ARC 523 – Individual Presentation

Seungmin Lee

NC STATE College of Design

1. Building description and weather data

Building Information

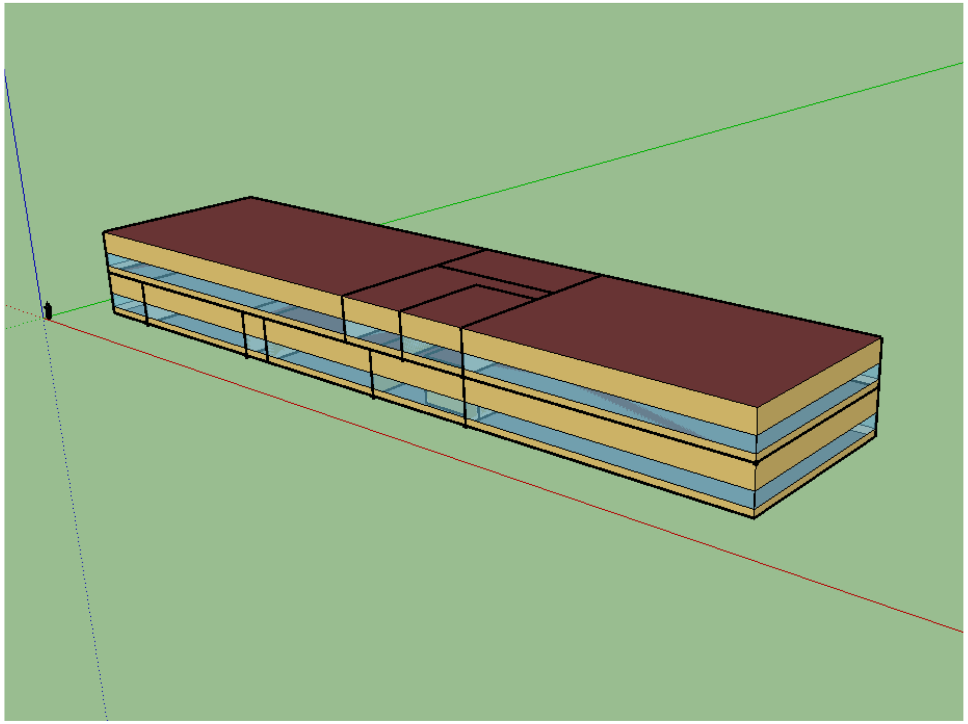


Figure 1. Modeling of the target building

Categories	Details
Building type	Office
Number of floors	2
Building size	275 ft × 65 ft
Building height	30.4 ft
Window-to-Wall-Ratio(WWR)	33%[1)]

1) 2003 CBECS Data and PNNL's CBECS Study 2007

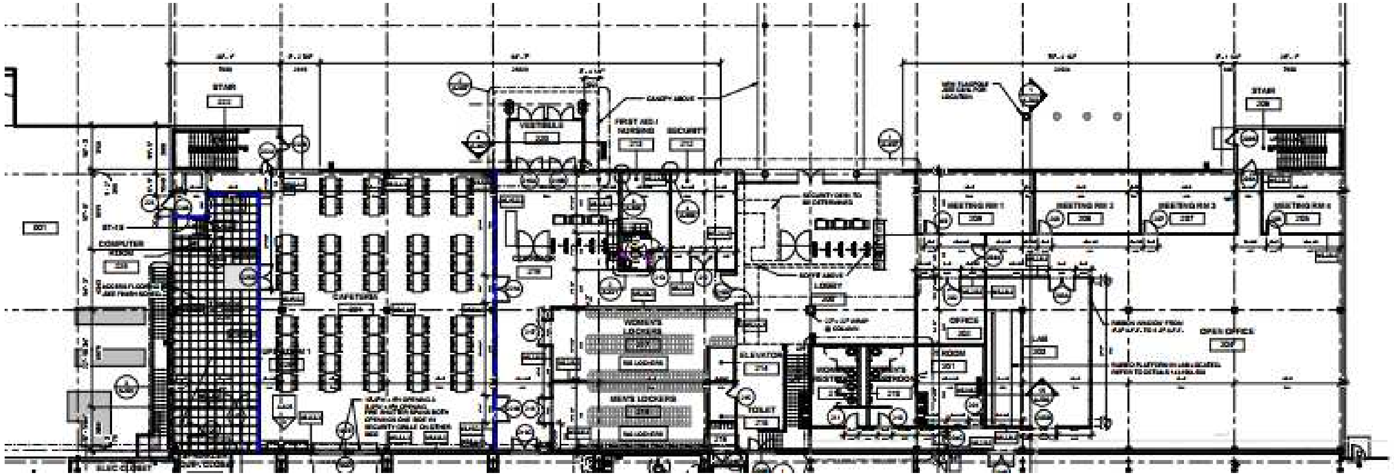


Figure 2. Floor 1 of the target building

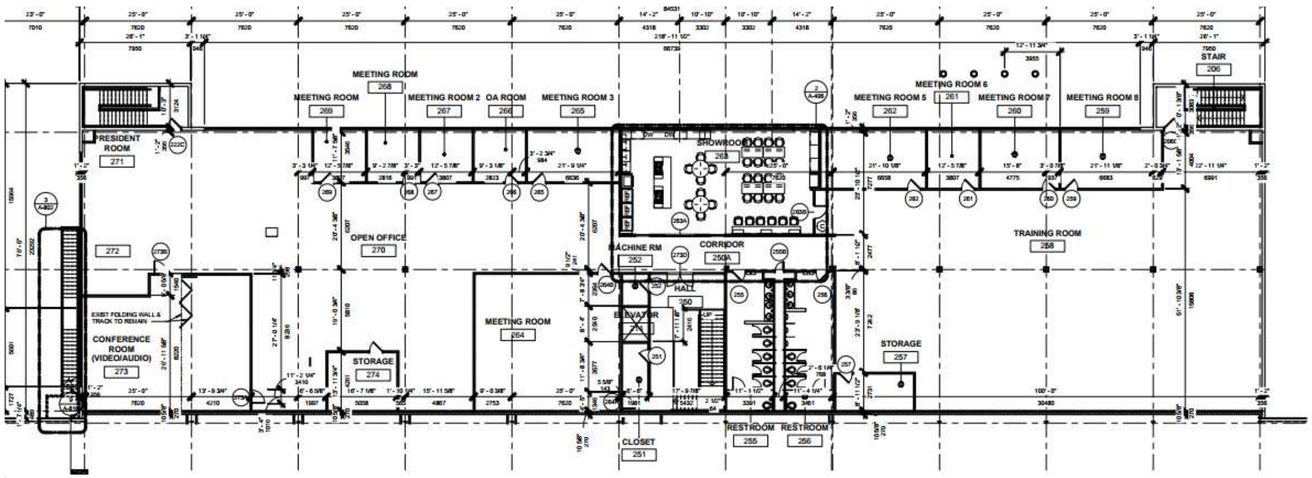


Figure 3. Floor 2 of the target building

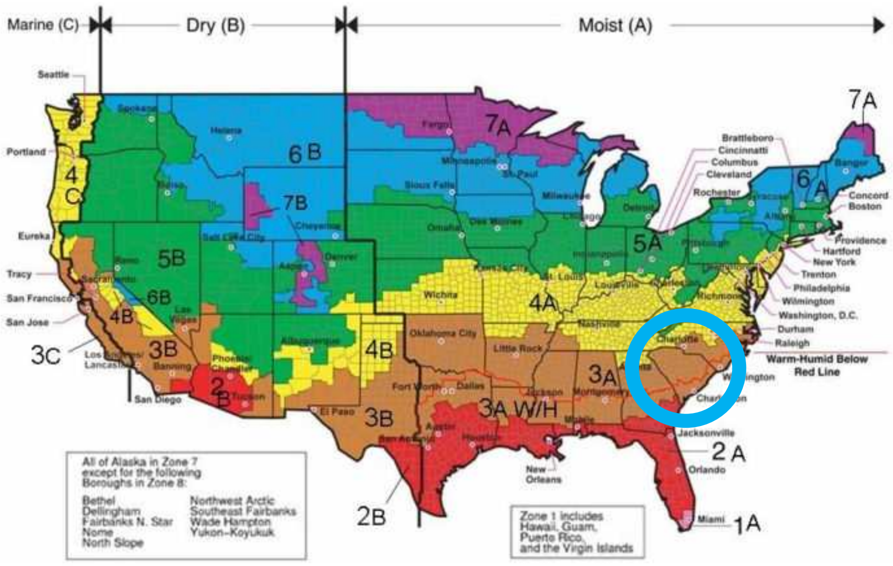


Figure 4. The climate zone map of IECC

HYGRO-THERMAL ZONE CRITERIA

Zone	Type	Thermal Criteria	Hygric Criteria	Representative City
1A	very hot - humid	CDD50 > 9000		Miami FL
1B	very hot - dry	CDD50 > 9000		(no US locations)
2A	hot - humid	CDD50 > 6300 ≤ 9000	> 20" precipitation, Tavg > 45° (note 2)	Houston TX
2B	hot - dry	CDD50 > 6300 ≤ 9000	< 20" precipitation, Tavg > 45°	Phoenix AZ
3A	warm - humid	CDD50 > 4500 ≤ 6300		Memphis TN
3B	warm - dry	CDD50 > 4500 ≤ 6300		El Paso TX
3C	warm - marine	HDD65 ≤ 3600		San Francisco CA
4A	mixed - humid	CDD50 ≤ 4500 & HDD65 ≤ 5400		Baltimore MD
4B	mixed - dry	CDD50 ≤ 4500 & HDD65 ≤ 5400	< 20" precipitation, Tavg ≤ 45°	Albuquerque NM
4C	mixed - marine	HDD65 > 3600 ≤ 5400		Salem OR
5A	cool - humid	HDD65 > 5400 ≤ 7200		Chicago IL
5B	cool - dry	HDD65 > 5400 ≤ 7200		Boise ID
5C	cool - marine	HDD65 > 5400 ≤ 7200		(no US locations)
6A	cold - humid	HDD65 > 7200 ≤ 9000		Burlington VT
6B	cold - dry	HDD65 > 7200 ≤ 9000		Helena MT
7	very cold	HDD65 > 9000 ≤ 12,600		Duluth MN
8	subarctic	HDD65 > 12,600		Fairbanks AK
A = Humid	Not Marine and Precipitation ≥ 0.44 x (Tavg - 19.5)			
B = Dry	Not Marine and Precipitation < 0.44 x (Tavg - 19.5)			
C = Marine	Tavg coldest month 27° - 65° and Tavg warmest month < 72° and at least 4 months Tavg > 50° and dry season in summer (note 1)			
note 1	cold season Oct-Mar and heaviest cold season monthly rainfall at least 3 times as much as heaviest warm season monthly rainfall			
note 2	≥ 67° wet bulb temp for ≥ 3,000 hours or ≥ 73° wet bulb temp for ≥ 1,500 hours during the warmest six consecutive months			

