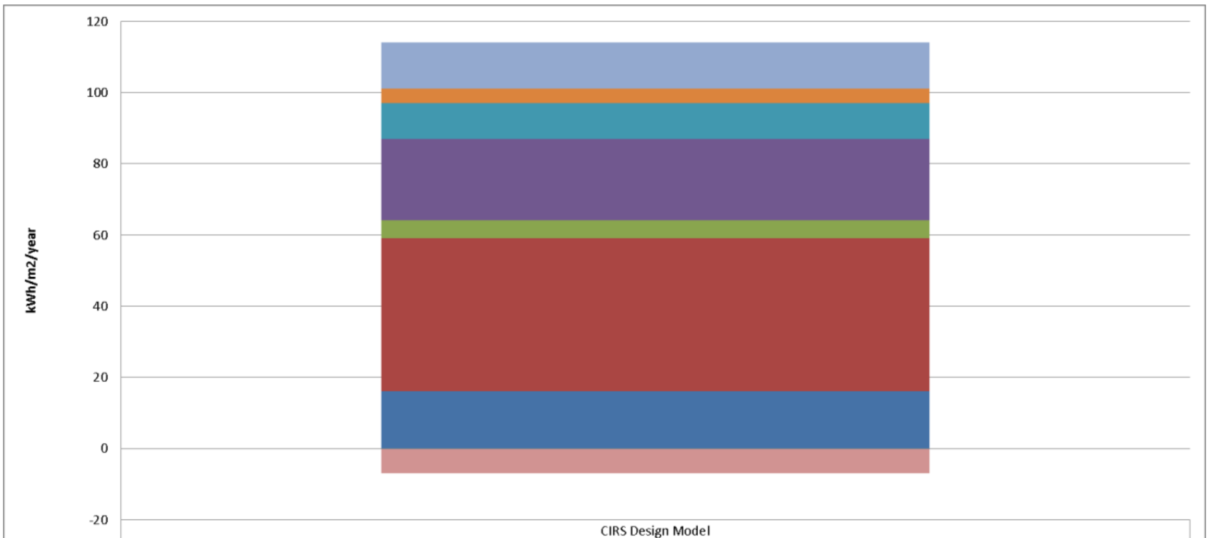
CIRS Building Energy Systems

The CIRS energy concept combines multiple energy systems: A heat reclaim system that captures waste heat from the exhaust ventilation from the adjacent EOS building and transfers it to the heat pumps in CIRS. Heat pumps provide heating for the building and cooling mostly to auditorium as well as to server and electrical rooms. The energy exchange system rejects excess heat from the CIRS heat pumps to the EOS building. A ground source geo-exchange field supplements the waste heat recovery and provides warm and cold water to the heat pumps. An evacuated tube array on the roof that captures solar energy and an internal heat recovery system that captures waste heat from the building systems pre-heat the domestic hot water in the building. Photovoltaic cells on the atrium roof and the window sunshades on the south and west facades convert solar energy into electricity (CIRS Building Manual, 2011). Offices have underfloor air distribution and perimeter heating. The auditorium and café have displacement ventilation. The atrium is naturally ventilated with radiant heating. There are some unit heaters and unit elevators in the basement, Water-to-air heat pumps in electrical, data and security rooms, and some distributed fan coil units for cooling of electrical and data rooms. Ventilation to the office spaces and atrium can also be provided through natural ventilation, with operable, user-controlled windows in the office spaces and openings at the top of the central atrium for air exhaust. Ventilation is demand controlled through CO2 sensors. There is heat recovery from exhaust from offices, washrooms, lecture hall, offices, data and main electrical room heat pump units feeding into the service hot water loop.

3 Energy Consumption Predictions in Design Model

The design energy model presented here is the original design energy model used by the consultant on the design team. The results presented in this section are from the “post-tender energy study”, which is the most detailed model available. This model was developed when the design details had been decided and was mainly used to confirm performance and for an incentive program. There are earlier models and simulations that were used during the design process at earlier stages to support design decisions. The measured building performance is compared to the “post-tender” model and simulation because this is the design model that represents most of the final design decisions among the available models. The model was created using eQUEST v3.61 simulation software. In addition to the eQUEST model an external hourly spreadsheet calculation has been used to calculate the energy transfers from heat reclaim and heat rejection to the adjacent EOS building. RETScreen v4.0 has been used to calculate energy savings in regards to solar hot water and PV panels (Stantec Cons., 2010).

