Energy Retrofit for Children's Research Center

FINAL PROJECT

You Jeong Kim | ARCH 576 FALL 2021 | 12/07/2021

Contents

1. Introduction

Energy retrofit of an existing building aims to improve the energy performance of the building and to maximize health and comfort of building users. A whole-building energy retrofit considers the building envelope, HVAC and lighting systems, appliances and renewable generation systems. Building energy simulation is employed to assess current energy performance and to identify the most impactful retrofit measures. (US DOE)

This project proposes energy retrofit strategies for Children Research Center in University of Illinois, Urbana-Champaign. The aim is focused on the improvement of energy-efficiency of the building. Throughout the building energy simulation using DesignBuilder, which is a whole-building energy simulation tool based on EnergyPlus, Radiance and CFD, current energy use of the building is assessed thoroughly and energy-saving potential of various retrofit strategies are investigated.

In this section the project framework and basic description of the project building is explained.

1.1. Project framework

Information gathering: Information on building geometry, construction, internal loads and schedules, HVAC systems and energy usage history were collected through drawings, utility bills and site survey. Such data are used as inputs of the energy model.

Energy audit: Energy audit helps identify and prioritize specific areas for improvement. Energy auditing process can be divided into three sub-processes:

1) Energy modeling: An initial energy model for the project building is created with DesignBuilder v7. This process requires detailed information that are described in Information gathering part.
2) Model calibration: Since some of the building data may not be known or available, some assumptions may need to be made based on the knowledge of the modeler. These assumptions can result in significant gap between predicted and real energy

performance. (Krarti, 2018) To assess the energy performance and energy-saving potentials of the retrofit strategies more precisely, it is highly recommended to calibrate the initial model with actual energy usage data. In this project, the model is calibrated by manually modifying the uncertain input parameters.

3) Performance analysis: The results of the energy, daylighting simulation are analyzed thoroughly. Finally, the areas for improvement in energy-efficiency can be identified and prioritized.

Building energy optimization: Based on the results from energy audit, several retrofit strategies that can reduce the building energy performance are proposed. Moreover, the energy saving-potential of each measurement is calculated.

1.2. Project building description

The project building is Children Research Center located on the north campus of the university in Research Park at 51 East Gerty Drive. It is 2-story concrete building with brick-finishing and has a total of 40,761 square feet. The building has been used for office and primary school. Therefore, it is used mainly by students and faculty members. Figure 1 is the western façade of the building.

Figure 1 Children's Research Center

The building was originally completed in 1964, but remodeled several times throughout the years. The following is a current timeline of the retrofit:

- 1964: Original construction of the Children's Research Center was completed.
- 1992: The building was re-roofed.
- 2011: Boilers and chillers were replaced.
- 2012: Retro commissioning visited building.

Additional to the above, seminar rooms in the office zone were refurbished with LED lightings, but exact time is unknown.

Preliminary assessment:

Even though it has been retrofitted several times, the exterior wall and window which might have poor insulation have never been considered. Moreover, since individual control is impossible, the HVAC systems and lightings are on even in vacant rooms. Therefore, the building is expected to have low energy-efficiency.

2. Site Survey

Building information for the inputs of the energy model was collected through drawings and site survey.

2.1. Geometry

The building is a rectangular 2-story building with a flat roof. Notable thing is that the southern facade of the ground floor is fully exposed to the outside. The building has a courtyard that let the daylight into the rooms. Figure 2 shows the exterior and the courtyard.

Figure 2 Exterior and courtyard of Children's Research Center

2.2. Construction

The main structural material of the building is reinforced concrete and it is finished with brick and stone. Since the section drawing was unavailable, assumptions were made on the construction layers based on the year of construction completed. In 1964, when the building originally built, there was no energy code for commercial buildings like ASHRAE Standards.

Therefore, the walls and the roof would have built without the insulation. However, the roof was renovated in 1992. The energy code was still not developed in that time, but it is expected that insulation was added for the renovation. All windows are made of single glazing with aluminum frames.

2.3. Floor plans

Floor plans and programs of each room were identified by the survey. For the ground floor, about a half of the rooms are classrooms and seminar rooms for the primary school, and the other half is office area. For the first floor, most of the rooms are office and there is a lounge where people can rest with coffee. There are also rooms for building operation, such as mechanical rooms and service rooms.

2.4.Internal loads and schedules

Occupancy and wattages for lighting and appliances were investigated through the site survey. The data were collected for four main space types: office, classroom, seminar room and lounge.

The schedules for occupancy, lighting, appliances, and HVAC system were also investigated. For occupancy schedule, only those for office and classroom could be investigated. The whole building is using the same schedule for lighting and HVAC system, meaning that lighting and HVAC system are unable for the individual operation. Also, the building is using the same schedules regardless of the seasons.

Following is a simple description about internal heat sources and schedules for main space types:

1) Office: All of the office rooms are small office for one person and occupied from 9 am to 6 pm on weekdays. Each office has 1 PC, 1a monitor, 1 lazer printer and 1 desk lamp. For lighting, two linear fluorescent bulbs (4' F32) are installed.
2) Classroom: The total number of students is approximately 100. They are occupied from 9 am to 5 pm on weekdays and partially (about 10% of the total) occupied from

11 am to 4 pm on Saturday. Each classroom has 1 laptop and 1 projector. For lighting, 24 linear fluorescent bulbs (4' F32) are installed.

3) Seminar room: The occupancy of a seminar room can be assumed to be the same with the number of chairs, which is 20. Each seminar room has a 53" television. For lighting, only one room in the basement is installed with 20 LED bulbs and the rest are installed with 20 linear fluorescent bulbs (4' F32).
4) Lounge: The occupancy of a lounge was not known. Therefore, the default value in a pre-defined schedule in DesignBuilder library was used. There are 1 medium size coffee maker, 1 mini microwave and 1 mini refrigerator in the lounge. For lighting, 12 linear fluorescent bulbs (4' F32) are installed. Figure 3 shows the interior of the lounge.

Figure 3 Interior of the lounge

2.5. HVAC system

The building is connected to a chiller and two natural gas boilers for heating. All three are located on the lower level in the mechanical room. Heating and cooling are supplied by the constant volume air handling unit (AHU). There are four AHUs in the building and active exhaust fans are installed for the restrooms and the kitchenette. The efficiency of chillers and boilers were unable to find. A setpoint of 72°F was used for both heating and cooling. Table 1 shows the properties of the HVAC systems. Figure 4 illustrates the system zoning.

Figure 4 HVAC system zoning

Table 1 HVAC system properties

System name	Fan HP	Design flow rate [CFM]	Serving area [ft2]
AHU 1	3.0	12,051	11,005
AHU 2	2.0	11,124	9,401
AHU 3	2.0	10,197	12,243
AHU 4	1.5	6,886	8,895
Toilet Exhaust Fan	0.083	750	-
Kitchenette Exhaust Fan	0.083	750	-

3. Energy Model

Based on the information gathered from the survey, an energy model for the building was generated in DesignBuilder v7. In this section, the inputs of the model are described.

3.1. Geometry

The building geometry was created as Figure 5 - 6. To calculated the energy transfer under the ground, the ground was modeled with the component blocks.