Figure 5. The Thermal zone criteria of IECC

- According to the IECC's climate zone map, South Carolina falls within Zone 3A(Figure 4).
- Zone 3A represents a mild and humid climate condition(Figure 5). Winters are relatively mild, while high temperatures and humidity characterize summers. The summer months can bring heavy rainfall.
- Therefore, an air conditioning system capable of effectively managing the high temperatures and humidity during the summer is necessary.

Construction Set

1) Construction Set name: ‘Seungmin_Construction Sets’

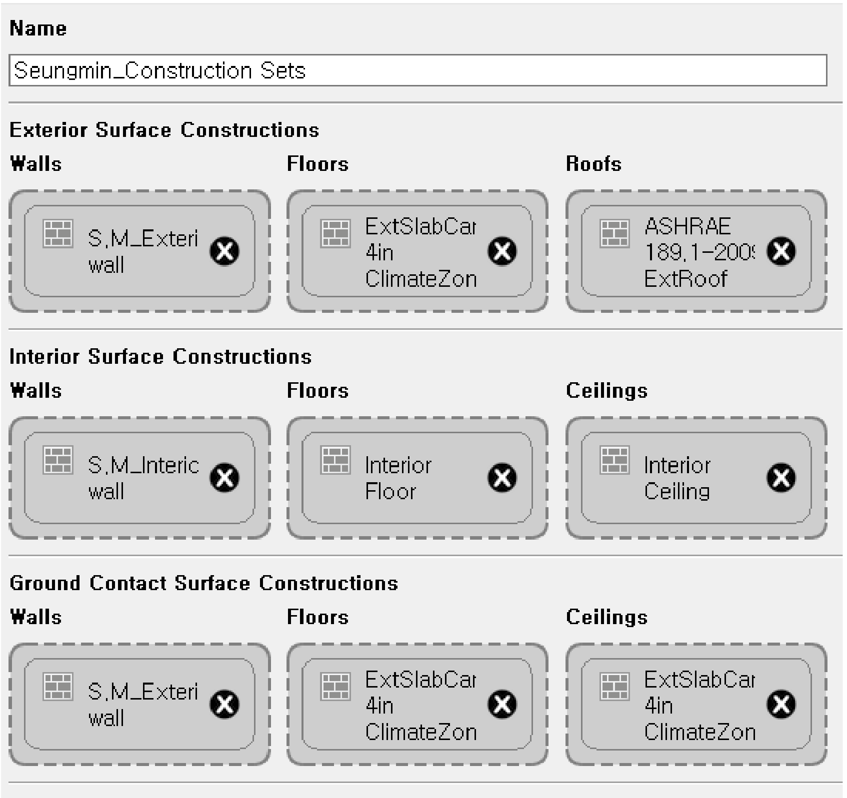


Figure 6. ‘Seungmin_Construction Sets’ details

2) Wall materials

The wall consists of two 5/8-inch gypsum boards, insulation, and metal studs (Figure 7).

The wall composition was based on the ‘wall type legend’ of the building I referenced (Figure 8).

The order of materials should be opposite for the exterior and interior walls, but the wall composition I referenced is 'gypsum board-stud-insulation-stud-gypsum board', so the exterior and interior walls are the same.

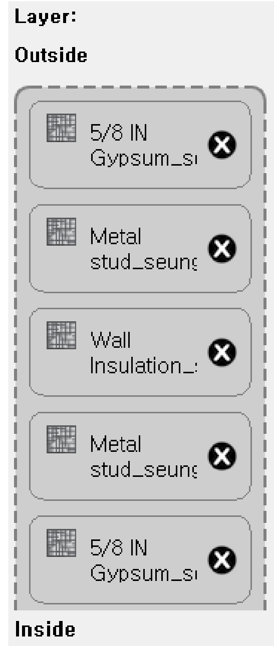


Figure 7. ‘S.M_Exterior wall’ details

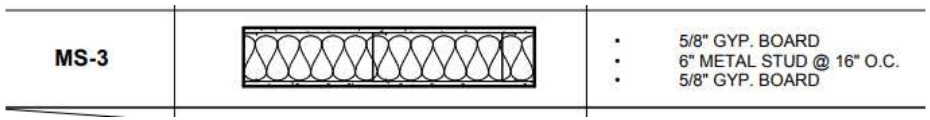


Figure 8. Wall type legend

1) People definitions

I changed the 'People per Space Floor Area' of office to 0.005(Figure 9), referring to ASHRAE 62-1(Figure 10).

Name:

Seungmin_office people definition

Number of People:	People per Space Floor Area:	Space Floor Area per Person:
	0.005000 people/ft^2	ft^2/person

Figure 9. 'Seungmin_office people definition' details

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Office Buildings									
Office space	5	2.5	0.06	0.3	H	5	17	8.5	1

Figure 10. ASHRAE Standard 62-1 [Table 6.2.2.1]

Internal Heat Gain

2) Lights definitions

I changed the 'Watts per Space Floor Area' of office to 0.56(Figure 11), referring to ASHRAE 90.1(Figure 12).

Figure 11. 'Seungmin_office light definition' details

Common Space Types[a]	LPD, W/ft^2
Office	
Office ≤150 ft^2	0.73
Office >150 and ≤300 ft^2	0.66
Offices >300 ft^2	0.56

Figure 12. ASHRAE Standard 90.1 [Table 9.5.2.1-1]

Schedule Set

- I referred to the office schedule provided by ASHRAE (Figure 13).
- The Schedule is divided into Mon-Fir, Sat, and Sun.
- Because it is an office, Mon-Fir has reduced rates for both People, Lights, and Equipment from 12-1pm during lunch hours.
- Saturdays operate at approximately 30% of weekday hours, and Sundays operate at a very low rate.

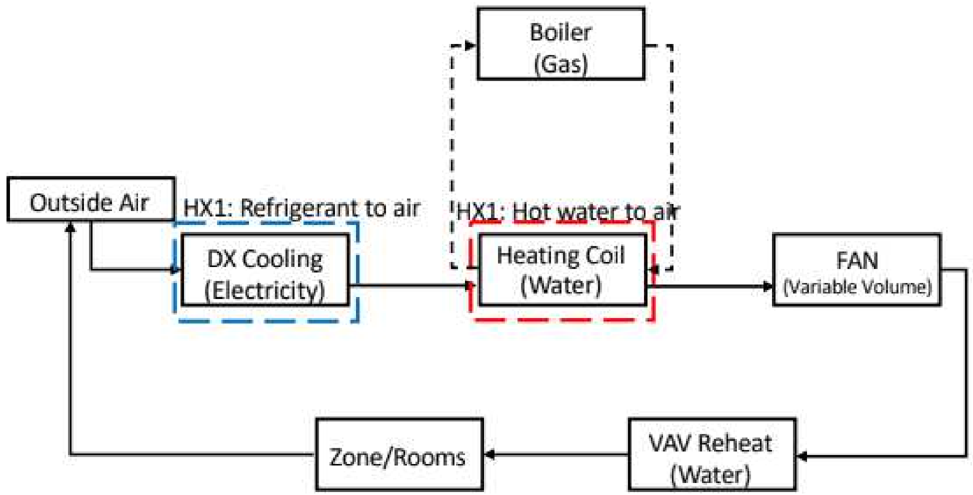
	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12am	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12pm
Occupants																								
Mon – Fri	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95	0.5	0.95	0.95	0.95	0.95	0.3	0.1	0.1	0.1	0.1	0.05	0.05
Sat	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0	0	0	0	0
Sun	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0
Lighting																								
Mon – Fri	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Plug Loads																								
Mon – Fri	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Sat	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.35	0.35	0.35	0.35	0.35	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sun	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Figure 13. ASHRAE 'Building Envelope Trade-Off Schedules and Loads'