All energy associated with heating, cooling and ventilation of the CIRS building is represented in the energy model including all energy required to capture waste heat from the adjacent building. Energy associated with rejecting heat for preheating the adjacent EOS building outdoor air was excluded; this also applies to related pumps and fans.



	CIRS Design Model
Renewables	-7
Plug Loads	13
DHW-Elec	4
Fans	10
Pumps	23
Cooling	5
Heating-Elec	43
Lighting	16

Figure 1: Annual Energy Utilization Intensity by End Use (kWh/m2/year) (Stantec Cons., 2010)

The input parameters of the final design model are available in post-tender energy study report (Stantec cons., 2010). The overall goals for CIRS were to be a net-positive energy producer and a net-zero carbon building. In order to achieve these goals the electricity taken from the grid needs to be offset. This is attempted by including into the design heat transfer equipment to use heat rejection from cooling in CIRS to preheat the make-up air of the adjacent Earth and Ocean Sciences (EOS) building. The design intent was that heating provided to the EOS fresh air would reduce heating needs of the EOS building and displace heat taken from the central steam plant on campus, and thus eliminate a portion of the fossil fuel consumed at the plant that would have been needed to produce steam for EOS heating. As will be seen later on, there are such problems with the implementation of this system that there are to this date no fossil fuel savings realized.

There are many modelling work around solutions[1] for the design model, as the capability of the program (at the time) did not allow full representation of this complex mechanical system. The heat reclaim from the lab exhaust of the neighbouring EOS building is not simulated directly in eQuest, but modelled outside of the simulation software based on hourly loads data and calculations. In summary, the air side of the mechanical systems is modeled in eQUEST 3.61, and water side is completed with hourly spreadsheet calculations. Process loads such as elevators and data room cooling are included in the simulation, but not process energy related to the wastewater treatment plant or any appliances and tenant equipment other than anticipated plug-load density as per Table 1.

Occupancy, lighting and plug-load inputs are defined in ASHRAE 62.1, 2009.

4 Measurements

Electricity is the only type of utility energy ("fuel") consumed in CIRS. In this paper we are comparing electricity consumption predictions with measured electricity consumption. Other measures are recorded and evaluated here to gain an understanding of the processes in the CIRS energy systems.

Despite the showcase nature of the CIRS project, there is no comprehensive document explaining which electricity data reading refers to which energy use in the building. The measurement and verification plan was put together without involvement of researchers, who may later on use the data. The BMS system is not configured to enable breakdown of performance results of different consumption measures within the building at 100% accuracy. Only lighting metering is given with electric panel names, but still without defining the space, where the respective lighting is installed. Water-to-air heat pumps used for distributed cooling of server rooms and such appear to be on the same panel as plug loads. Energy flows on the water side of the system are metered individually, but the sums recorded by the system are the sums of the absolute values of the flows, such that the sums do not represent a heat balance of the system. This applies to the flows to the geothermal field, the heat reclaim from the EOS building lab exhaust, and the heat rejection to the make-up air of the EOS system. The solar hot water system is not metered at all.

Collected Data

The large amount of data that is collected in CIRS is processed and used for various different research activities within the building. While processing the data for performance analysis and as-built energy model input (Salehi et al. 2013), it was discovered that there are some misleading data variables and un-calibrated data points within the system. In a first step, some simple wiring problems and inefficiencies in the data measurement programming were found addressed.

There are two water meters installed along the same water line (Fedoruk, 2013). In lighting, lack of controls and wiring problems causes excess usage. Occupancy sensors on lighting system are not efficiently placed. The occupancy sensors of washrooms on all levels are wired together, which results as all washrooms to be lighted at the same time although they're not all occupied. Occupancy sensors in the basement were programmed as emergency lighting

1 Work-around solutions are summarized in detail in Appendix B of UBC - Centre for Interactive Research on Sustainability (CIRS) LEED – EAP2 and EAC1 Energy Modeling Report, Stantec Cons., Jan 21, 2011.

requirements (24/7 lit) between July–November 2012; reprogramming was possible in the basement by the BMS technical specialist, which resulted in energy savings.

While the building was tested by a whole-building blower-door test on 23rd of Feb, 2013, static pressure sensors were tested as well. As, the building was pressurized and depressurized up to 75Pa; validation of static pressure sensor measurements at levels 2, 3, and 4 on both wings was possible. There were calibration and wiring problems in these sensors (indicating whether windows are open or closed) also needed calibration.