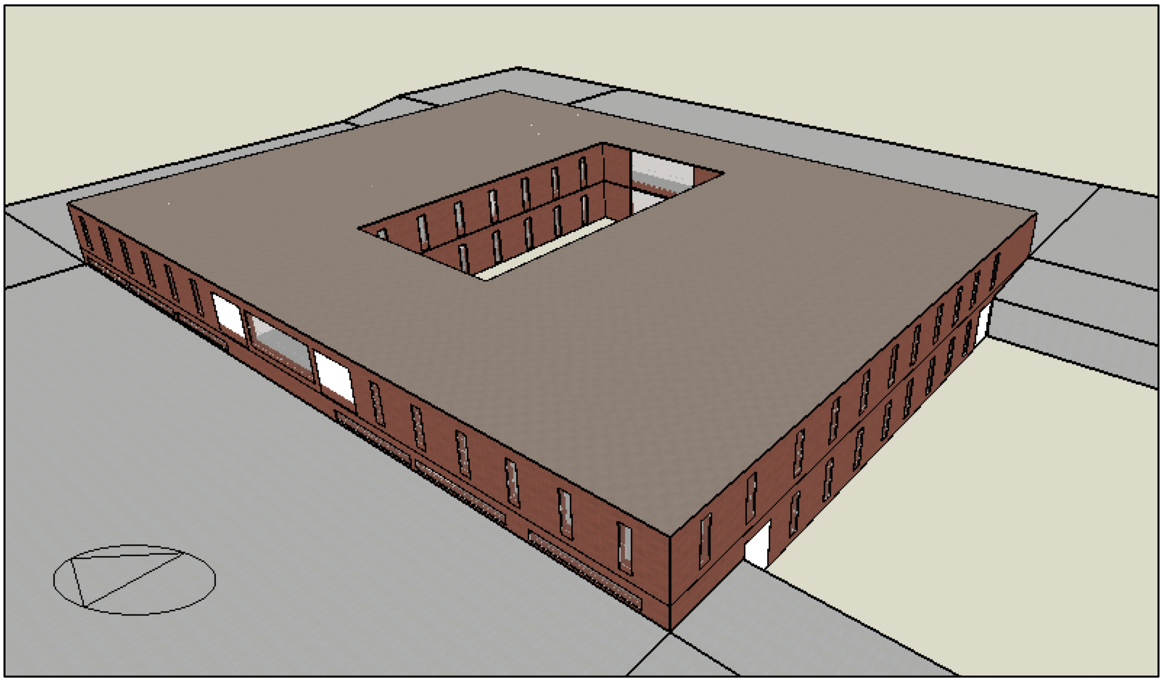

Figure 5 3D view of the energy model

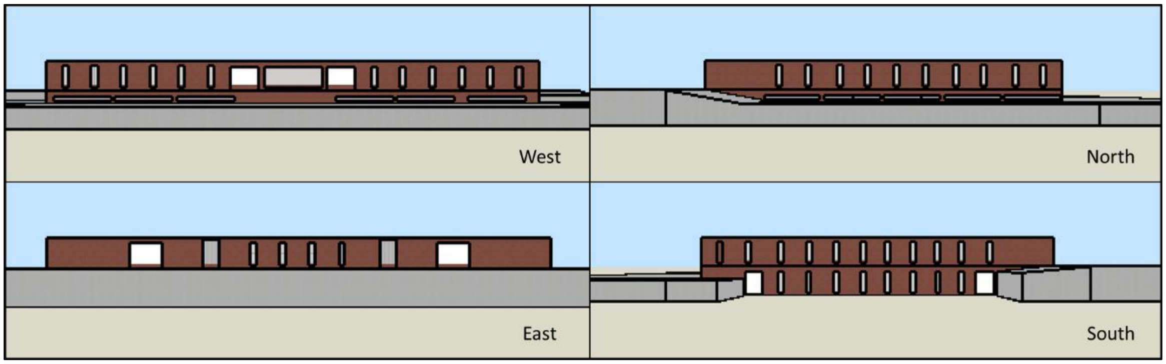

Figure 6 Views from each orientation

3.2. Construction

The materials for external walls, below grade walls, roof and windows were modeled as described in Table 5. To set adequate insulation thickness of the roof, the insulation requirements presented in ASHRAE 90.1 – 2004 was referred. (Mathis, 2011)

Table 2 Construction components properties

Component	Layers	U-value [Btu/h ft2 °C]
External walls	1 in brick / 12 in reinforced concrete / 1 in brick	0.481
Below grade walls	12 in reinforced concrete / 1 in cement	0.521
Roof	1 in grave / 8 in glass-fiber insulation / 14 in reinforced concrete	0.035
Windows	Glazing: 0.12 in clear glass Frame: 0.197 in aluminum	Glazing: 1.038 Frame: 1.036

3.3. Zoning

To consider different internal loads and schedules of different space types, the thermal zones were created as Figure 7 based on the floor plan of the building described in section 2.3.

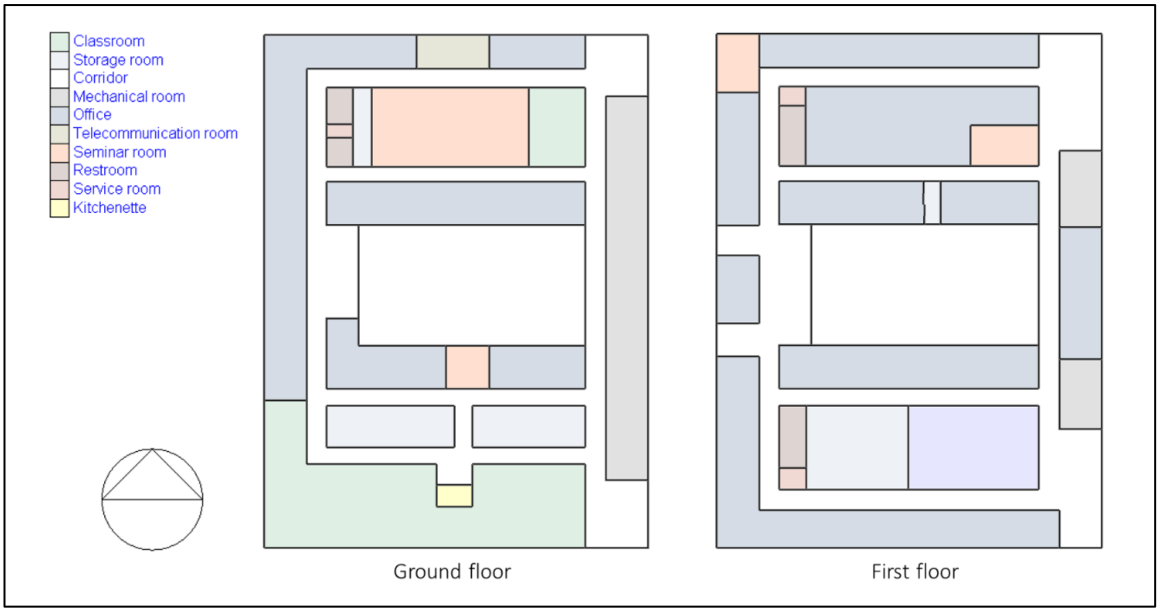

Figure 7 Thermal zoning

3.4. Internal loads and schedules

For offices, classrooms, seminar rooms and lounge, the internal loads were set as actual values using the survey data. For other space types where the actual values are unknown, the activity templets in DesignBuilder library were used.

To calculate the density values, the number of occupants and the wattages for lighting and appliances were divided by the total area of each space type. For the normalized power density for lighting, the lighting power density was divided by the target illuminance (fc) of each space type. Since some appliances like a printer is not used for a whole hour, the average wattages for appliances were adjusted with the actual usage hours. Table 3 shows the internal loads for the main space types.

As explained in section 2.4, schedules for HVAC system and lighting are identical in all space types. Schedules for appliances are assumed as the same with occupancy schedules for all space types. This assumption is plausible since the appliance-usage pattern is highly related to the occupancy pattern (Ahmed et al., 2017; Zhao et al., 2014). Detailed setting is described in Table 4 – 5.

Table 3 Internal loads for main space types

Internal loads	Office	Classroom	Seminar room	Lounge
Occupants density [W/ m^2]	0.00524	0.01420	0.05410	0.01999
Lighting power density [W/ fc m^2]	0.0120	0.0330	0.0620	0.0204
Appliances power density [W/ m^2]	1.046	0.299	0.460	0.229

Table 4 Occupancy schedules for office and classroom

Time	Office			Classroom		
	Weekday	Saturday	Sunday/ holiday	Weekday	Saturday	Sunday/ holiday
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0.05	0	0
8	0	0	0	0.75	0	0
9	1	0	0	0.9	0	0
10	1	0	0	0.9	0	0
11	1	0	0	0.8	0.1	0
12	1	0	0	0.8	0.1	0
13	1	0	0	0.8	0.1	0
14	1	0	0	0.8	0.1	0
15	1	0	0	0.45	0.1	0
16	1	0	0	0.15	0	0
17	1	0	0	0.05	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

Table 5 HVAC system schedules for all zones

Time	Heating			Cooling		
	Weekday	Saturday	Sunday/ holiday	Weekday	Saturday	Sunday/ holiday
1	55.4	55.4	55.4	89.6	89.6	89.6
2	55.4	55.4	55.4	89.6	89.6	89.6
3	55.4	55.4	55.4	89.6	89.6	89.6
4	55.4	55.4	55.4	89.6	89.6	89.6
5	55.4	55.4	55.4	89.6	89.6	89.6
6	55.4	55.4	55.4	89.6	89.6	89.6
7	72.0	55.4	55.4	72.0	89.6	89.6
8	72.0	55.4	55.4	72.0	89.6	89.6
9	72.0	55.4	55.4	72.0	89.6	89.6
10	72.0	55.4	55.4	72.0	89.6	89.6
11	72.0	72.0	55.4	72.0	72.0	89.6
12	72.0	72.0	55.4	72.0	72.0	89.6
13	72.0	72.0	55.4	72.0	72.0	89.6
14	72.0	72.0	55.4	72.0	72.0	89.6
15	72.0	72.0	55.4	72.0	72.0	89.6
16	72.0	55.4	55.4	72.0	89.6	89.6
17	72.0	55.4	55.4	72.0	89.6	89.6
18	55.4	55.4	55.4	89.6	89.6	89.6
19	55.4	55.4	55.4	89.6	89.6	89.6
20	55.4	55.4	55.4	89.6	89.6	89.6
21	55.4	55.4	55.4	89.6	89.6	89.6
22	55.4	55.4	55.4	89.6	89.6	89.6
23	55.4	55.4	55.4	89.6	89.6	89.6
24	55.4	55.4	55.4	89.6	89.6	89.6

3.5. HVAC system

The HVAC system was modeled as ‘Simple HVAC’ using a pre-defined template: ‘CAV, ‘Water-cooled Chiller, Boiler HW’. Even though the building has 4 AHUs, they were modeled as one HVAC system since they have similar properties and operated with identical schedule. Table 6 describes the HVAC system properties.

Table 6 HVAC system properties

Properties		Description
Heating	Plant system	Boiler (supply: AHU)
	Fuel	Natural gas
	Efficiency	0.85
Cooling	Plant system	Water-cooled chiller (supply: AHU)
	Fuel	Electricity from grid
	Efficiency	1.8
Ventilation	System	Constant air volume AHU
	Fan efficiency	0.7
	Heat recovery	No

4. Initial Results

4.1. Total energy consumption

Table 9 and Figure 12 show the calculated annual energy consumption of the building. Since the building is located in cold region, the energy consumption for heating is higher than that for cooling. The energy consumption for appliances takes about 60% of the total energy.