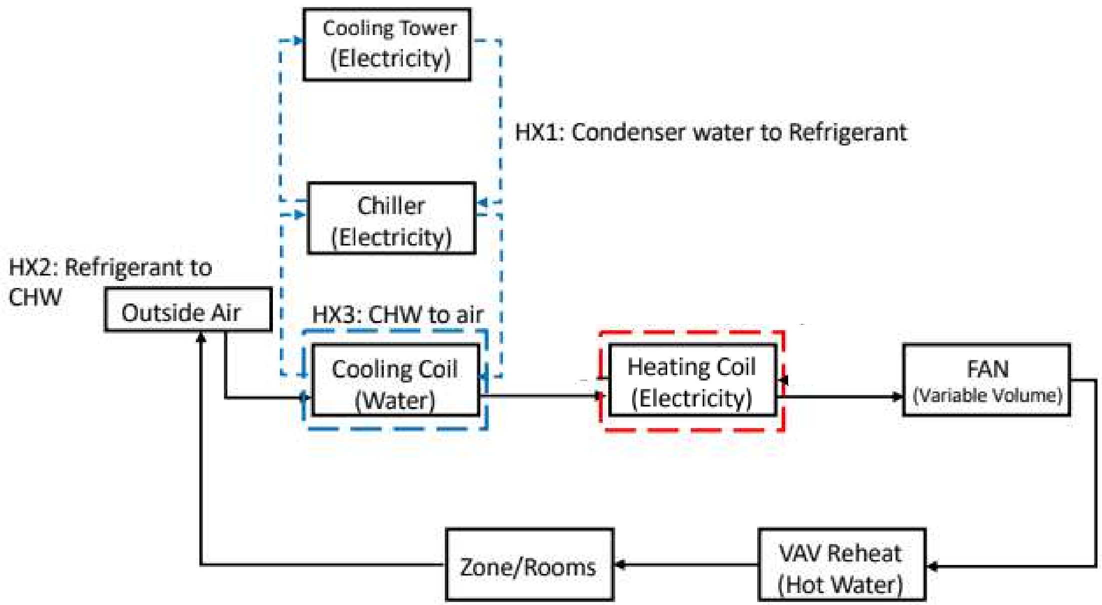
2. HVAC systems

HVAC System

System-3
Packaged DX Rooftop VAV with Reheat



System-6
Packaged Rooftop VAV with Reheat



Comparing overall energy consumption

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	1879.40	565.87	565.87
Net Site Energy	1879.40	565.87	565.87
Total Source Energy	4809.48	1448.08	1448.08
Net Source Energy	4809.48	1448.08	1448.08

Figure 1. Site Energy of HVAC System 3

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	1873.67	564.14	564.14
Net Site Energy	1873.67	564.14	564.14
Total Source Energy	5933.90	1786.63	1786.63
Net Source Energy	5933.90	1786.63	1786.63

Figure 2. Site Energy of HVAC System 6

- The total site energy of System 3 is slightly greater than that of System 6.
- On the other hand, the total source energy of System 6 is about 1.23 times greater than that of System 3. The reason is that the heating source of System 6 is electricity (3.167), while the heating source of System 3 is natural gas (1.084), resulting in different conversion factors.

Comparing sector consumption

- System 3's heating exclusively uses natural gas, while System 6's heating exclusively uses electricity.

- By comparing Systems 3 and 6, it can be observed that there's a difference in heating energy consumption depending on the fuel used, even when heating the same space. Through this example, I confirmed that the heating energy consumption of natural gas is greater than that of electricity for the same area.

	Electricity [GJ]	Natural Gas [GJ]
Heating	0.00	548.53
Cooling	375.32	0.00
Interior Lighting	265.75	0.00
Exterior Lighting	0.00	0.00
Interior Equipment	643.95	0.00
Exterior Equipment	0.00	0.00
Fans	20.70	0.00
Pumps	25.15	0.00
Heat Rejection	0.00	0.00
Humidification	0.00	0.00
Heat Recovery	0.00	0.00
Water Systems	0.00	0.00
Refrigeration	0.00	0.00
Generators	0.00	0.00
Total End Uses	1330.87	548.53

Figure 3. End Uses of HVAC System 3

	Electricity [GJ]	Natural Gas [GJ]
Heating	461.18	0.00
Cooling	314.72	0.00
Interior Lighting	265.75	0.00
Exterior Lighting	0.00	0.00
Interior Equipment	643.95	0.00
Exterior Equipment	0.00	0.00
Fans	20.51	0.00
Pumps	94.45	0.00
Heat Rejection	73.11	0.00
Humidification	0.00	0.00
Heat Recovery	0.00	0.00
Water Systems	0.00	0.00
Refrigeration	0.00	0.00
Generators	0.00	0.00
Total End Uses	1873.67	0.00