Temperature sensor readings were verified in 2nd floor North wing in summer 2012.

Electricity consumption in the building is the main performance data, since all consumption is in electricity, so verification of electricity data needed to be confirmed before using it for comparisons. As seen in Table 1 total electricity meter data, utility meter data, and calculated total electricity by panels correlate well with 1-5% monthly and 0-1% annually errors.

Table 1: CIRS Total Electricity Validation with Discrepancies (MWh)

monthly totals	Total Electicity	Utility meter	Mean Bias Error	Total electricity Mt	Mean Bias Error
Mar-12	70.69	71.76	0.01	70.91	0.00
Apr-12	58.54	59.73	0.02	58.58	0.00
May-12	55.46	56.99	0.03	55.60	0.00
Jun-12	55.29	54.97	-0.01	55.40	0.00
Jul-12	56.34	55.62	-0.01	55.48	-0.02
Aug-12	54.40	54.00	-0.01	54.47	0.00
Sep-12	59.87	56.43	-0.06	57.08	-0.05
Oct-12	65.73	65.71	0.00	65.52	0.00
Nov-12	65.74	68.11	0.03	67.35	0.02
Dec-12	76.25	77.88	0.02	78.68	0.03
Jan-13	83.55	84.70	0.01	83.83	0.00
Feb-13	64.29	65.52	0.02	64.98	0.01
tot Mar12-Feb13	766.15	771.42	0.01	767.87	0.00

After verification of accuracy in electricity metering, electricity breakdown (lighting, plug-load, mechanical load) of the building is done with mean bias error discrepancies as a first step. Then the total Motor Control Center (MCC) panels' data is separated as pump, fan, heating, and cooling loads. For calculating the pump and fan work, it is needed to calculate the energy consumption of each motor component. This is done by logged power data for multiple speed drive pumps, and calculated individually for constant speed pumps by the following equation.

$$W = \sqrt{3}IVcos(phi) \tag{1}$$

Where, I is the measured current, V is the voltage, and $\cos(phi)$ is the nominal power factor of the motor. There are 3 MCC panels; one of them is mainly dedicated for water treatment system within the building. This panel's elements also calculated individually for as-built energy model (Salehi et al., 2013), but not used in comparisons with design model.

Processing the Data in Order to compare it to Simulation Predictions

The measured data presents in a different format than the results from the whole building energy simulations. In order to compare the two, measures have to be derived from both simulations and measurements that can be compared.

After analyzing the BMS electricity data, it is observed that the quality and the consistency of the data acquired from the BMS system are more reliable after March 2012 than previous months. Thus, the first annual report is prepared for the 12 month period of March 2012-February 2013.

According to Honeywell data acquisition system, there are 27 electricity panels with 2 elevator meters defined. The PV panel (2P0A) is not one of the panels in the Honeywell system; therefore data for this panel is not available. There are also 3 MCC's that are metered each containing a panel. 5 transformers (only 3 of them used in this report, since TX5 is for PV's that's on the renewable energy side, and TX4 is not metered by BMS) and a UPS meter for critical systems.

All the electricity panel contents are identified from descriptive panel info pages and electrical drawings (as-built set, see Appendix A for example drawings), and confirmed in meetings with BMS Technician. The contents of each individual electric panel are given in panel descriptions given as an example in Table 3. According to contents of electricity panels, these are grouped under plug-load, lighting or mechanical loads. Then the needed data for accurate breakdown is defined with summation of following electric panel readings:

- 17 electricity panels and 2 elevator panel loads for <u>plug load</u>
- 7 electricity panels for <u>lighting load</u>
- 3 MCC panels & 3 electricity panels & heat pump 3 & boiler for <u>mechanical load</u>

Validated through following data:

- Transformer & UPS panel *(used for validation of data)*
- Main electricity meter & lighting meter *(used for validation of data)*
- Utility meter data *(used for validation of data)*

Data gathered mostly from data acquisition system with Microsoft Query in Excel. Only utility meter data is read from utility bills. Data filtered from Microsoft Query with hourly and 24 hour snapshots.

The data acquisition system by Honeywell used in CIRS qualifies data as either "GOOD" or "BAD" in value. Data is labeled "BAD" if the system detected problems, such as for example the connection to the main server. Data labeled "BAD" is not used in our analysis; instead it is replaced by its neighbouring "GOOD" value. We further process this data to remove outliers by using standard filters. To be certain that these outliers are not meaningful, a spot check was done revealing that there were not special circumstances present that might have led to extreme data (maximum 2-3% range in datasets).