Table 7 Simulation results – Initial model

End uses	Annual energy consumption [kBtu]
Heating	428204.4
Cooling	323250.1
Lighting	412984
Appliances	1915300
DHW	137381.8
Total	3217120.3

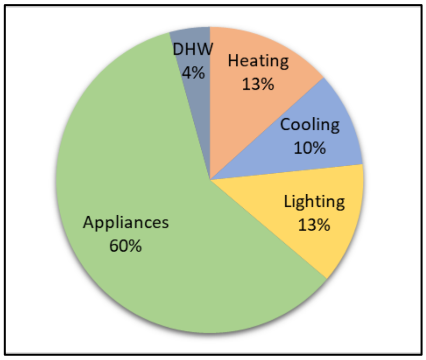

Figure 8 Energy breakdown

Table 8 and Figure 9 show the monthly results for electricity and gas consumptions. As shown in the graph, electricity usage increases during summer and decreases during winter, while the gas usage shows the opposite pattern. Moreover, it can be observed that the base load for the electricity is considerably high (about 180 GBtu), which means that the electricity use for lighting and appliances takes significant part of the total energy consumption.

Table 8 Monthly results – Initial model

Months	Electricity [GBtu]	Gas [GBtu]
1	199.2	110.5
2	178.9	99.3
3	198.0	59.6
4	196.4	34.3
5	217.5	17.7
6	258.8	10.8
7	292.3	11.8
8	280.6	11.8
9	235.4	13.1
10	205.9	31.8
11	191.4	59.2
12	197.2	104.4
Sum	2651.5	564.3

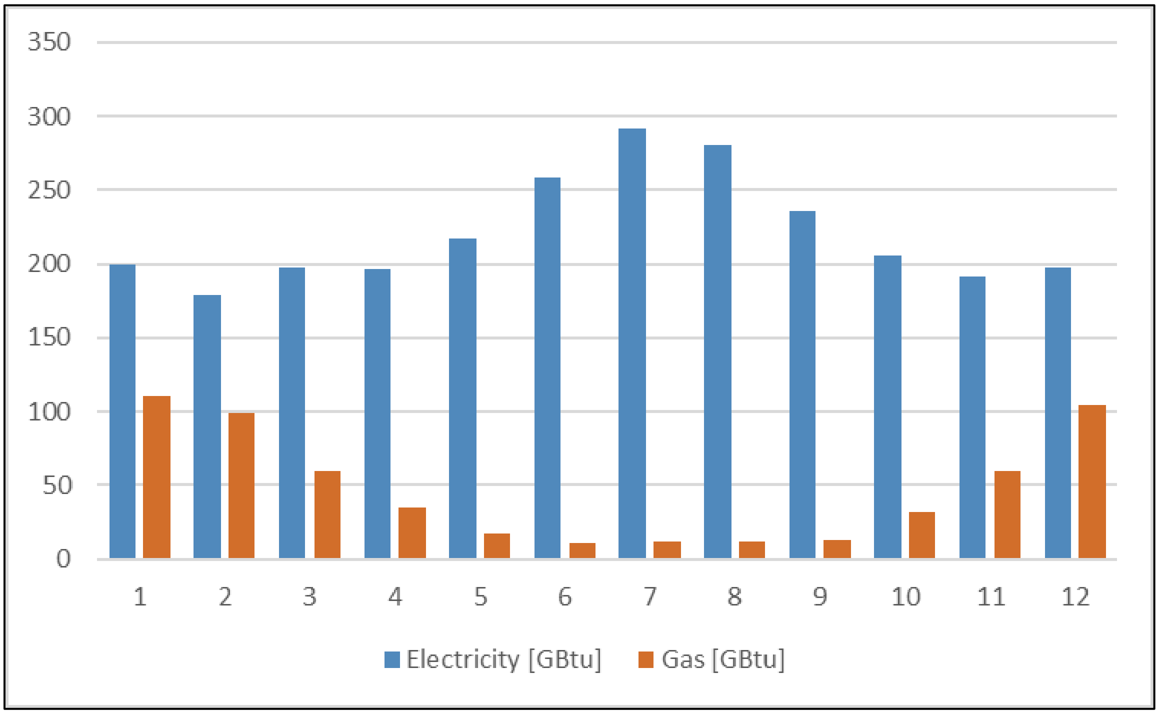

Figure 9 Monthly results [GBtu] – Initial model

4.2. Comparison with metered data

The initial result was compared with the metered energy consumption data which was collected through the energy bill. Table 9 and Figure 10 - 11 show the comparison.

For electricity, there is 71% difference between calculated and metered data. Looking into the monthly data, it is able to be found that the difference was greater during non-cooling periods. This indicates that the main cause of the difference is the base load by lighting and appliances.

For gas, there is -77% difference between calculated and metered data. Unlike electricity, the differences are not focused to a specific season. Rather, it is distributed evenly throughout the year, meaning that the main cause of the difference could be both heating and domestic hot water usage.

Table 9 Comparison between calculated and metered energy consumption

Months	Electricity [GBtu]		Difference	Gas [GBtu]		Difference
	Calculated	Metered	[%]	Calculated	Metered	[%]
1	199.2	97.3	105%	110.6	371.8	-70%
2	178.9	94.6	89%	99.4	327.0	-70%
3	198.0	88.6	123%	59.7	242.7	-75%
4	196.4	91.1	116%	34.4	177.3	-81%
5	217.5	118.1	84%	17.8	144.0	-88%
6	258.8	181.0	43%	10.9	124.2	-91%
7	292.3	193.6	51%	11.9	110.5	-89%
8	280.6	176.5	59%	12.0	103.5	-88%
9	235.4	183.1	29%	13.2	128.7	-90%
10	205.9	128.3	61%	31.9	147.0	-78%
11	191.4	104.4	83%	59.3	234.5	-75%
12	197.2	96.9	103%	104.5	337.2	-69%
Sum	2651.5	1553.5	71%	565.6	2448.4	-77%

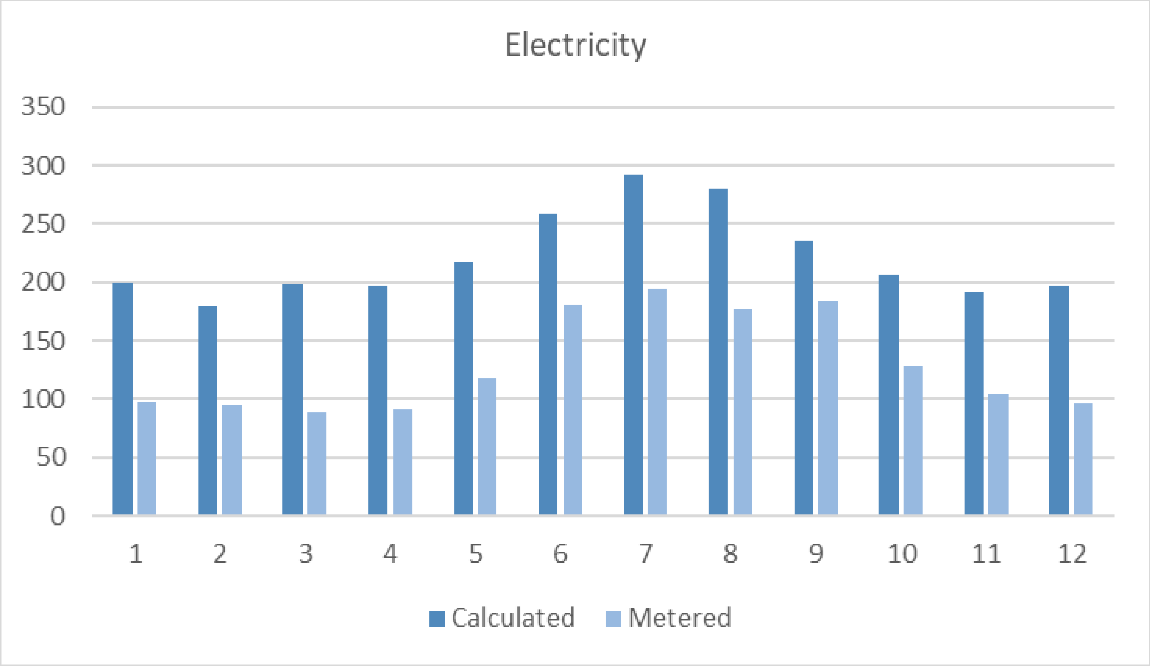

Figure 10 Comparison between calculated and metered electricity use [GBtu]

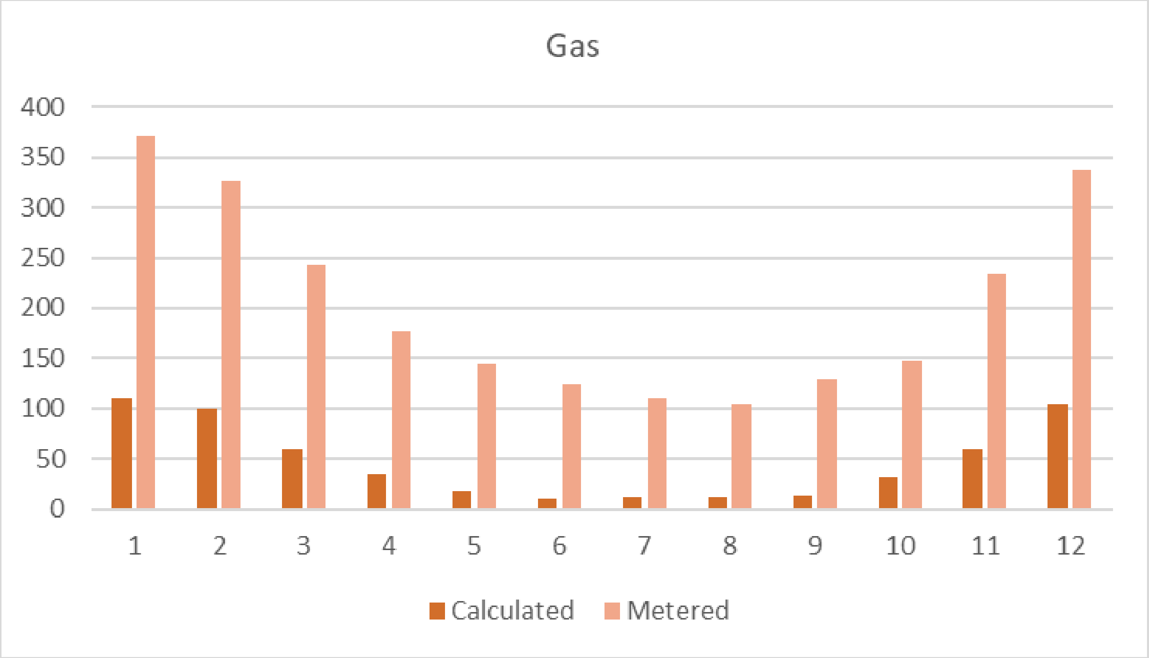

Figure 11 Comparison between calculated and metered gas use [GBtu]

5. Model Calibration

Based on the analysis results in section 4.2, strategies for the calibration were made as following:

1) To reduce the base load of the electricity, the power density for lightings or appliances could be reduced.
2) Infiltration rate and mechanical ventilation rate could be modified to effectively increase the calculated heating energy.
3) The consumption rate of the domestic hot water could be increased to increase overall gas consumption.

