ISSAM FARES INSTITUTE

FOR PUBLIC POLICY & INTERNATIONAL AFFAIRS

NET ZERO ENERGY BUILDING ANALYSIS

ARAMI MATEVOSYAN | FLORA LEE | MOURAD DABBOUR

TABLE OF CONTENTS

Overview and Recommendations

The Issam Fares Institute for Public Policy and International Affairs is a unique building set in the Lebanese campus of the American University of Beirut. Its concrete massing distinguishes it from its surrounding stone buildings and, consequentially, requires an energy analysis specific to its design. The recommendations of this report will address energy use in the categories of building envelope, equipment and appliances, lighting, heating systems, cooling systems, and renewable energy.

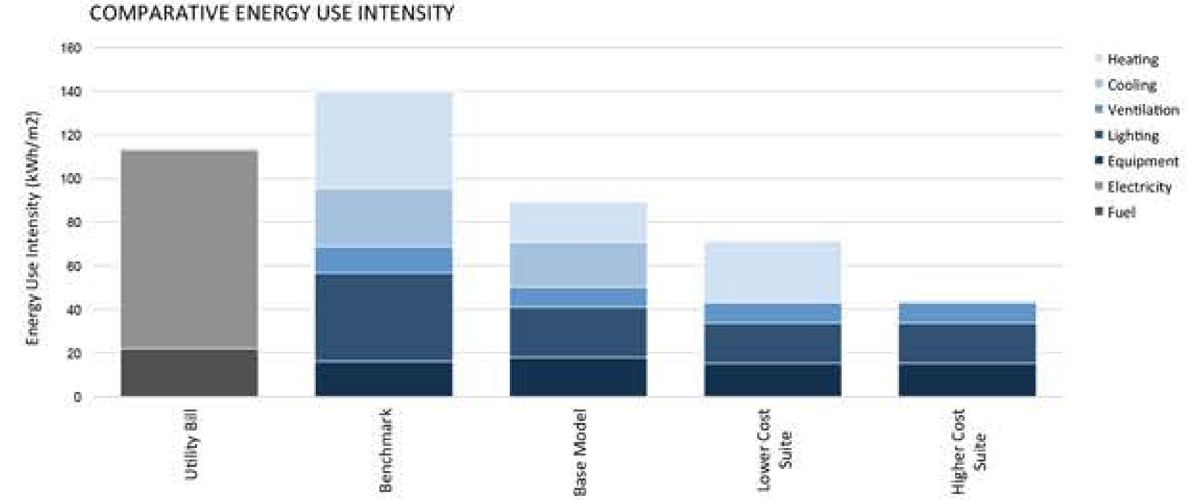
Building Envelope

The building currenly employs thick exterior walls of 250mm of concrete with minimal to no insulation. The lack of insulation does not deter from the building's performance because the thermal mass (concrete) is effective in balancing the thermal conditions of the building (via thermal lag and reduced peak loads). However, increasing the massing of the exterior roof from 150mm to 500mm will improve the building's ability to store and release trapped heat and coolth from the outside.

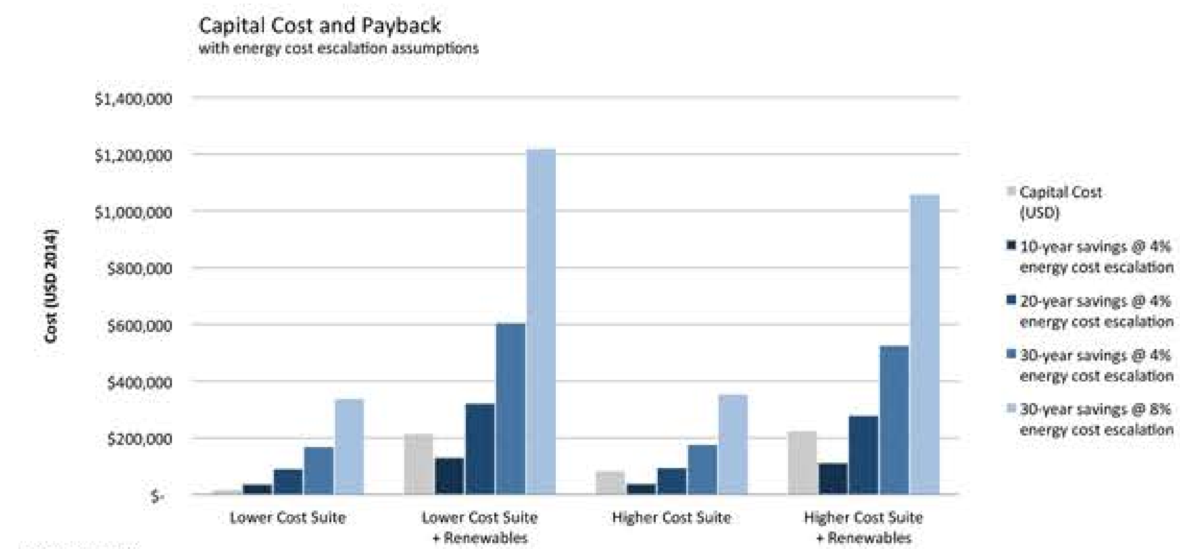
The thick, concrete façade doubles as a shading device for the recessed windows, which are double-pane, low-e, clear glass with alumnium framing. This architectural shading design blocks the direct solar radiation from the summer sun and allows some of the direct solar radiation the winter sun to penetrate the space, aiding the thermal mass. Switching to VE 1-85 window glass (triple-pane, double-coating, low-e, clear glass) will increase the window's capability to allow in more solar heat gain will decrease heat loss from the inside to the outside due to a higher solar heat gain coefficient (SHGC) and a lower u-value of 0.96, compared to 3.8 (SI units).