As an example to electricity breakdown within the building, mechanical system's electricity breakdown is given in Table 2 and Table 3 with descriptive explanation of panels, and how the totals are calculated.

Table 2: Mechanical Panel Descriptions of CIRS Building

Mechanical Panel Descriptions			
Panel Name	**Contents on Panel**	**Extra Functions on Panel**	**Annual (MWHr)**
CIRS_2N2NC	Spare & Moisture Detection Panel	NA	0.2
CIRS_2N4SC	UH-20&EXF-3&UH-21&UH-22 *EXF-5&-6 (future)*	Spare & L4 polorized Glazing	1.351
HP_03	Heat pump 3	NA	19.656
CIRS_2E1A	Water Treatment Room (Access Door &pumps& honewell panel & HIGH BAY Lights)	NA	20.384
CIRS_B01_HL_BOILER	Boiler	NA	0.998
MCC6N0P	water treatment system	NA	47.81
MCE0M	cooling system load mainly	NA	78.21
MCC6N0M	heathing system	NA	262.39
Total			**431.00**

The mechanical load is gathered from MCC (Motor Control Center) panels. There are three main MCC panels: MCC6N0P is water treatment system's panel, MCE0M is emergency systems (mainly works as cooling), and MCCN0M is the other mechanical load panel that combines heating and distribution system loads. All the electric panels adding up to mechanical load is given in table 3. There's not a specific code, which points out panels 2N2NC, 2N4SC, 2E1A as mechanical load panels.

As mentioned before, the mechanical systems are together to quite some extend in the electricity readings that, it is not possible to separate the loads accurately, and thus the breakdown of heating and emergency systems remains as an estimate.

Table 3: Mechanical System Panels' Load Breakdown (MWh)

	MCC6N0P	MCE0M	MCC6N0M	tot MCC	CIRS_2E1A	CIRS_HP03	CIRS_2N4SC	CIRS_2N2NC	boiler	monthly totals
Mar-12	1.14	6.68	30.40	38.22	1.07	1.57	0.17	0.00	0.01	41.03
Apr-12	1.19	5.65	21.09	27.93	1.21	1.62	0.13	0.00	0.01	30.91
May-12	3.95	5.62	17.79	27.35	1.31	0.77	0.14	0.00	0.00	29.57
Jun-12	4.33	6.00	14.81	25.14	1.23	2.11	0.11	0.00	0.94	29.54
Jul-12	2.80	4.62	16.76	24.18	2.10	2.12	0.06	0.00	0.00	28.46
Aug-12	2.23	6.42	13.60	22.24	2.15	2.24	0.09	0.00	0.00	26.71
Sep-12	3.00	6.17	15.60	24.76	1.98	2.47	0.14	0.00	0.00	29.35
Oct-12	4.36	7.27	19.20	30.84	2.17	1.79	0.14	0.00	0.00	34.95
Nov-12	5.15	7.09	22.21	34.45	1.78	1.46	0.12	0.12	0.01	37.93
Dec-12	6.73	8.15	32.06	46.94	1.46	0.88	0.08	0.09	0.00	49.43
Jan-13	8.23	8.02	35.59	51.84	1.48	1.45	0.10	0.00	0.04	54.90
Feb-13	4.71	6.53	23.29	34.53	2.44	1.18	0.08	0.00	0.00	38.23
Totals	47.81	78.21	262.39	388.41	20.38	19.66	1.35	0.20	1.00	431.00

Although, most of the pump and fan loads are on the main MCC panels, there are some other electric panels which feed a few pumps, fans, fan-coil units and unit heaters. According to panel & MCC definitions, MCC6N0P and 2E1A panels are added for water treatment load, panel 2N4SC is summed up with MCE0M panel for cooling load, and HP03 panel& B01_HL_BOILER loads added on top of MCC6N0M for defining heating load, and 2N2NC panel load added on total mechanical load only, since it only measures moisture detection panel of green roof. See Table 3 for system intensities.

Overall Annual Building Energy Performance Totals

After verifying the data, overall breakdown results are presented as follows in this section.