5.1. Correction 1: Power density for appliances

In the initial model, the power density for appliances of the mechanical rooms and service rooms was set to 64.5156 W/ft2 which is default value in the pre-defined template: 'Electrical equipment room'. However, in reality, there are only the AHUs in those rooms which does not use electrical power that much. Therefore, the power density was modified to 4.6452 W/ft2 which is default value in another template: 'Heavy plant room'. The calibration results are as Figure 12. For electricity, the annual difference reduced from 71% to -22%. For gas the annual difference reduced from -77% to -72%.

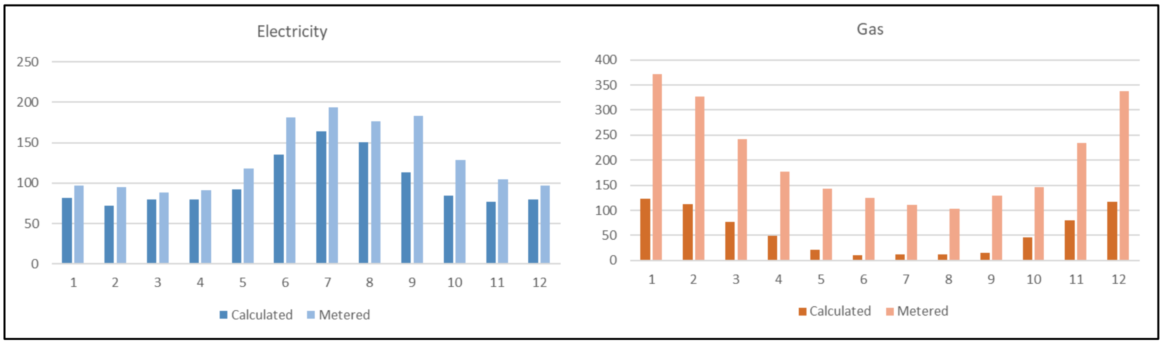

Figure 12 Results for correction 1

5.2. Correction 2: Infiltration rate

In Figure 16, the calculated gas consumption shows relatively low inclination during the winter season comparing to that of metered data. It means that the model is still less sensitive to the outside temperature. One way to increase such sensitivity is increasing the outside air flow rate.

The infiltration rate of the initial model was set to 0. Since the building is old and the exterior walls had not been retrofitted, it is expected that it is not air-tight. Moreover, through the site survey, several holes and cracks were found (Figure 13). According to a previous study, infiltration rate of an old building, especially those who constructed before 1970 could be around 5 to 6 ACH at 50 Pa (Rønneseth et al., 2019).

Figure 13 A hole in ceiling

Therefore, the infiltration rate was modified to 6 ACH. The calibration results are as Figure 14. For electricity, the annual difference changed -22% to -13%. For gas, surprisingly, the annual difference reduced significantly: -72% to -28%.

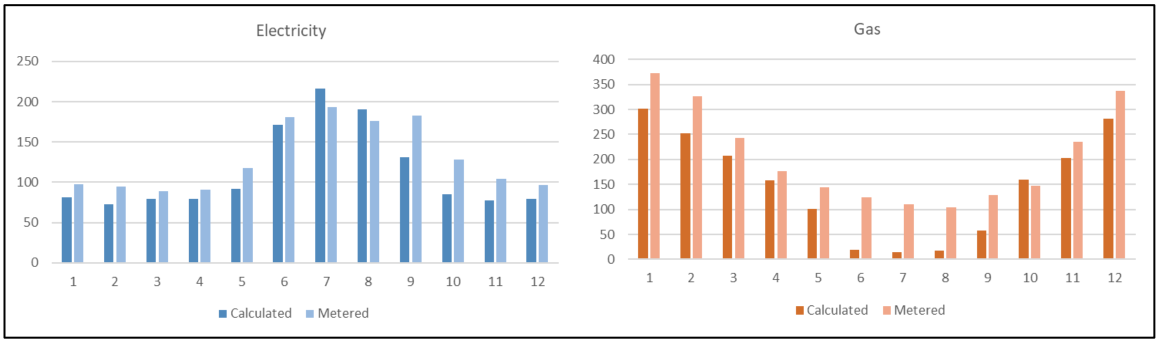

Figure 14 Results for correction 2

5.3. Correction 3: Domestic hot water usage

To increase the calculated gas consumption for all moths, the DHW consumption rate (gal/ft2 day) was tripled. The calibration results are as Figure 15. The annual difference for gas significantly reduced from -28% to -9%.

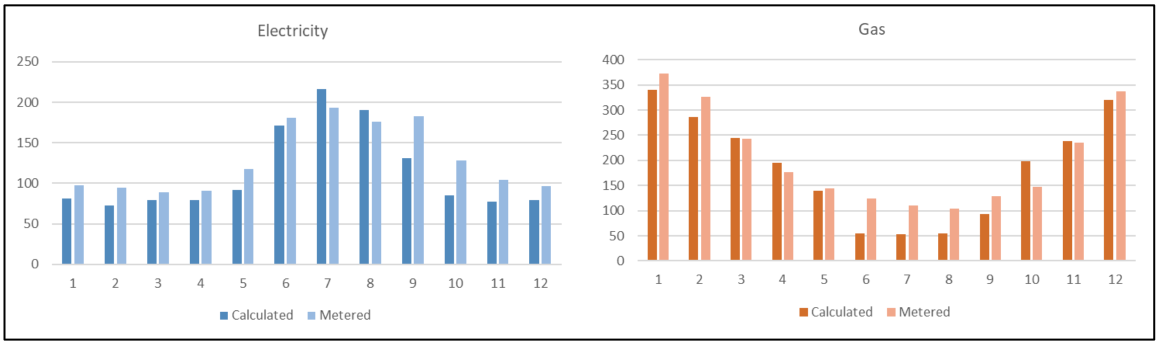

Figure 15 Results for correction 3

5.4. Correction 4: Boiler efficiency

In the initial model, the system type for the DHW was set to '4-Instantaneous hot water only'. However, the building uses the same boiler for both heating and DHW. Therefore, the system type changed to '1-Same as HVAC'. Moreover, the actual efficiency of a boiler tends to get lower than the rated efficiency as it gets old. Thus, the boiler efficiency for was modified from 85% to 70%. The calibration results are as Figure 19. The annual difference for gas significantly reduced from -9% to 1%.

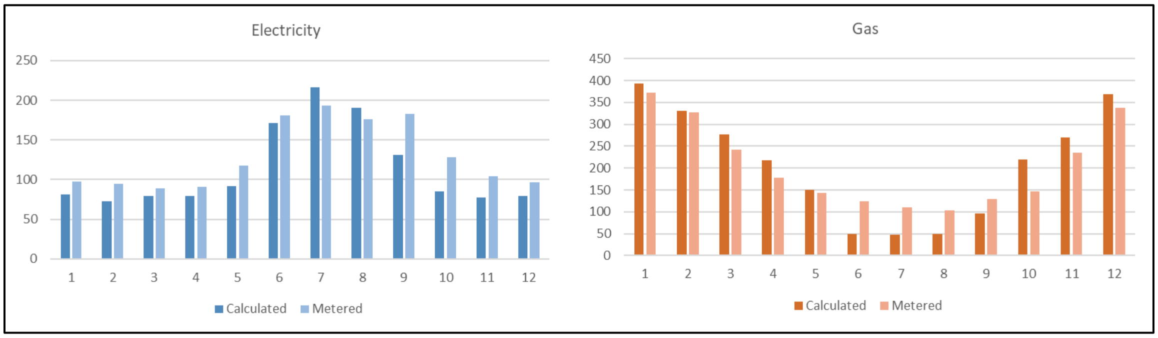

Figure 16 Results for correction 4

5.5. Calibration results

After four steps of correction, the annual calculation difference reduced to -13% and 1% for electricity and gas respectively. Still the model underestimates the electricity consumption, but the difference seems to be ignorable. Therefore, the model can be said well-calibrated.

As shown in Figure 17, the energy consumption distribution by end-uses of the calibrated model is quite different to that of the initial model. This demonstrates how important the calibration is to get accurate results.