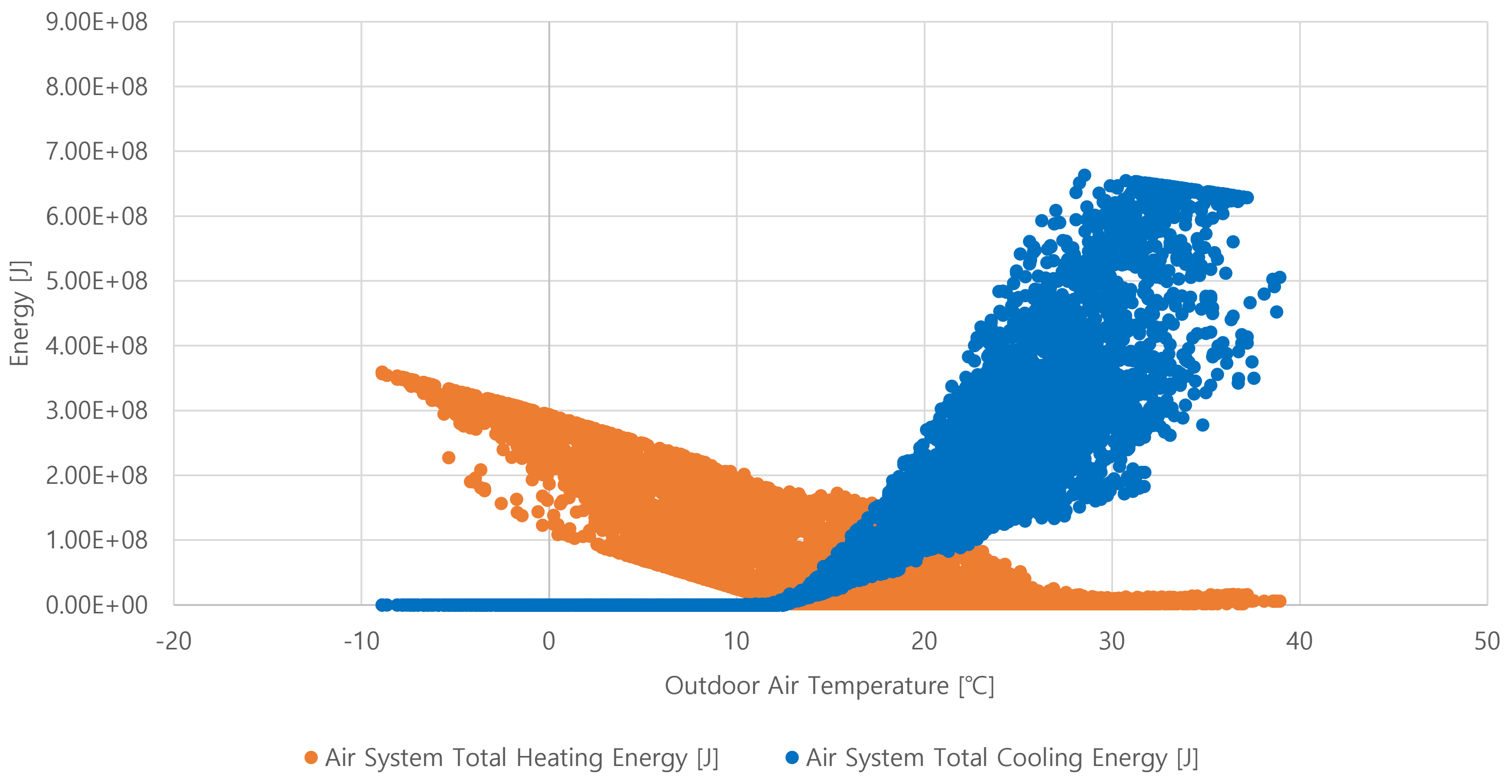
Figure 4. End Uses of HVAC System 6

A graph for HVAC System 3

Output Variables for System 3

- Air System Total Heating Energy
- Air System Total Cooling Energy

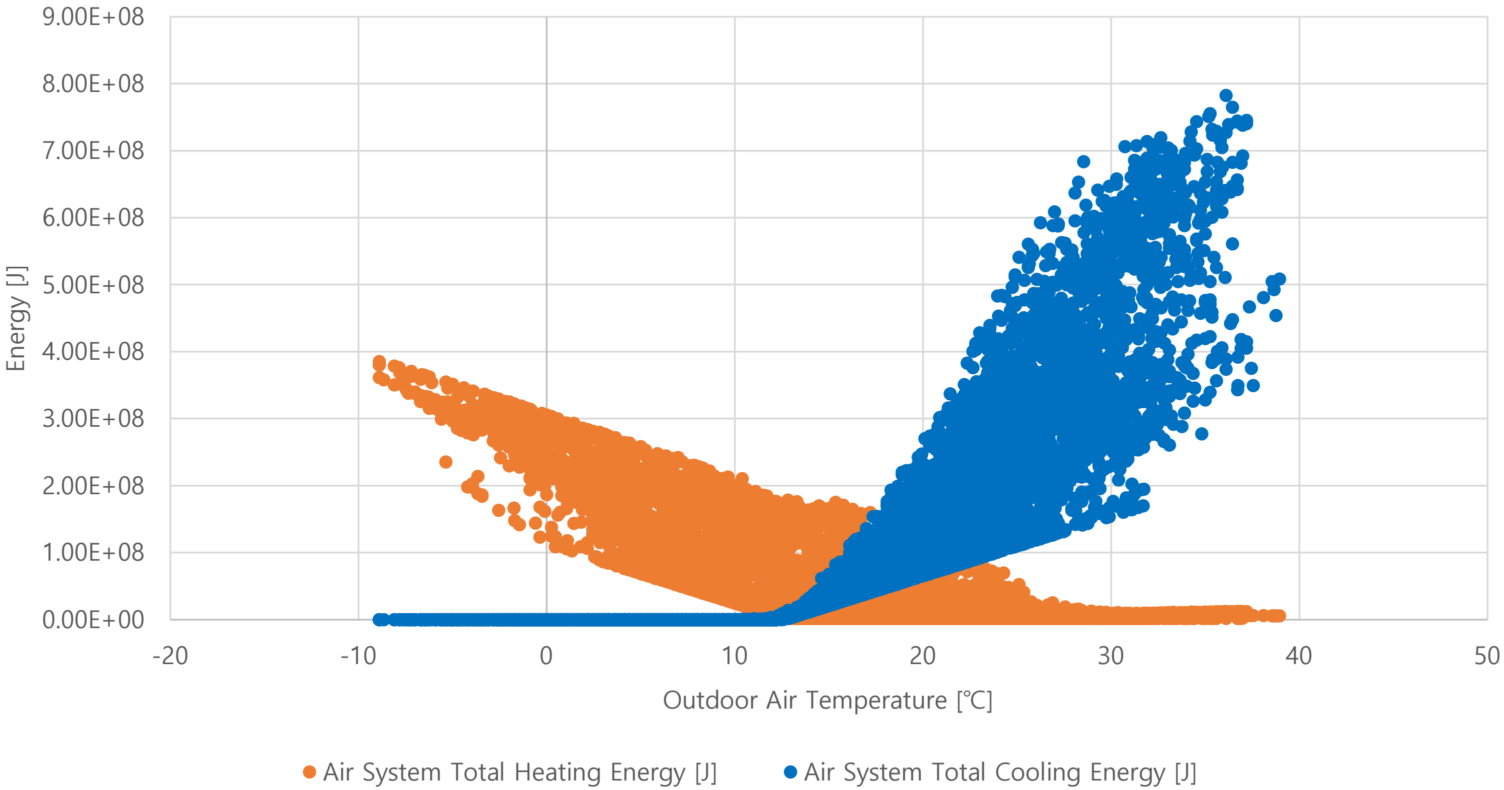
* Due to a version issue with OpenStudio, only two variables can be extracted.



A graph for HVAC System 6

Output Variables for System 6

- Air System Total Heating Energy
- Air System Total Cooling Energy



Comparing the data

- Firstly, regarding heating energy, system-3 uses gas, and system-6 uses electricity, which tends to result in slightly higher heating energy for system-6.

- For cooling energy, although both systems use electricity, system-6 uses a chiller, which tends to result in higher cooling energy.

- Although not represented in the graph, it is presumed that system-3, which uses gas for heating, will have a lower overall electricity usage than system-6.

System-3

Packaged DX Rooftop VAV with Reheat

- This system uses electricity for cooling and gas for heating.

Advantages

- Boilers that use gas generally have a higher thermal efficiency than heating systems that use electricity.

Disadvantages

- Using electricity for cooling and gas for heating means depending on two different energy sources, which can increase the complexity in management and supply.

System-6

Packaged Rooftop VAV with Reheat

- This system uses electricity for cooling and heating systems.

Advantages

- Using electricity for both cooling and heating simplifies energy supply and eases management.

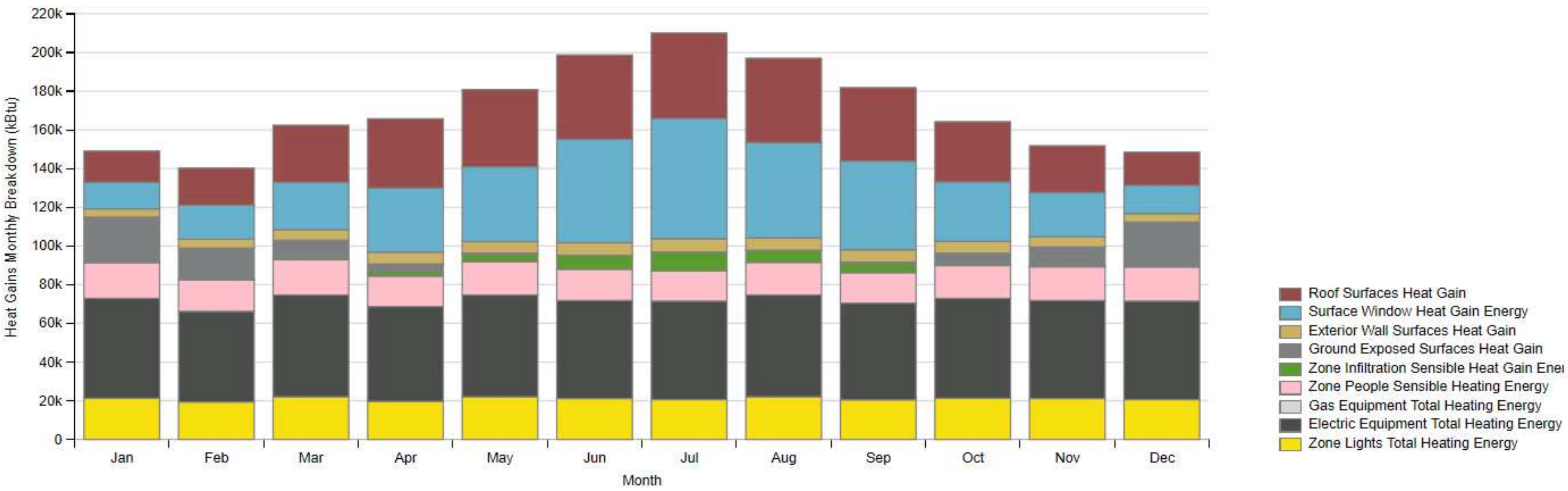
Disadvantages

- Using electricity for both cooling and heating can increase electricity costs, which can be significantly higher in areas with high electricity rates.
- A sufficiently sizeable mechanical room is needed to install the chiller, and space is also required on the rooftop to install the cooling tower.

3. Compare the simulation results

Envelope Internal Load Breakdown

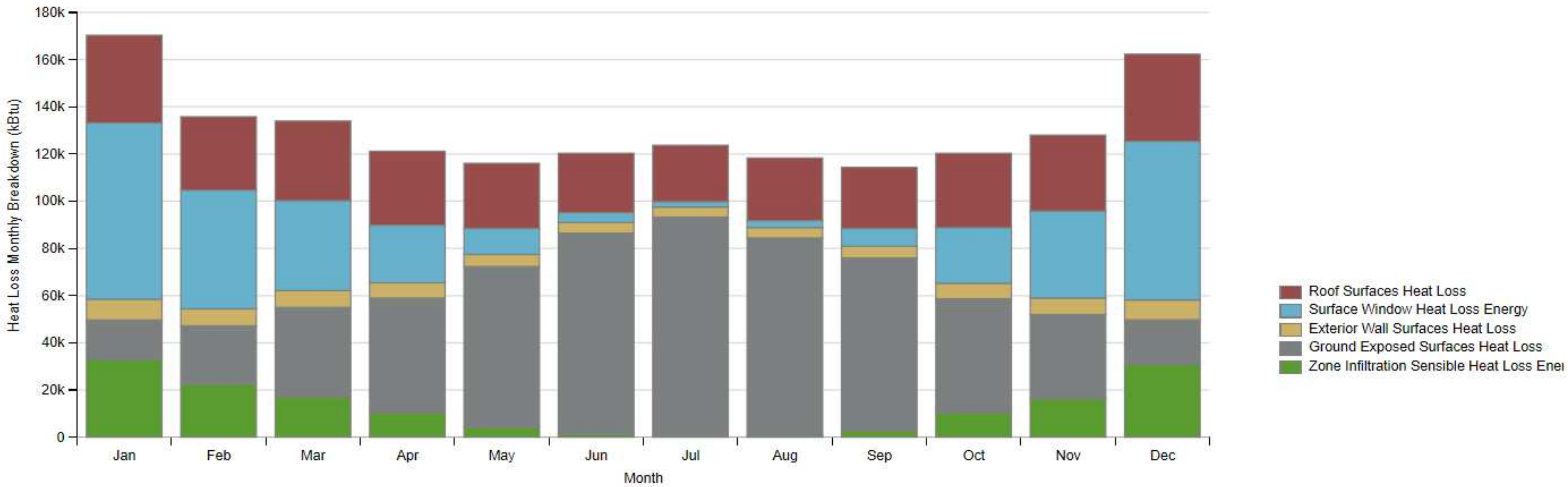
Heat Gains



- In summer, the proportion of heat gained through roofs and windows increases. This is because the sun is higher in the sky during summer, leading to more direct sunlight reaching the roofs and windows.
- On the other hand, in winter, the proportion of heat gained from the ground increases. Even when the external or building temperature is low in winter, the temperature underground remains relatively high. This results in heat being transferred to the building interior through the floors in contact with the ground.