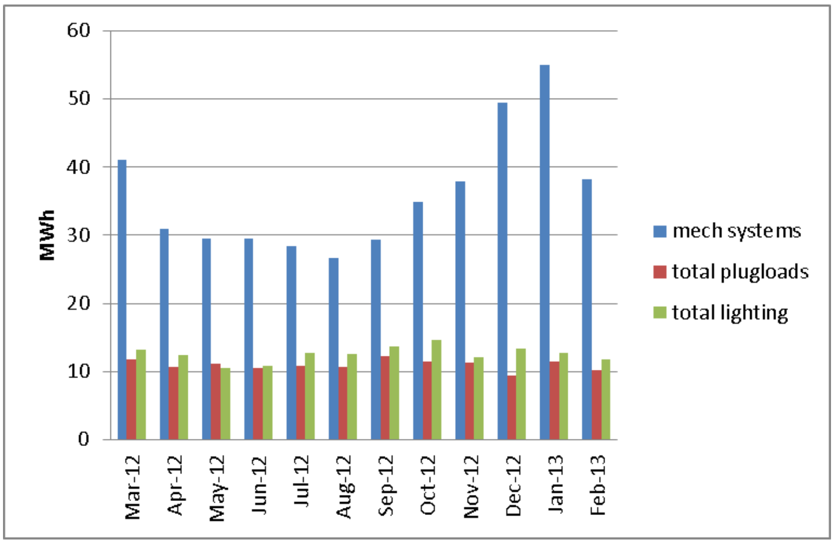


Figure 2: CIRS Monthly Measured Data Breakdown

According to the graph in Figure 2, monthly lighting consumption varies between 10.45-14.64 MWh throughout the year, while HVAC consumption is in relation with the heating schedule of the building. Plug loads vary in relation to occupancy schedule change in the building, mostly the consumption is more than double the intended monthly plug loads in design stage.

Emergency lighting consumes the highest between 7 defined electric panels for lighting. Reason of this consumption can easily be seen in the building's common spaces as 24/7 lights on in day lit areas such as atrium, café, and ground floor main halls. However, emergency lighting panel do not enable reprogramming. If the emergency lighting can be reprogrammed by the building management system (BMS), the load on the system can be decreased as well. Lighting retrofit project is already planned for the building. According to retrofit plans, emergency lighting hours can be reduced by 80%, and rest of the lighting requirement can be reduced by 25-30%with addition of programming availability, and new occupancy sensor plan.

5 Comparison between Simulation Results and Measured Data

In the case of CIRS, total energy consumption equals to the total electricity from the grid utility electricity consumption. All pump and fans associated with reclaiming heat from the neighbouring EOS building are on CIRS's meters. The heat reclaimed from the EOS building is not counted as consumed energy.

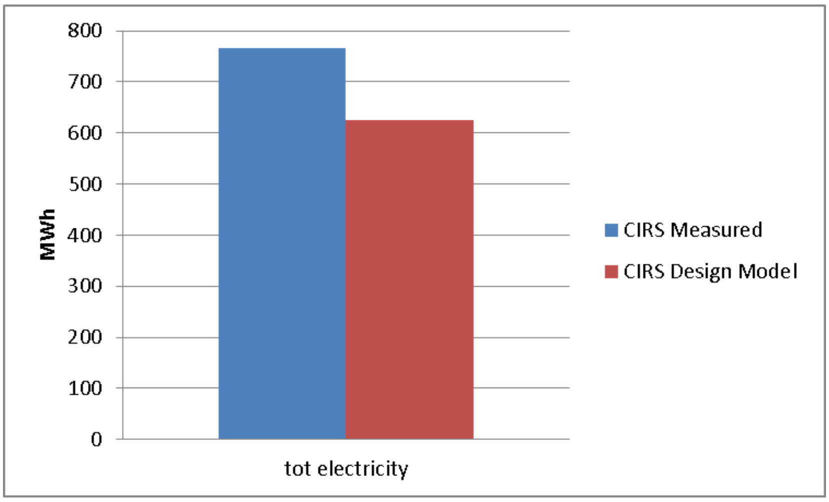


Figure 3: CIRS Total Annual Energy Consumption (Mar 2012-2013)

The actual measured total electricity data for Mar 2012-2013 is 23% over the predictions of the CIRS design model, as in Figure 3. A break-down in Figure 4 shows 71% over prediction in lighting, and 49% in total plug-loads, the overall measured prediction of total mechanical system is 4% under design predictions.

Measuring the actual performance of CIRS it was found that the building operates quite differently from intended. Most significantly, the energy-efficiency concept of the building which is intended to operate at net-zero energy included using waste heat from a neighbouring building to reduce its own energy needs for heating, and then offset its own energy-consumption impact by displacing steam consumption of the neighbouring building by providing it with heat. Neither of those heat exchanges works as intended.