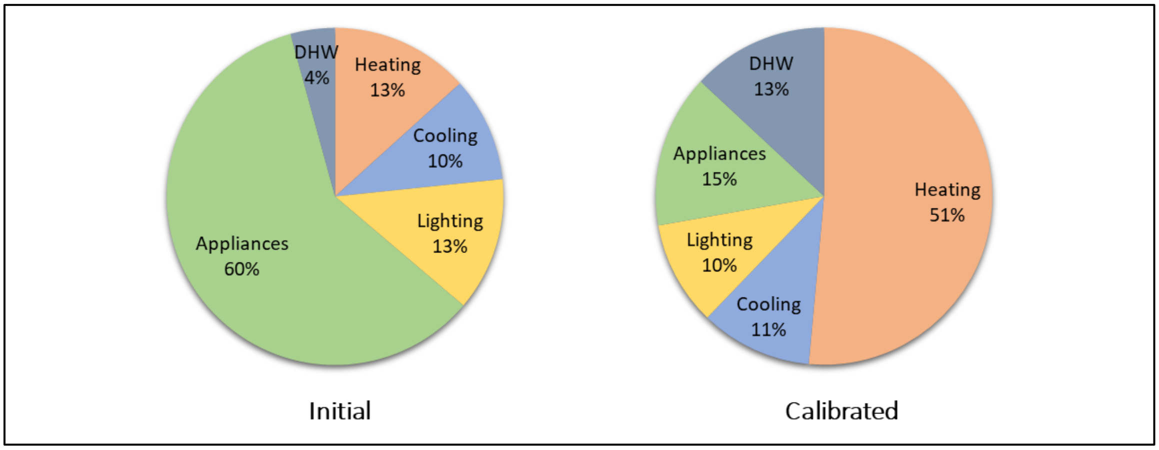

Figure 17 Comparison between the results of initial and calibrated model

6. Space Performance Analysis

In this section, the energy and daylight performance of the building are analyzed using the calibrated model. Then, the areas for improvement in energy-efficiency are identified and prioritized.

6.1. Energy performance

Table 10 – 11 and Figure 18 – 19 shows the simulation results for the whole-building. Overall, the heating energy takes the most of the total energy. Therefore, the first target of improvement would be something that can reduce the heating demand.

Table 10 Simulation results – calibrated model

End uses	Annual energy consumption [kBtu]
Heating	428204.4
Cooling	323250.1
Lighting	412984
Appliances	1915300
DHW	137381.8
Total	3217120.3

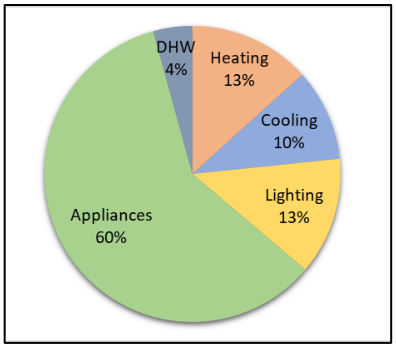

Figure 18 Energy distribution – calibrated model

Table 11 Monthly results – calibrated model

Months	Electricity [GBtu]	Gas [GBtu]
1	81.4	392.6
2	72.4	329.8
3	79.0	277.4
4	79.4	217.7
5	91.4	149.4
6	171.4	49.5
7	216.2	47.1
8	190.3	49.3
9	131.3	95.9
10	85.5	219.6
11	77.3	270.7
12	79.7	368.1
Sum	1355.2	2467.1

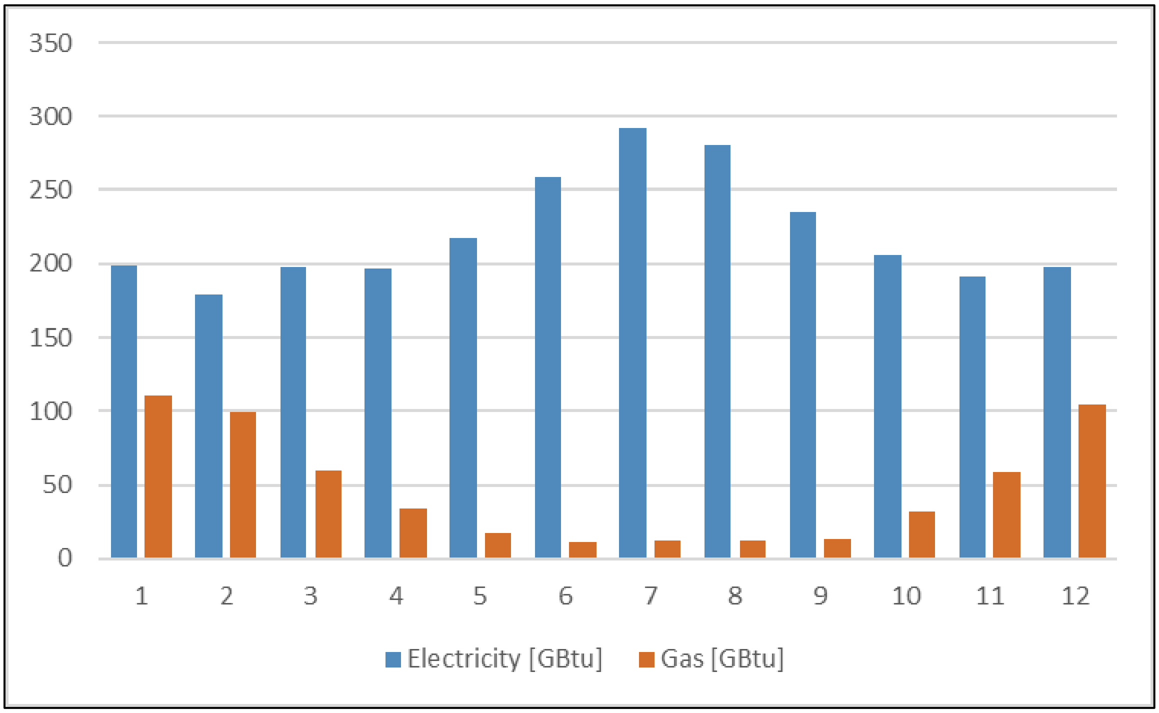

Figure 19 Monthly results – calibrated model

To identify the main cause of the heating demand, the heat transfer through the fabrications and ventilation was analyzed. As shown in Figure 20, the heat loss by the external is the most significant problem. Interestingly, the ground floors are shown to be even advantageous in terms of heating. Even though the exterior wall is not insulated, the impact of wall is not considerably high. It might be because the positive effect of the below grade walls compensates the negative effect of the exterior walls.

Figure 20 Heat transfer through fabrications and ventilation

Next, energy use heating and cooling were identified by zone. Figure 21 – 22 show the energy use for each zone sorted largest to smallest. For both heating and cooling, the mechanical room on the ground floor (G_MEC_2) showed to have excessively high energy consumption. It is because G_MEC_2 has a large floor area (2,007.85 ft2) and it generates relatively high amount of heat than other area, resulting high cooling energy demand. In general, mechanical rooms and service rooms do not require air-conditioning. However, those in Children's Research Center are set to be conditioned 24 hours. Therefore, it would be more efficient for the building to have individual operation systems to prevent unnecessary energy use.

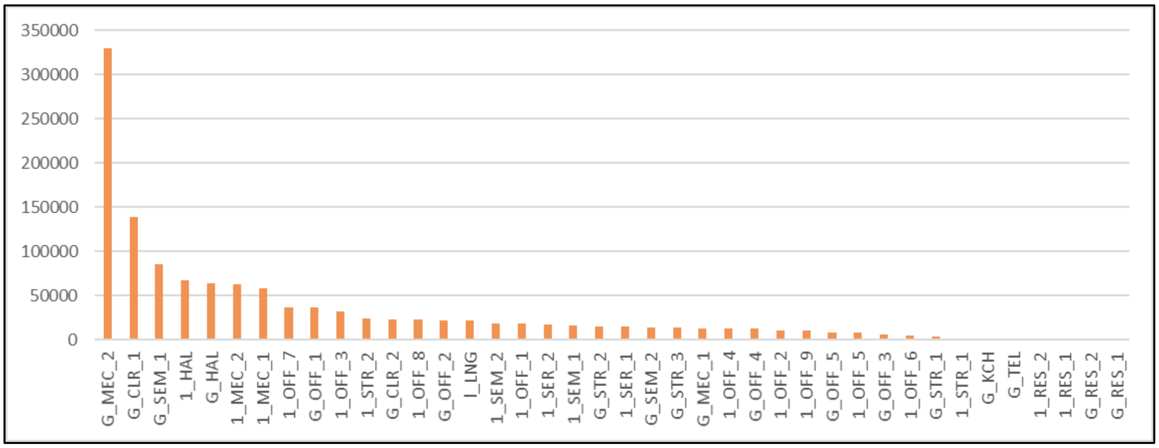

Figure 21 Annual heating energy by zone [kBtu]

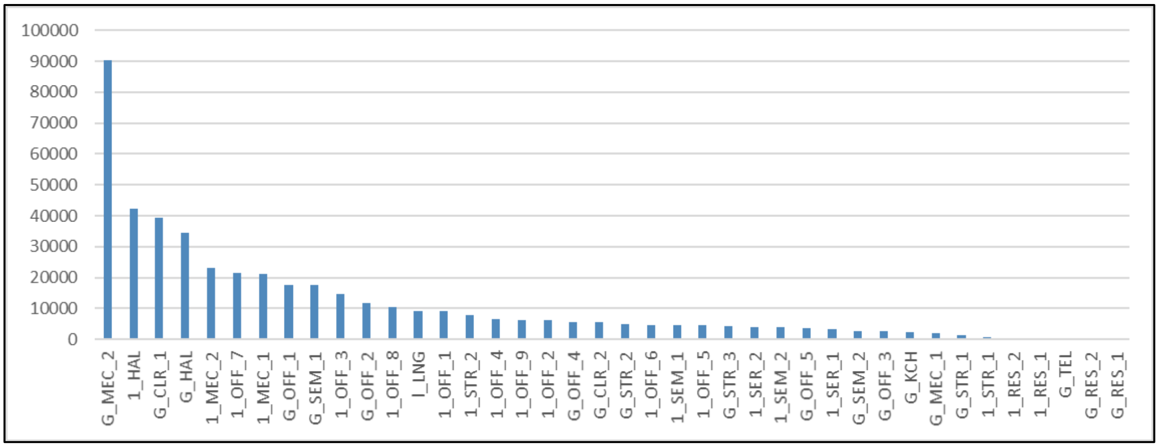

Figure 22 Annual cooling energy by zone [kBtu]

6.2. Daylight performance

Figure 23 – 24 are illuminance maps for each floor level. Since the window-to-wall ratio of the building is only 22%, it showed poor daylight performance. The hallway area near the entrances showed the highest maximum illuminance, 267 lux. The average illuminance of the office area in the perimeter zone was only 21 lux. These results indicate that it would be hard to employ daylight to reduce the lighting energy.