Envelope Internal Load Breakdown

Heat Loss

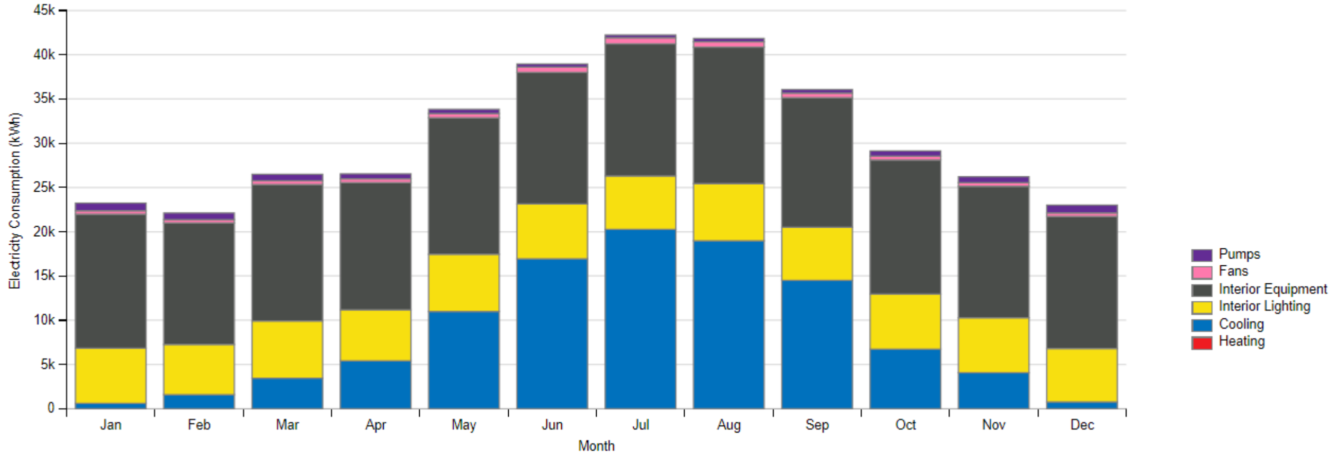


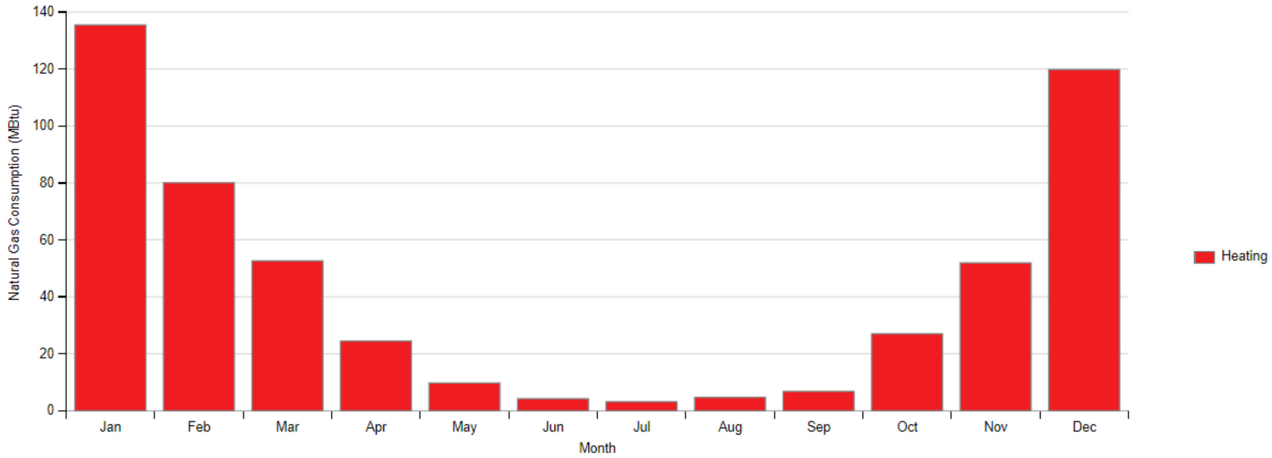
- In winter, the proportion of heat loss through drafts and windows increases. This is because the temperature difference between indoors and outdoors is significant in winter, causing heat to move from inside the building to the outside. This process results in heat loss. Additionally, windows have a higher thermal conductivity compared to other structural components, making them a primary pathway for indoor heat to escape to the outside.
- On the other hand, in summer, the proportion of heat loss through floors in contact with the ground increases. The temperature underground remains relatively cool during the summer. Therefore, if the indoor temperature is higher than the underground temperature, heat will move from the floor to the ground.

OpenStudio Results

System-3

- In summer, the consumption of electricity for cooling increases. This is because cooling systems only use electricity.
- In winter, the consumption of gas for heating increases. This is because heating systems only use gas. The reason why gas is also consumed in summer is for hot water supply.

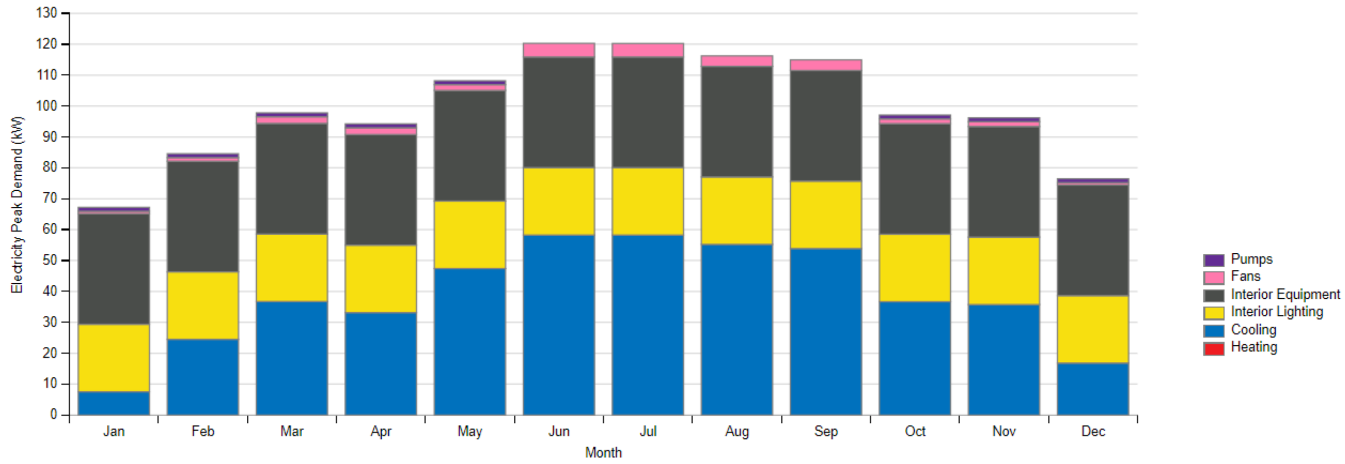


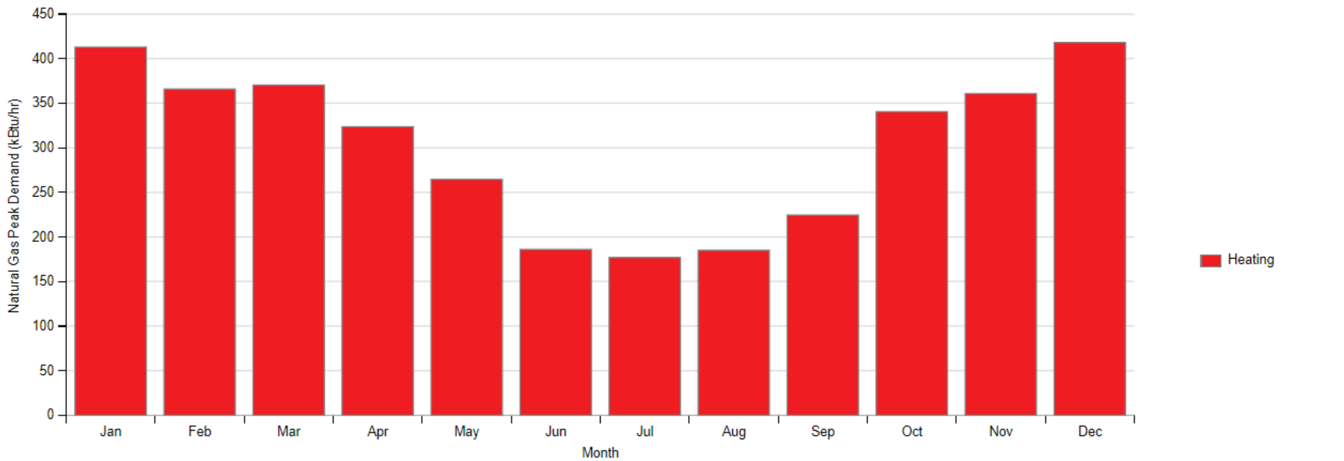


OpenStudio Results

System-3

- The graph of demand shows a trend similar to the graph of usage.
- The reason for the demand for cooling energy in winter is due to the presence of IT rooms.