The simulation software used was limited in representing the building's innovative design features (such as radiant floors) and therefore work-arounds and additional spreadsheet calculations were necessary. Despite these findings, the overall energy consumption of the building is surprisingly close to the predicted total energy consumption by the simulations, being only 23% higher (Figure 3). Separating lighting and plug-loads from the mechanical systems (Figure 4) it is even found that the total HVAC energy is only 4% less than the simulation prediction. Breaking it down even further (Figure 5), however, the heating and cooling predictions are found to be over-predicted 39% and under-predicted by 167%, respectively, showing that the apparent high accuracy of the HVAC simulations (4%) is a result of errors at a lower level cancelling out, so this cannot be relied upon. Lighting and plug-loads are quite different from the input in the design model as actual usage was not known at the time of design, contributing at least partially to deviations between measurements and predictions. The significantly higher lighting and plug-loads reduce the heating loads and increase the cooling loads.

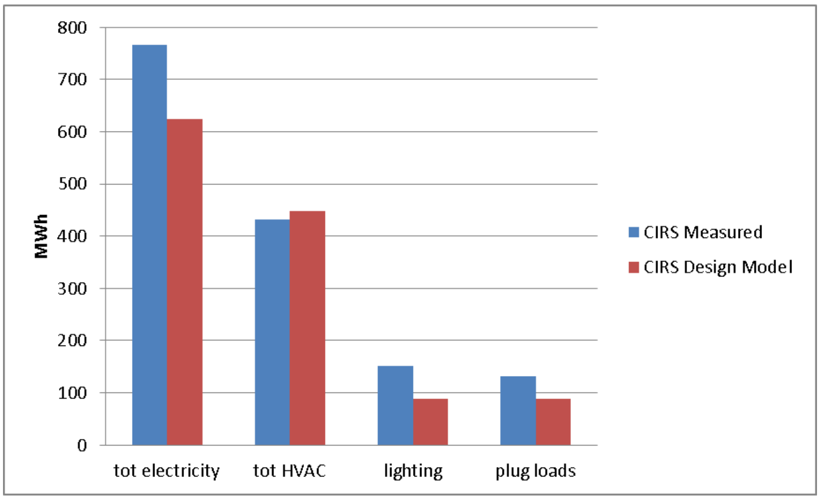


Figure 4: CIRS Annual Measured Energy Data versus Design Model Data

In order to compare sub-systems similar to the design model, heating-electricity, cooling, pumps, and fans are separated as defined calculations in section 3. For heating-electricity, HP01 (heat pump 1) and HP02 are considered as main compressor work summed up with heat recovery (Laboratory exhaust HRC-LEX served by S-P4/S-P5, washroom exhaust HRC-WEX served by S-P7, Air-Handling Unit exhaust HRH-AH served by SP-6), geothermal loop (served by GL-P1 to P3 -heating mode calculated-), hydronic heating devices (In Slab heating in all levels i.e. IS-HL P5.1A) and boiler work. For cooling, water-to-air heat pumps (HPWA 01 to 03) and HP03 (confirmed as used for mainly cooling) are summed up with geothermal loop (served by GL-P1 to P3 -cooling mode calculated-), heat rejection (Heat Recovery coil HRC-LEX served by S-P4/S-P5, washroom exhaust HRC-WEX served by S-P7, Air-Handling Unit exhaust HRH-AH served by SP-6), Fun-coil units (FCU 1 to 5) and Air Handling Unit (AHU-2). For pumps work, all other pumps are added together besides water treatment plant dedicated ones (P11 and P14). Domestic hot water is calculated from pump dedicated (P12). For fans, Air Handling Unit 1 to 2 supply and return fans and other fan work is summed. Process loads are discovered to be more than anticipated limits, which needed to be addressed, since there's no process load defined in the energy model. Renewables representing only the metered PVs (Transformer 5 TX-5) energy, since solar hot water system is not available as mentioned.