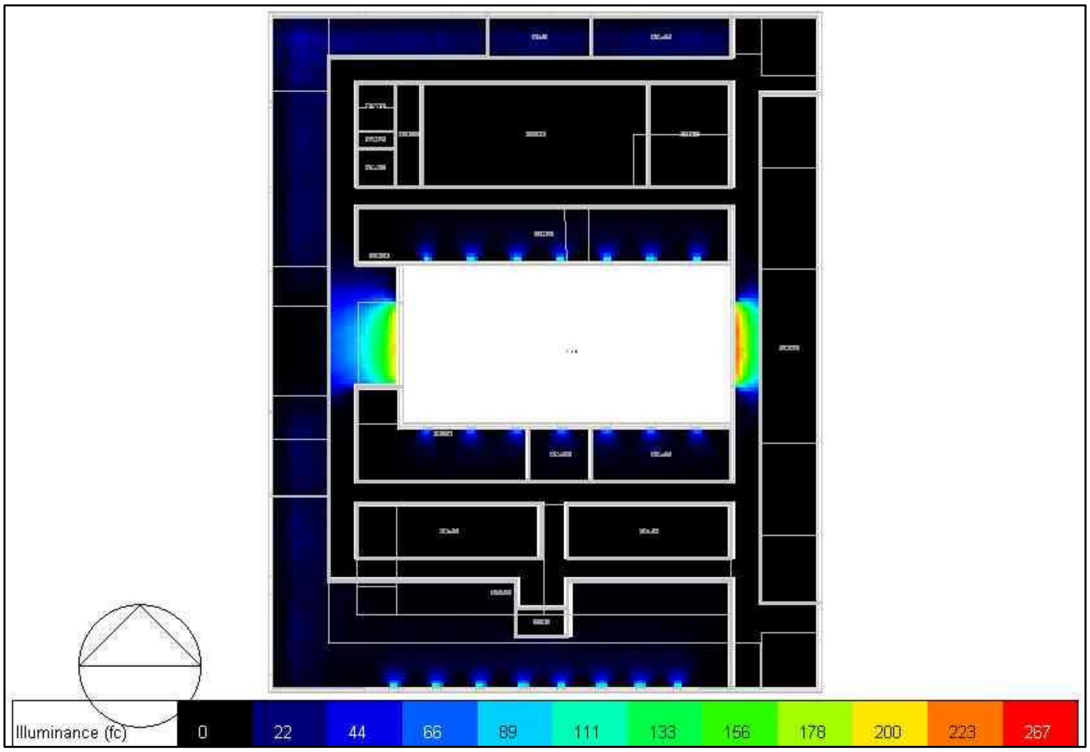

Figure 23 Illuminance map – ground floor

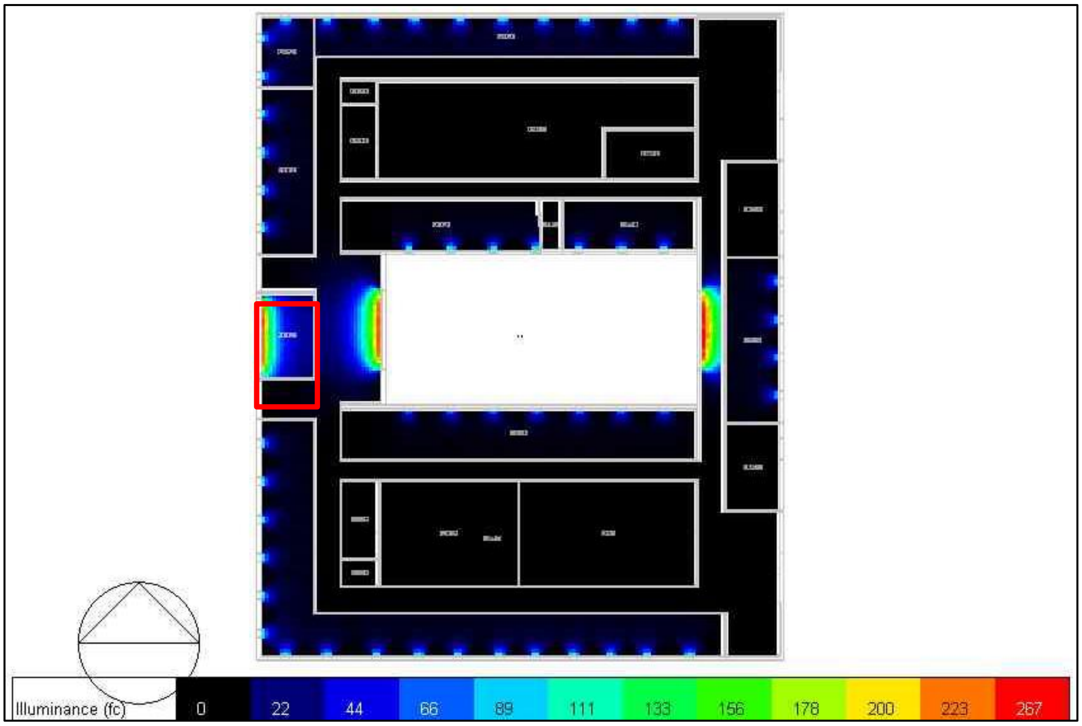

Figure 24 Illuminance map – first floor

7. Energy Retrofit Strategies

In this section, three different retrofit strategies are proposed based on the analysis results. Moreover, the energy saving-potential and the predicted percentage of dissatisfied (PPD), which is an indicator of human thermal comfort, were tested for each case.

7.1. Strategy 1: Air-tightness improvement

Airtightness is critical importance in improving the energy performance of buildings. The low airtightness can be caused by uncontrolled air leakage and a reduction in effectiveness of mechanical ventilation systems. The majority of observed air leakage is usually attributable to a combination of a number of cracks, joints and gaps rather than to a single element or component.

However, it is not always beneficial to have low infiltration rate. Too low infiltration rate may cause the increase in cooling energy demand, especially in office buildings where the internal gains are relatively high. Moreover, it can poor the indoor air quality if the minimum outside air supply is not guaranteed.

To find the optimal infiltration rate that can minimize the sum of heating an cooling energy, multiple simulation were run with different infiltration rate values.

The result is shown in Figure 25. Unlike expected, both of the heating and cooling energy decreased continuously as the infiltration rate decreased. Therefore, presuming that the most of the joints and cracks are sealed with air tight adhesives, the new infiltration rate was set to 0.6 ACH which is the criteria threshold of a Passive House (BRE).

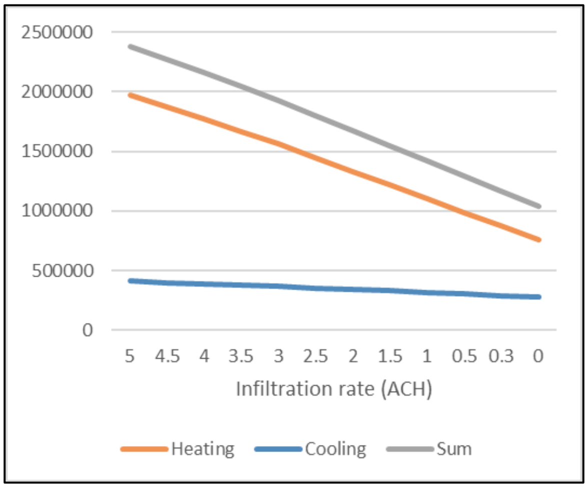

Figure 25 Simulation results [kBtu] by infiltration rate variation

Table 12 and Figure 26 - 27 show the test result of strategy 1. The annual heating and cooling energy decreased 54% and 28% respectively, resulting the 31% decrease of total energy consumption. Moreover, the annual PPD also decreased from 38% to 27%, meaning the improvement of thermal comfort.