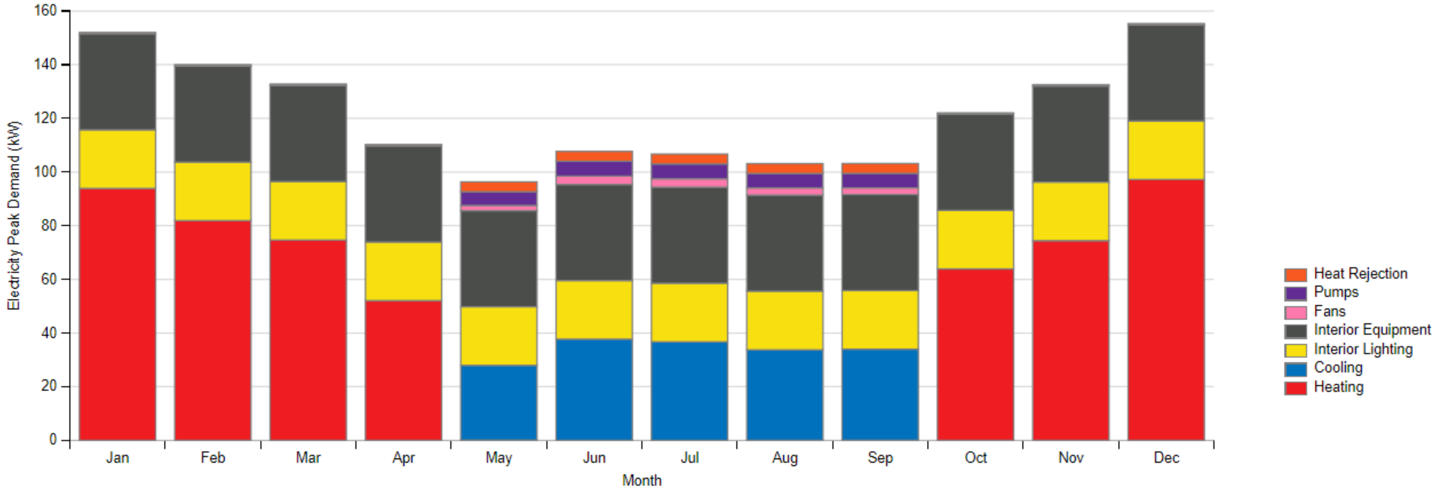


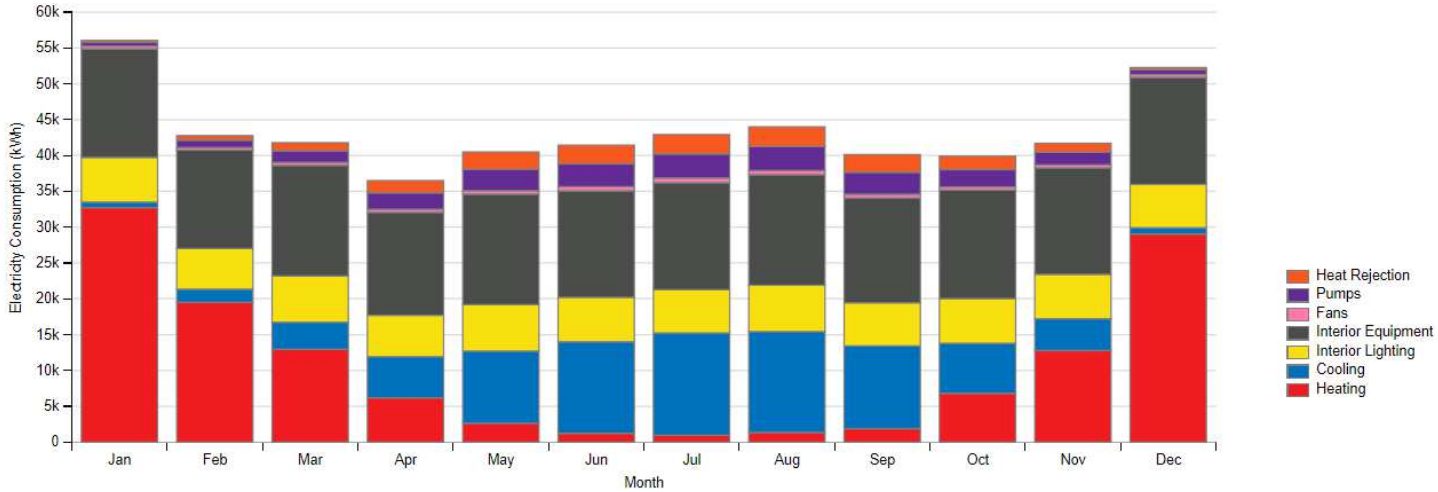


OpenStudio Results

System-6

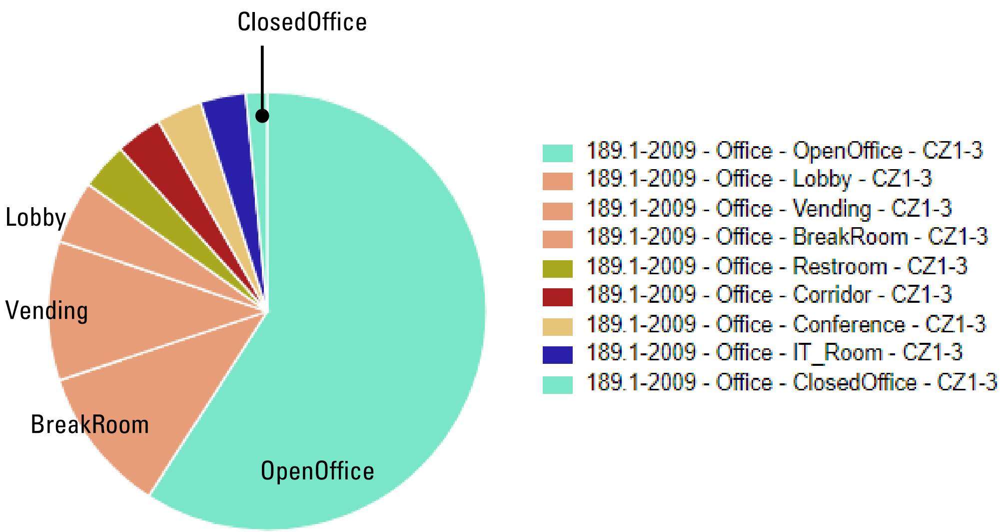
- System 6 exclusively uses electricity.
- The overall pattern for cooling and heating energy is similar to System 3.
- However, unlike System 3, there is an increase in the proportion related to pumps, fans, and heat rejection during the summer. This is because the devices associated with the cooling system are in operation.





OpenStudio Results

Space type breakdown

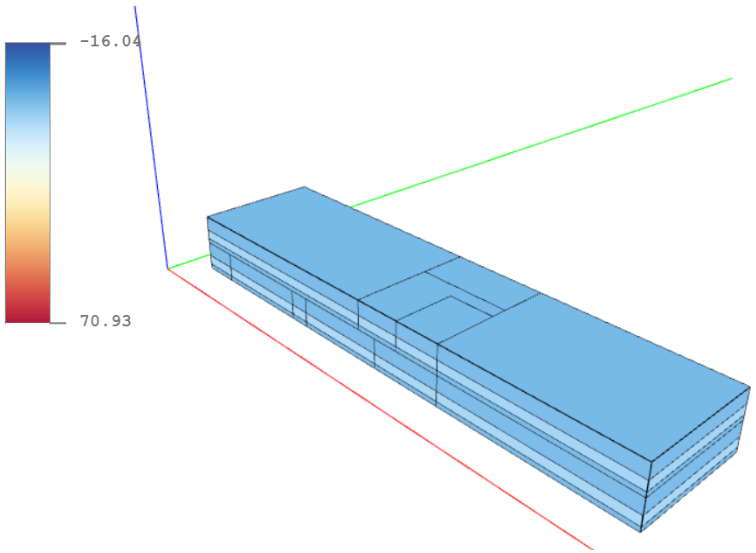


- Open offices occupy a significantly more significant proportion compared to closed offices.
- Open offices are more significant, which may lead to higher energy consumption for heating or cooling to maintain a consistent temperature throughout the space. Additionally, the more people and equipment using an open office during the summer, the greater the internal heat generation, which can further increase the use of cooling energy.

View Data

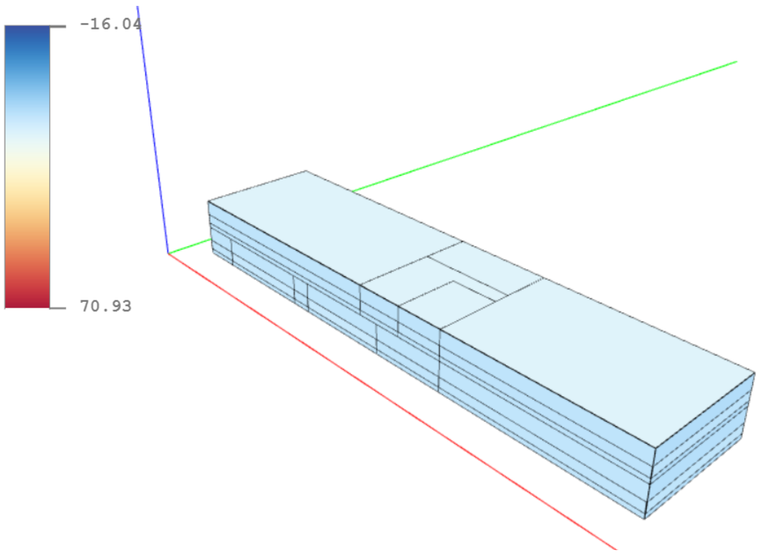
Winter

01/12 – 6:00 AM



- In the early morning, the temperature of the roof and walls is similar and low.
- The windows are warmer than the walls. This is presumed to be due to the warm air from indoor heating escaping through the windows in the winter.