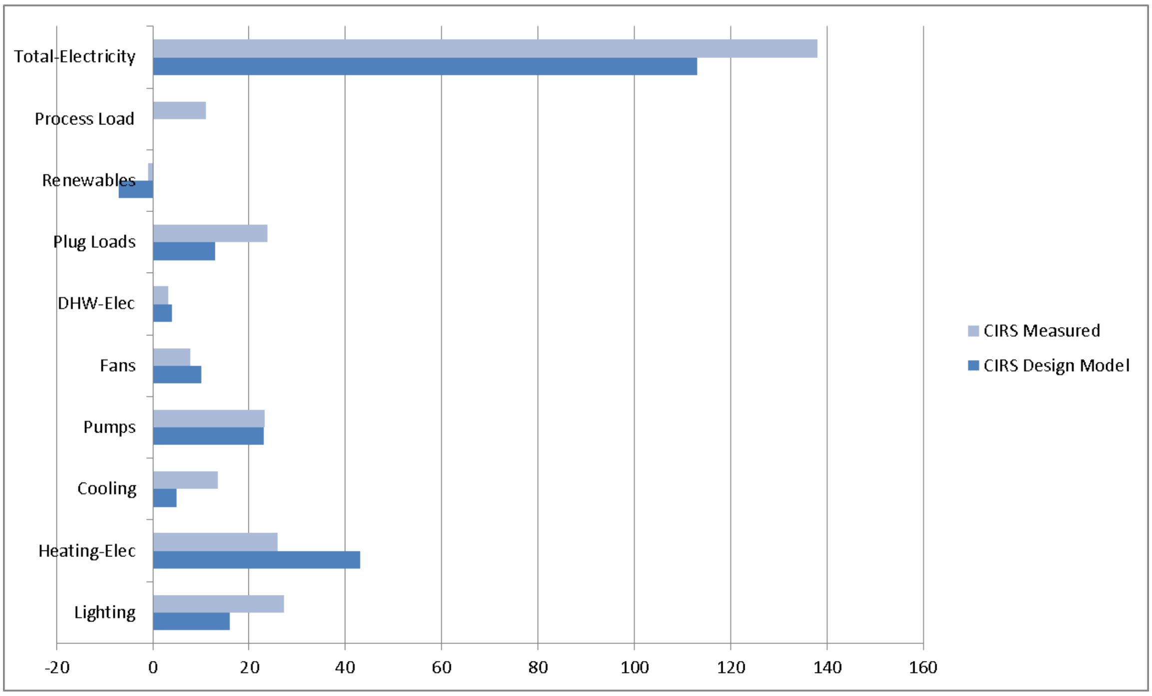


Figure 5: Comparison of Measured Data with Design Model by CIRS Annual Energy Utilization Intensity by End-Use (kWh/m2/year)

It is challenging to compare the measured energy to the break-down by end uses as is commonly given for simulation results. The data recorded in CIRS is by electric panel, where the uses are not identified, particularly not to this level of detail (Figure 5).

6 Heat Exchange between CIRS and EOS

As previously mentioned in section 4, absolute, non-directional metering on some energy meters caused misleading results about EOS heat exchange at the beginning. The predicted heat harvest from EOS was 906 MWh/year, yet according to the measured results CIRS only able to harvest 272 MWh/year thermal energy from EOS exhaust. The meter measuring how much heat CIRS rejected to the EOS building shows 126 MWh/year, yet the meter measuring how much heat was received by the EOS building measures only 2 MWh, when the direction of the flows considered in separation. These two readings should be equal but are not, which is subject to further investigation. In any case this is a much smaller amount than the predicted 622 MWh/year (Figure 6).

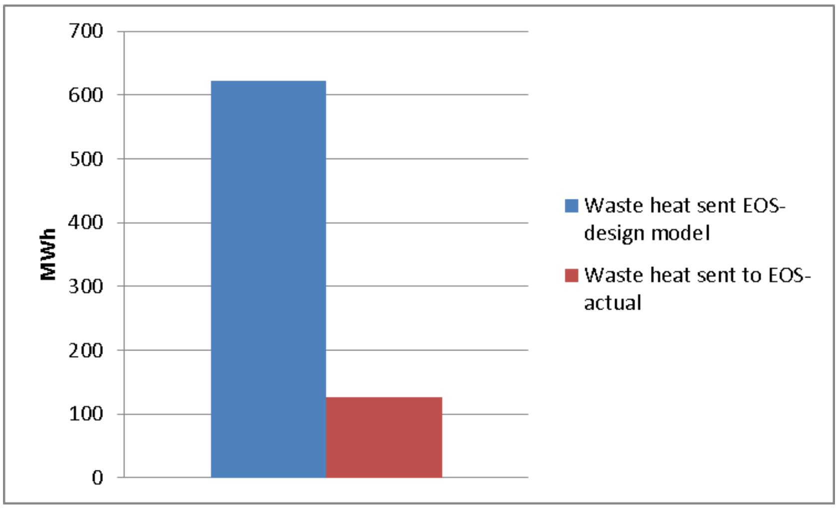


Figure 6: Total Waste Heat Sent to EOS from CIRS (Mar 2012-2013)