Table 12 Test results – strategy 1

	Annual energy consumption [GBtu]		
End uses	Base case	Strategy 1	Change rate
Appliances	561.4	561.4	0%
Lighting	383.0	383.0	0%
Heating	1966.6	898.7	-54%
Cooling	410.7	295.9	-28%
DHW	500.5	500.5	0%
Total	3822.2	2639.5	-31%

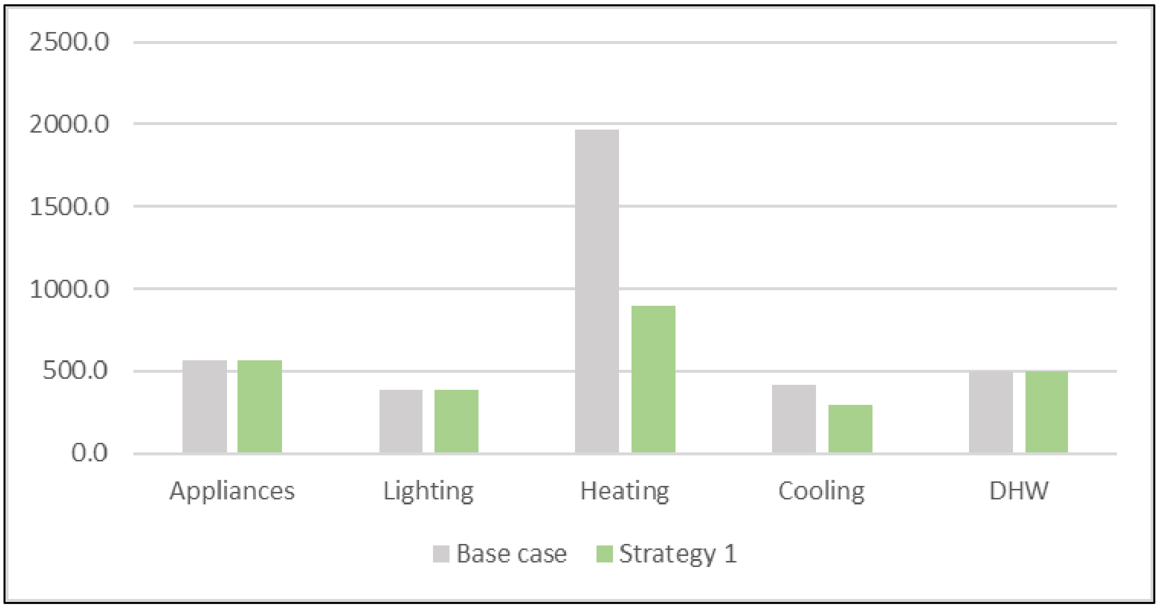

Figure 26 Test results [GBtu] – strategy 1

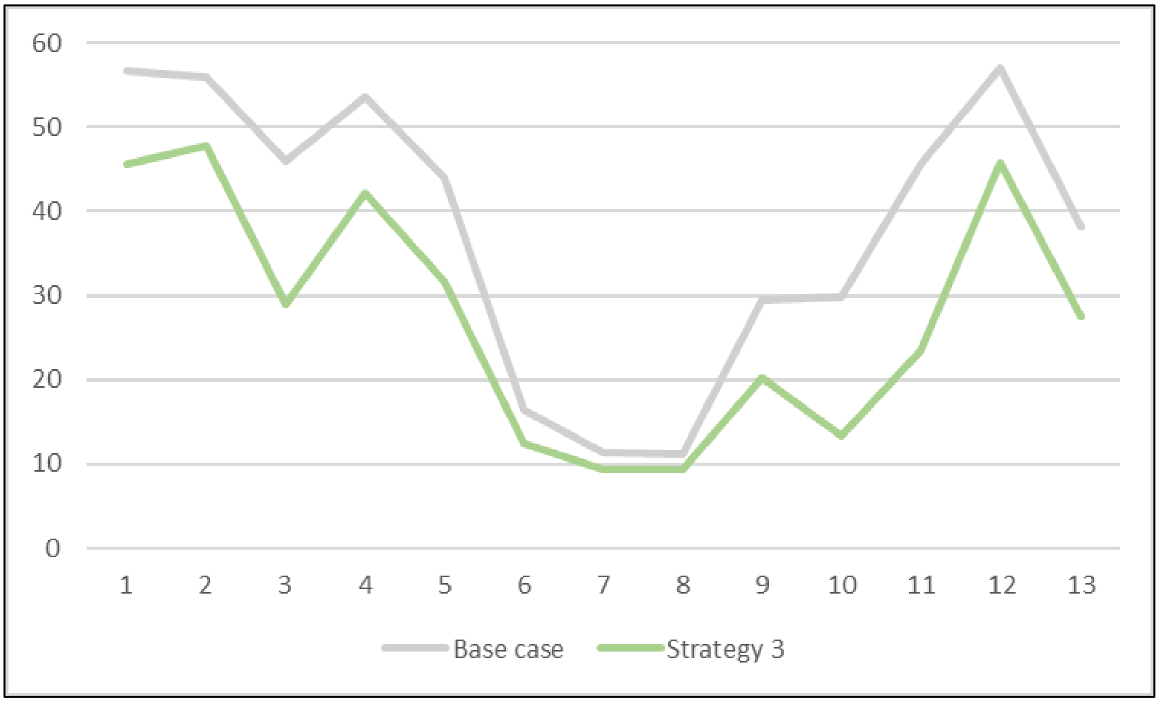

Figure 27 PPD [%] change – strategy 1

7.2. Strategy 2: Insulation and thermal inertia improvement

Since the walls are not insulated and the windows are made of single pane glazing, the building is vulnerable to the outside condition especially in winter. To enhance the thermal resistance of the exterior surfaces, it is recommended to install insulation on the wall and change the window glazing to double glazing.

The new properties of the exterior walls and the glazing is shown in Table 13. The gap between the glasses is filled with 00 to improve the convective resistance. The U-value of the new wall is improved from 0.481 to 0.035 Btu/h ft2 °C. The U-value of the new glazing is improved from 1.038 to 0.442 Btu/h ft2 °C.

Table 13 New properties of the exterior walls and the glazing

Component	Layers	U-value [Btu/h ft2 °C]
External walls	1 in brick / 12 in reinforced concrete / 1 in brick	0.035
Glazing	6 mm clear glass / 13 mm argon / 6 mm clear glass	0.442

Another important property of the construction material is thermal mass. It is a property of a high-density material such as concrete which enables it to store heat, providing inertial against temperature fluctuation. The benefit of high thermal mass is the delay of heat transfer, resulting lower peak demands. However, the impact of the thermal mass could vary according to its location with respect to the insulation layer.

To get the best result, the simulation was conducted for three different cases: 1) Mass outside, 2) Mass inside and 3) Sandwich. Figure 28 shows the wall construction layer of each cases. The construction of the roof was also changed to follow the same logic as the wall. Note the U-values of the three cases are identical.

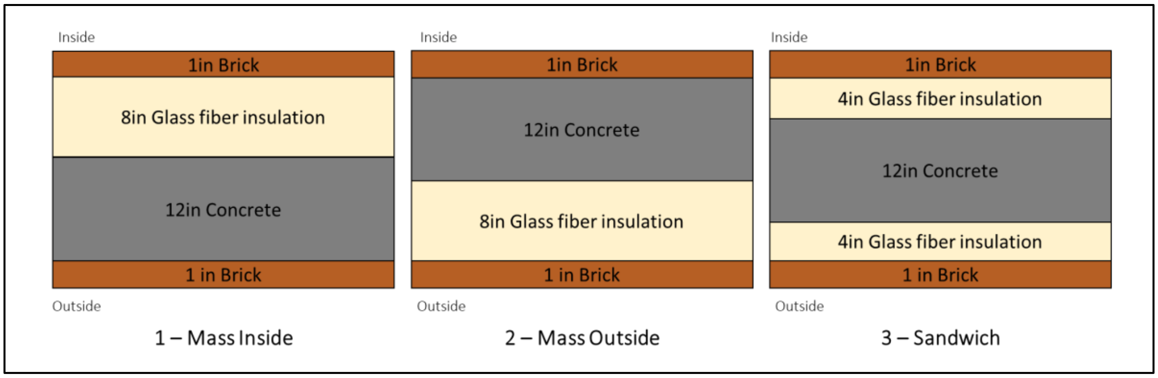

Figure 28 Wall construction layers for three cases

The result is shown in Figure 29. Among three cases, the case with the mass placed outside of the insulation showed the best performance. Therefore, it was decided to install the insulation (8 in glass fiber) on the inside of the concrete of the exterior wall and change the window glazing to double glazing.

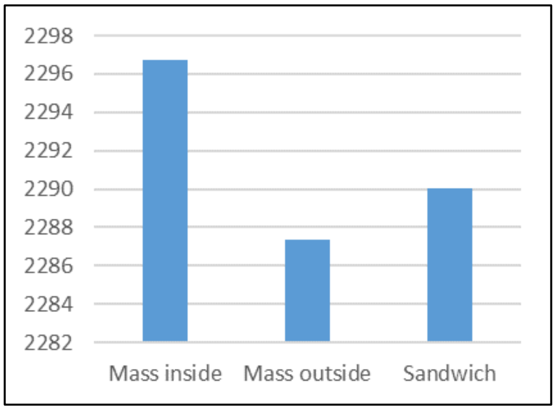

Figure 29 Total energy [GBtu] for three cases

Table 14 and Figure 30 – 31 show the test result of strategy 2. The annual heating and cooling energy only decreased by 4% and 3% respectively, resulting only 2% decrease of total energy consumption. The annual PPD increased from 38% to 43%, meaning that the occupants are more exposed to the discomfort.