01/12 – 1:00 PM

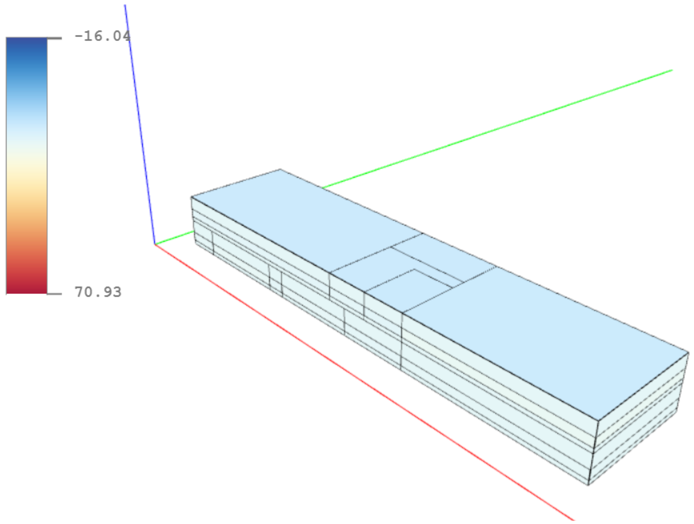


- In the afternoon, the roof is hotter than the walls.

View Data

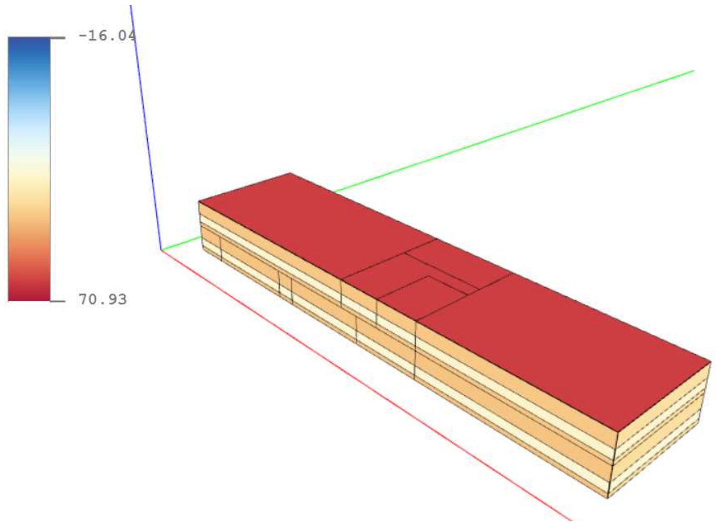
Summer

08/01 – 5:00 AM



- In the early morning, the roof is cooler than the walls.

08/01 – 2:00 PM



- In the afternoon, on the contrary, the roof is hotter than the walls.
- The windows are cooler than the walls. It is speculated to be because of the cold air from indoor cooling coming into contact with the windows in the summer.

4. Compare and analyze the Energy Use Intensity (EUI)

EUI numbers

System-3 **Packaged DX Rooftop VAV with Reheat**	
Total Source Energy Per Total Building Area [kBtu/ft^2]	127.43
Total Site Energy Per Total Building Area [kBtu/ft^2]	49.80
ENERGYSTAR - Office	
Source EUI [kBtu/ft^2]	116.4
Site EUI [kBtu/ft^2]	52.9

× 2.558

* 1 MJ = 0.947817 kBtu
1 m^2 = 10.7639 ft^2
1 MJ/ m^2 $\approx$ 0.088 kBtu/ ft^2

- This system uses electricity for cooling and gas for heating. Therefore, the conversion factor from Site Energy to Source Energy is calculated as a value (2.558) that lies between the factors for electricity (3.167) and gas (1.084).

- The Site EUI was calculated to be lower than the ENERGYSTAR values, but the Source EUI appeared slightly higher. This result is likely due to the high electricity usage rate in the system, leading to a higher conversion factor being applied.

EUI numbers

System-6 **Packaged Rooftop VAV with Reheat**	
Total Source Energy Per Total Building Area [kBtu/ft^2]	157.06
Total Site Energy Per Total Building Area [kBtu/ft^2]	49.59
ENERGYSTAR - Office	
Source EUI [kBtu/ft^2]	116.4
Site EUI [kBtu/ft^2]	52.9

× 3.167

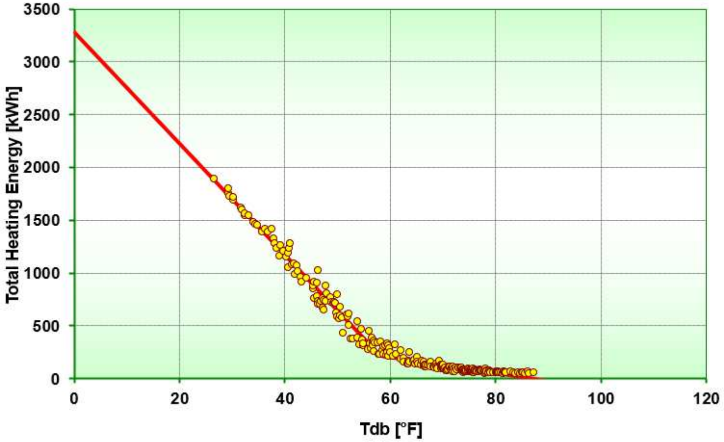
* 1 MJ = 0.947817 kBtu
1 m^2 = 10.7639 ft^2
1 MJ/ m^2 ≈ 0.088 kBtu/ ft^2

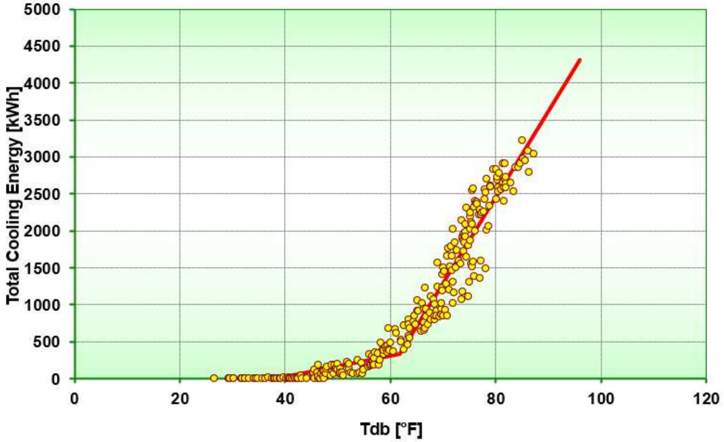
- Since this system uses electricity for cooling and heating, the conversion factor from Site Energy to Source Energy is calculated to be the same as that for electricity (3.167).
- The Site EUI was calculated to be lower than the ENERGYSTAR values, but the Source EUI was higher. This result is likely due to the system exclusively using electricity, leading to a higher conversion factor being applied.
- For the same reason, the Total Source Energy of System-6 was higher than that of System-3.