In the predictions of the amount of heat that could be reclaimed from the EOS laboratory exhaust, it was assumed that the exhausted air would have the same temperature as the inside air. However, according to measurements performed after CIRS was already occupied, the exhaust air temperature of EOS is often significantly lower than internal temperatures and may indicate that exhaust air is being mixed with outdoor air prior to reaching the heat exchanger to extract thermal energy for CIRS. The lower exhaust temperatures lead to less reclaimed heat.

With respect to rejecting heat to the EOS building's make-up air and displacing steam production at the central steam plant by reducing EOS's demand, evaluating the measured data it was found that the layout of the intake ventilation unit does not allow EOS to accept heat only in very cold weather periods (Fedoruk, 2013). It has been suggested that the new pre-heat coil might have been placed in front of the existing air handling unit (AHU), and that the existing, decades-old AHU is of a design that cools the air first before heating it, thus removing any pre-heat and actually increasing the energy consumption rather than reducing it at the EOS building. An investigation is ongoing to finally resolve this question.

Both heat exchanges with the EOS building are paramount for CIRS to reach its performance goals of net-zero carbon and net positive energy. Not only has the amount of heat received from the EOS building a major impact on the total energy needs of CIRS, but the heat provided to the EOS building, displacing fossil fuel consumption at the central steam plant, defines the "energy budget" for CIRS if it is to operate as a net-zero or even net-positive building. Despite the importance of those design features in CIRS's energy concept, the simulation professional at the design stage was not provided with the necessary information to make meaningful predictions of the contributions to the CIRS energy systems by the interaction with the EOS building. The temperature of the exhaust stream is fundamentally necessary piece of information to calculate the amount of energy that can be retrieved and it would have been advised to measure this for different seasons before finalizing the design. Similarly the processing that the supply air passes through needs to be known to predict how much heating energy might be saved.

7 Conclusion

In this paper we present the simulation predictions of the CIRS building from the design stage, the measured performance data, and a comparison of the two. While measured performance data is absolutely necessary to get a better understanding of simulation results, the data that is typically collected in the building presents in a very different format than simulation data. It is described what data is collected in CIRS building, and how it could be transformed to yield the common simulation break-down by end-use. In comparing the data at

1. an overall level,
2. the overall mechanical systems, and
3. the end-use break-out

it can be seen how differently the accuracy of the same simulation appears at those different levels. We find a 23% higher than simulated total measured energy, but only a 4% lower than simulated measured mechanical systems energy. However, the apparent high accuracy of the mechanical systems simulation, which is unlikely given how differently the building operates from how it was intended and how few of the innovative systems (underfloor-air, displacement ventilation, natural ventilation, heat exchange with neighbouring building etc.) could actually be represented in the simulation software (eQuest), is found to be the result of large discrepancies at the end-use level cancelling each other out. In the present paper the focus is on comparing the simulations from the design process to the measured data; other investigations into the reasons for detailed differences between simulations and model have used new models (Salehi 2013).

The CIRS building exchanges heat with its neighbouring EOS building in two ways (heat reclaim and providing heat to offset own consumption). The predictions of this crucial element of the CIRS energy concept, fundamental in its reaching its goals of net-positive energy and net-zero carbon, are dramatically deviating from predictions of first year of operation. In the case of the heat reclaim this could have been prevented by a more careful evaluation of the condition of the EOS building in the original design process, particularly measuring the exhaust air temperature in different seasons. The standard assumption that exhaust air is approximately at the same temperature as the internal space air temperature was found to be not correct in the case of EOS building. The heat that was intended to be provided to the EOS building to offset CIRS's energy use is apparently not received by the building and it is unclear at this point what the reason is. Investigations into this are ongoing. It is not surprising that the energy simulation professional during the design stage could not provide a reliable estimate of the heat that could be provided to and received by the EOS building, given that information about the details of the heat exchange were not available at the time. It would have been preferable had the effort that is now going into the investigation would have been expended during the design stage testing to save the extra cost involved in changing the setup that is underway now.

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