Table 14 Test results – strategy 2

	Annual energy consumption [GBtu]		Change rate
End uses	Base case	Strategy 1	
Appliances	561.4	561.4	0%
Lighting	383.0	383.0	0%
Heating	1966.6	1888.7	-4%
Cooling	410.7	397.5	-3%
DHW	500.5	500.5	0%
Total	3822.2	3731.1	-2%

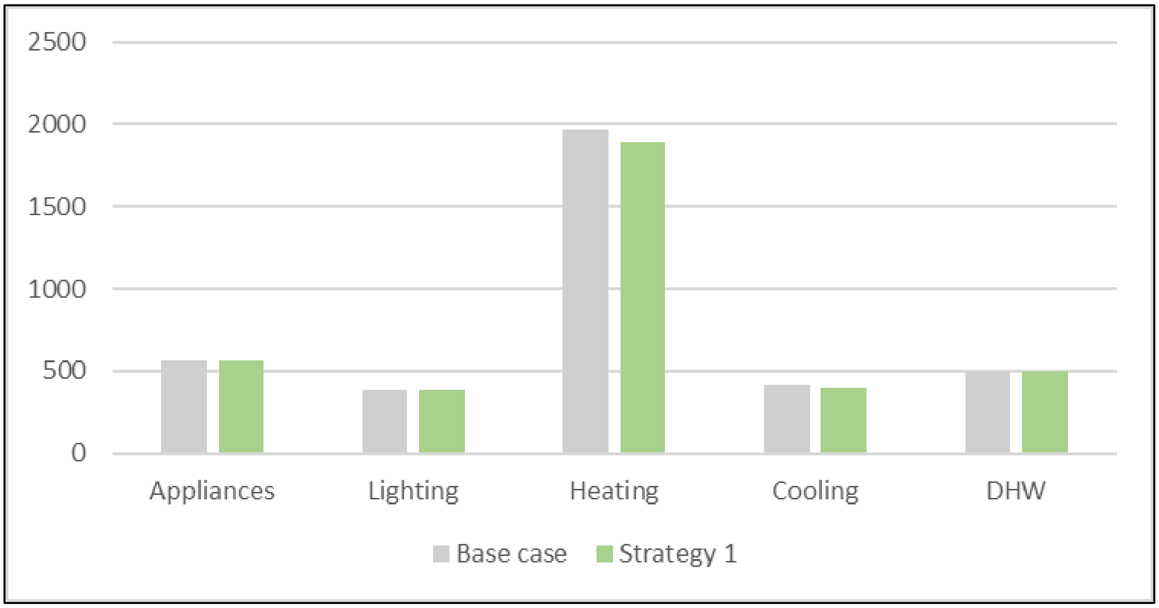

Figure 30 Test results [GBtu] – strategy 2

Figure 31 PPD [%] change – strategy 2

7.3. Strategy 3: Energy-efficient HVAC system with individual operation

Current HVAC system of the building is a CAV system without a heat recovery system. Heat recovery system, which is also called as mechanical ventilation heat recovery (MVHR), allows a part of the conditioned indoor air energy provided to be recovered with a system of mechanical ventilation. In winter, it preheats the cold outdoor air and, in summer, it cools it down (Picallo-Perez et al., 2021). Figure 32 shows the concept of heat recovery system. Since the project building has large volume supplied with mechanical ventilation, it would be helpful to reduce both heating and cooling energy if heat recovery system is applied.

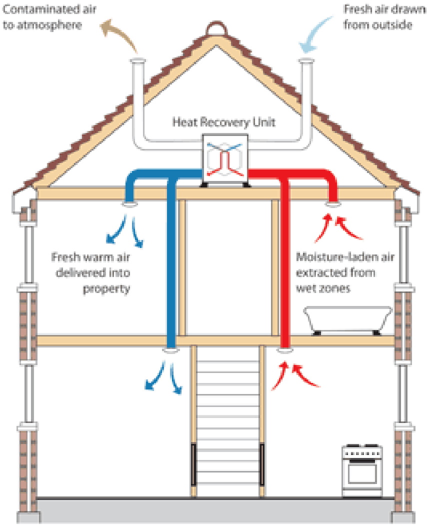

Figure 32 Concept of heat recovery system

(source: https://homestylegreen.com)

Moreover, all zones are having the same HVAC schedules, meaning that the zone is conditioned even if it is unoccupied. Moreover, from the analysis, it was discovered that the mechanical rooms are using excessive energy because of unnecessary air-conditioning. Therefore, it is urgent to make the HVAC system be operated in zone level.

For strategy 3, the heat recovery units were installed for all zones. Moreover, the HVAC schedules were modified to follow the occupancy schedules for offices, lounges, seminar rooms, and classrooms. The mechanical rooms and service rooms were set to be unconditioned, only be ventilated by the mechanical system.

Table 15 and Figure 33 – 34 show the test results of strategy 3. The annual heating and cooling energy only decreased significantly by 76% and 29% respectively, resulting 42% decrease of total energy consumption. However, the annual PPD showed little change, decreasing from 38.1% to 37.9%, meaning almost no improvement of thermal comfort.

Table 15 Test results – strategy 3

	Annual energy consumption [GBtu]		Change rate
End uses	Base case	Strategy 1	
Appliances	561.4	561.4	0%
Lighting	383.0	383.0	0%
Heating	1966.6	463.6	-76%
Cooling	410.7	291.9	-29%
DHW	500.5	500.5	0%
Total	3822.2	2200.4	-42%

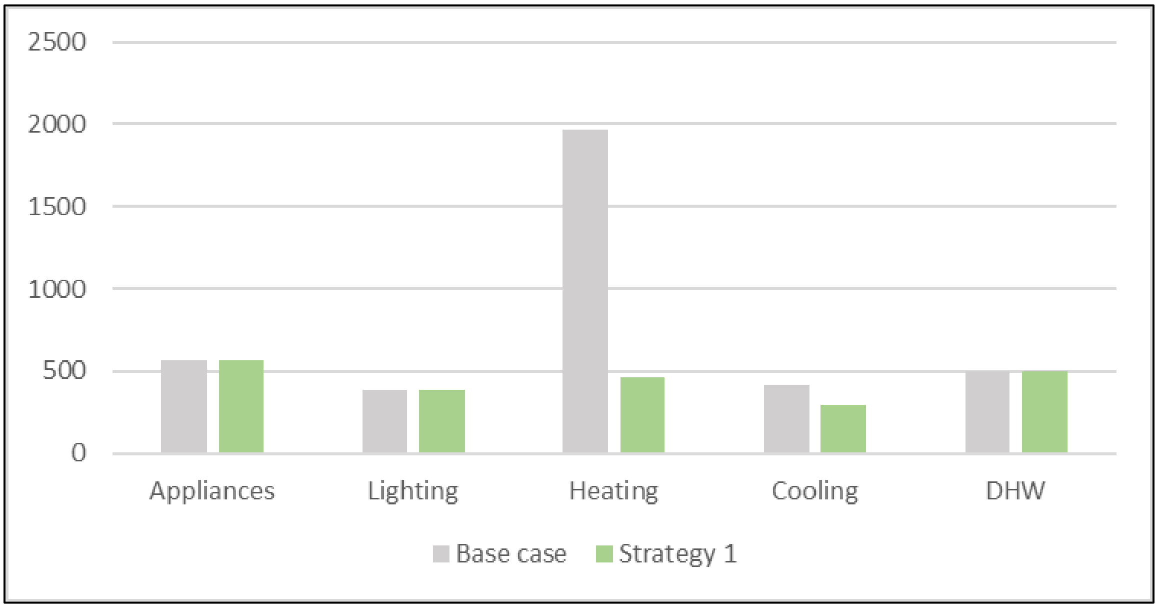

Figure 33 Test result [GBtu] – strategy 3

Figure 34 PPD [%] change – strategy 3

8. Conclusion

In this project, an energy model of Children Research Center was generated, calibrated and analyzed to identify and prioritize the area for improvement. Finally, three retrofit strategies that can reduce the building energy performance were proposed.

Following are the key findings from this project:

1) An initial energy model can have significant difference with the actual energy performance. However, the gap can be bridged by tuning the input parameters, especially those related to the building operation and occupants' behavior.
2) The project building uses much energy for heating (196.7 GBtu) and the main cause is the heat loss through the infiltration. Moreover, the whole building is conditioned using the same HVAC system, resulting unnecessary energy use.
3) By improving the air-tightness of the building from 5 to 0.6 ACH, the annual total energy consumption can be decreased by 31%. Also, by adopting heat recovery system and letting the HVAC system be controlled in zone-level, it can be decreased by 42%.
4) Unlike the two strategies, improving the insulation and thermal inertia is not very effective; the annual consumption can be decreased by only 2%.

Since one input parameter can affect different end-uses (i.e. heating, cooling, lighting, appliances, and DHW) coincidentally, it was difficult to find the best combination of the inputs manually. Therefore, to improve the calibration quality and work efficiency, an optimization algorithm that can find the best set of inputs automatically needs to be developed. .

The retrofit strategies proposed in this project were not helpful to improve the occupant's thermal comfort. In future projects, advanced strategies could be proposed which can balance both energy use and human comfort. Moreover, some other strategies like renewable energy generation systems would be helpful to reduce the net energy use significantly.

References

US DOE, https://www.energy.gov/eere/buildings/retrofit-existing-buildings

Moncef Krarti, Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers, Ch 9, 2018

Christopher Mathis, Roofs, energy efficiency, codes, and sustainability: Complexity and compromise on the road to Net Zero, 26th RCI Int. Conv. & Trade Show, 2011

Kaiser Ahmed et al., Occupancy schedules for energy simulation in new prEN16798-1 and ISO/FDIS 17772-1 standards, Sustainable Cities and Society, Vol 35, 2017

Jie Zhao et al., Occupant behavior and schedule modeling for building energy simulation through office appliance power consumption data mining, Energy and Buildings, Vol 82, 2014

Øystein Rønneseth et al., Is it possible to supply norwegian apartment blocks with 4th generation district heating?, Energies 2019, 12, 941, 2019

BRE, Passivhaus primer: Airtightness Guide

A. Picallo-Perez et al., Ventilation of buildings with heat recovery systems: Thorough energy and exergy analysis for indoor thermal wellness, Journal of Building Engineering, Vol 39, 2021