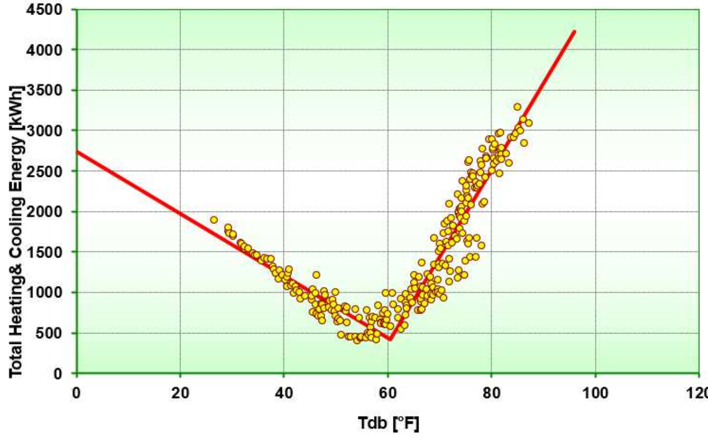
5. Develop regression model

HVAC System-3

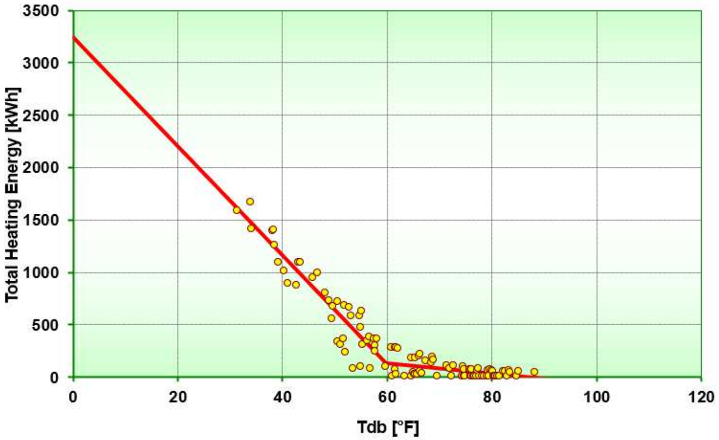
Weekdays

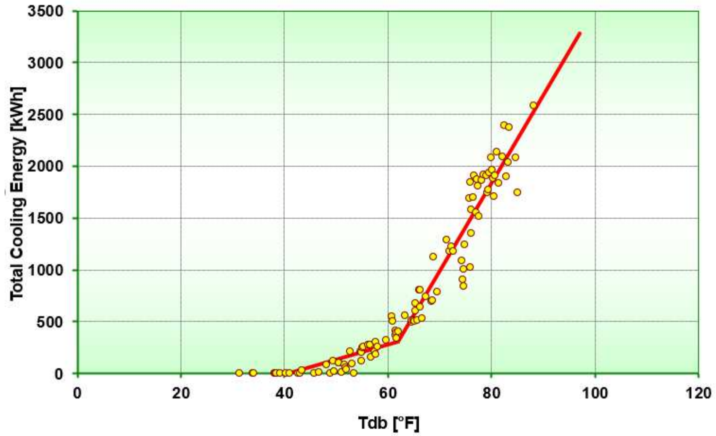


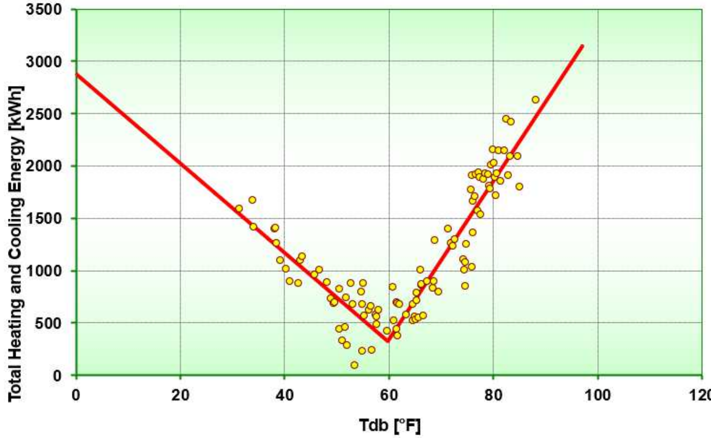




Weekends

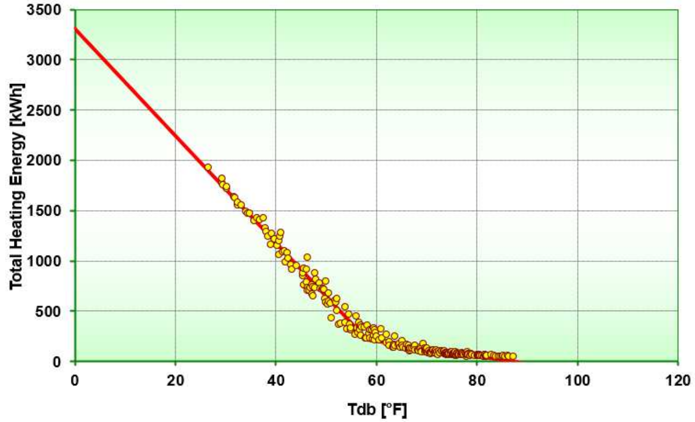


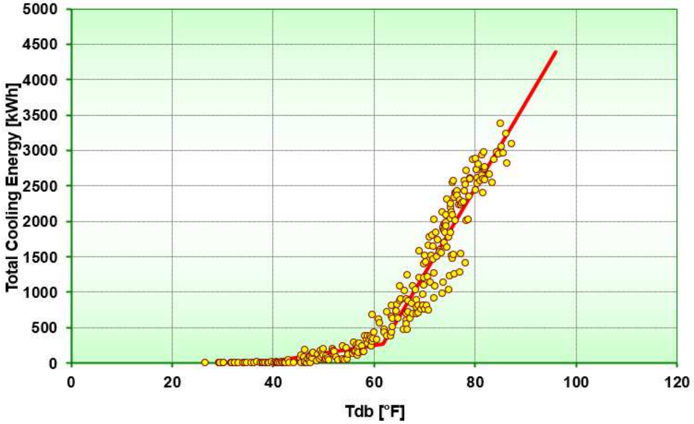


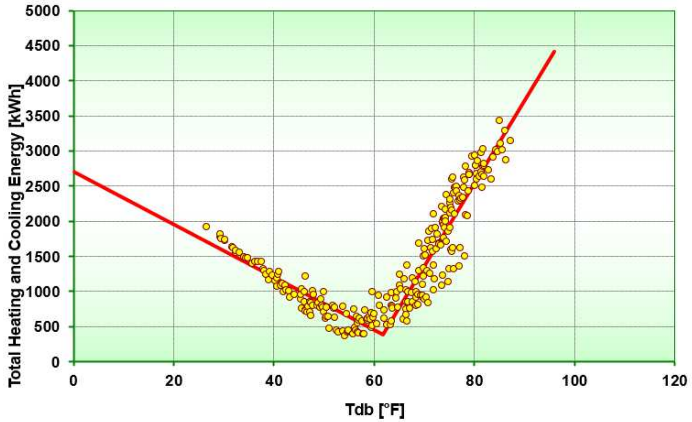


HVAC System-6

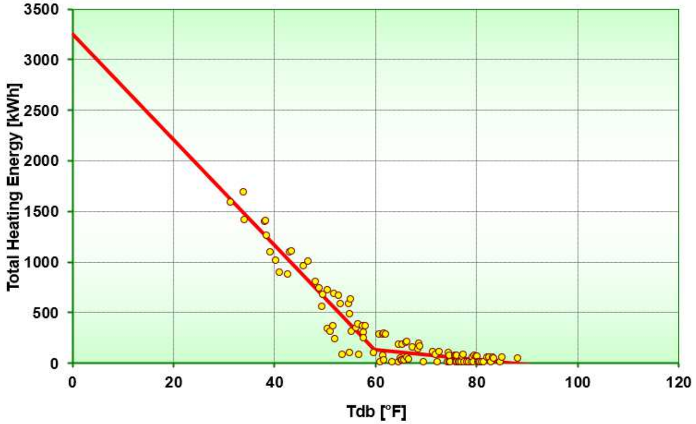
Weekdays

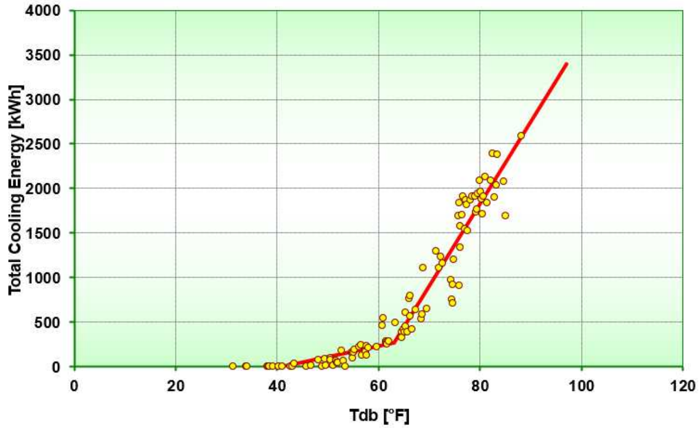


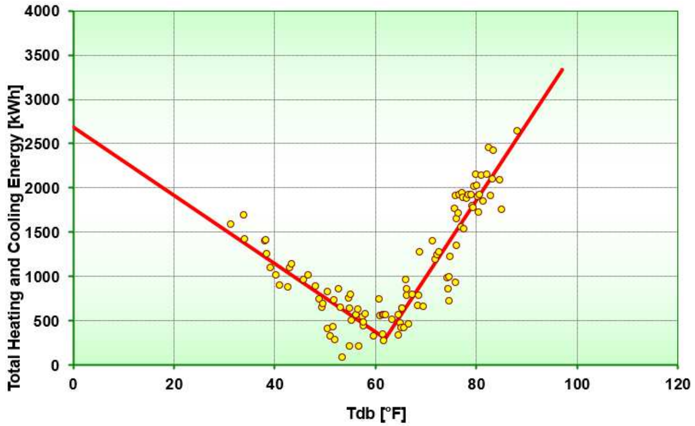




Weekends







HVAC System-3

Weekdays

Difference between left and right slope

Category	Heating	Cooling	Heating & Cooling
R2	0.9882	0.9479	0.8990
Change Point	58.0961	61.7422	60.5268
Left Slope	-52.7443	14.1744	-38.3920
Right Slope	-7.6010	116.0781	107.3361

45.1 101.9 145.7

Weekends

Category	Heating	Cooling	Heating & Cooling
R2	0.9262	0.9531	0.8702
Change Point	59.6918	61.9677	59.6918
Left Slope	-52.0959	14.3746	-42.6880
Right Slope	-4.8598	85.0617	75.6134

47.2 70.7 118.3

- In the heating, heating & cooling models, the R^2 value of the weekday model is closer to 1, indicating that it better explains the variance in the data.
- However, the weekend model explains the cooling model better.

- For heating, the difference of slope (left and right) in the weekend model is more significant. However, for cooling and heating & cooling, the difference is more significant in the weekday model.

- In conclusion, since the R^2 values of the weekday model are generally closer to 1, it can be seen as better reflecting the overall trend of the data.

HVAC System-6

Weekdays

Category	Heating	Cooling	Heating & Cooling
R2	0.9880	0.9400	0.8894
Change Point	58.0961	61.7422	61.7422
Left Slope	-53.2907	11.0928	-37.5886
Right Slope	-7.5895	120.4804	117.7423

45.7 109.4 155.3

Weekends

Category	Heating	Cooling	Heating & Cooling
R2	0.9254	0.9433	0.8627
Change Point	59.6918	63.1057	61.9677
Left Slope	-52.2167	12.0980	-38.6036
Right Slope	-4.8883	92.4769	86.9324

47.3 80.4 125.5

- Same with HVAC System-3
- In conclusion, since the R^2 values of the weekday model are generally closer to 1, it can be seen as better reflecting the overall trend of the data.

Select HVAC System

- When considering the Total Source Energy, HVAC System-3 can be determined as more suitable for the target building. This is because, although the difference in Total Site Energy is insignificant, a substantial difference arises in Total Source Energy due to the difference in fuels used.

- Comparing the Output Variables (Heating and cooling energy) also shows that HVAC System-3 uses less energy overall.

- In conclusion, HVAC System-3 can be selected as the most fit system for the building.

Lessons learned

- Firstly, regarding heating energy, system-3 uses gas, and system-6 uses electricity, which tends to result in slightly higher heating energy for system-6.

- For cooling energy, although both systems use electricity, system-6 uses a chiller, which tends to result in higher cooling energy.

- Although not represented in the graph, it is presumed that system-3, which uses gas for heating, will have a lower overall electricity usage than system-6.