Lighting, Equipment, and Appliances

Requiring that all light fixtures use LED or 150-Watt halogen light bulbs will reduce the energy use intensity of the building from 23.0 to 18.4 kWh/m^2. Additionally, replacing large appliances and high-power office and kitchen equipment will also reduce internal loads. It should be noted that reducing the number of equipment (i.e. one microwave instead of two) would improve overall energy consumption levels.



EUI	Utility Bills	Benchmark	Base Model	Low-Cost	High-Cost
Lighting		40.4	23.0	18.4	18.4
Cooling		26.7	20.6	--	--
Ventilation		12.1	20.6	--	--
Equipment		16.2	18.0	15.4	15.4
Heating		44.5	18.5	28.3	1.3
Fuel	22.0				
Electricity	91.0				
Total (kWh/m^2)	113.0	139.9	89.3	71.3	44.3



PAYBACK	Lower Cost Suite	Lower Cost Suite + Renewables	Higher Cost Suite	Higher Cost Suite + Renewables
4.0% escalation	4-years	14-years	18-years	17-years
8.0% escalation	4-years	12-years	14-years	13-years

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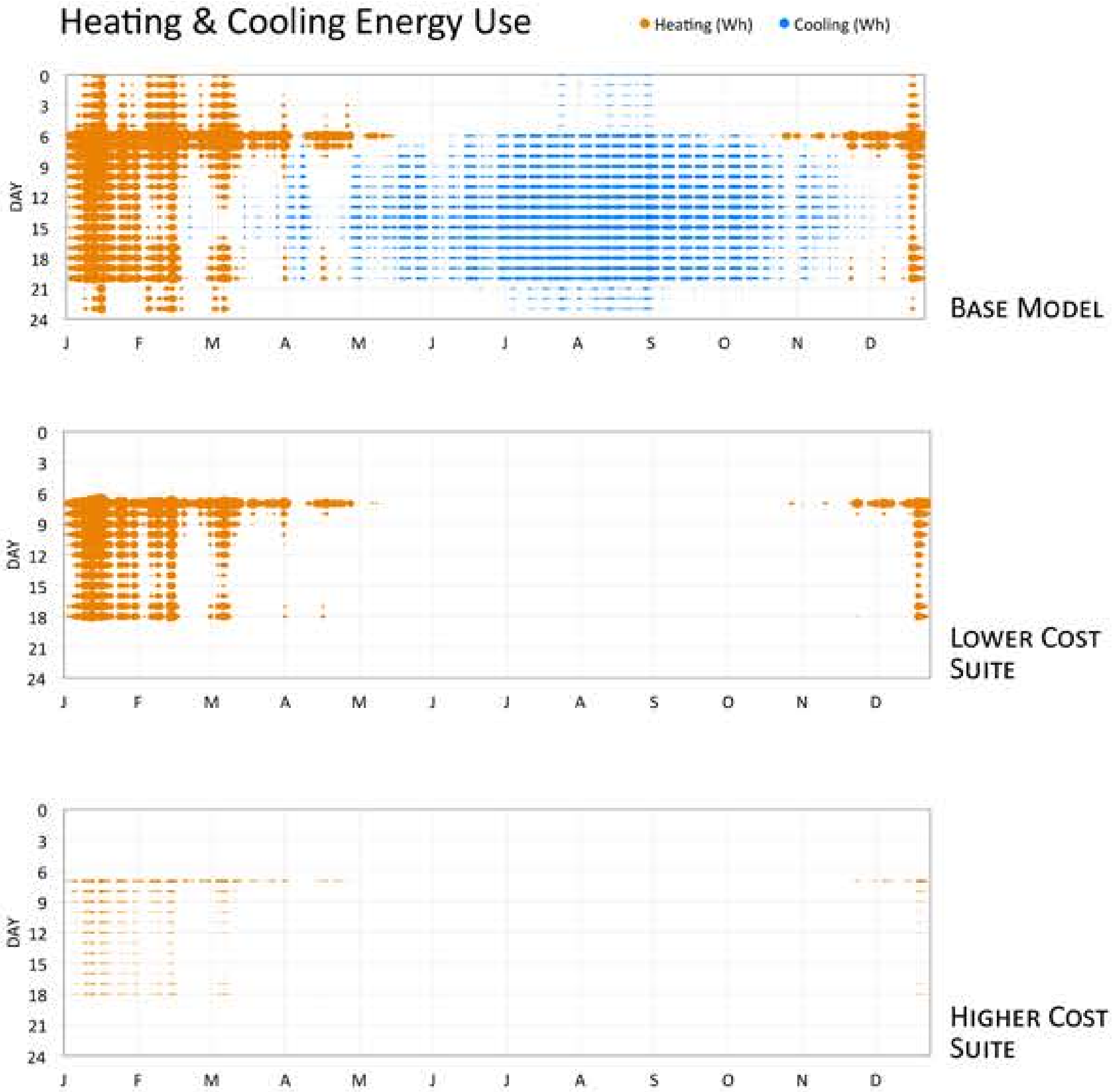


Heating and Cooling Systems

Issam Fares Institute's HVAC system consists of steam boiler and a roof chiller/water tower. The coefficient of performance for these systems is 0.3 and 4.5, respectively. The graphs on the right highlight the heating and cooling energy use of different HVAC systems.

The Base Model demonstrates the exisiting heating and cooling use throughout the year while both the Lower Cost and Higher Cost Suits demonstrate the incorporation of Mixed Mode Natural Ventilation in conjuction to the HVAC system.

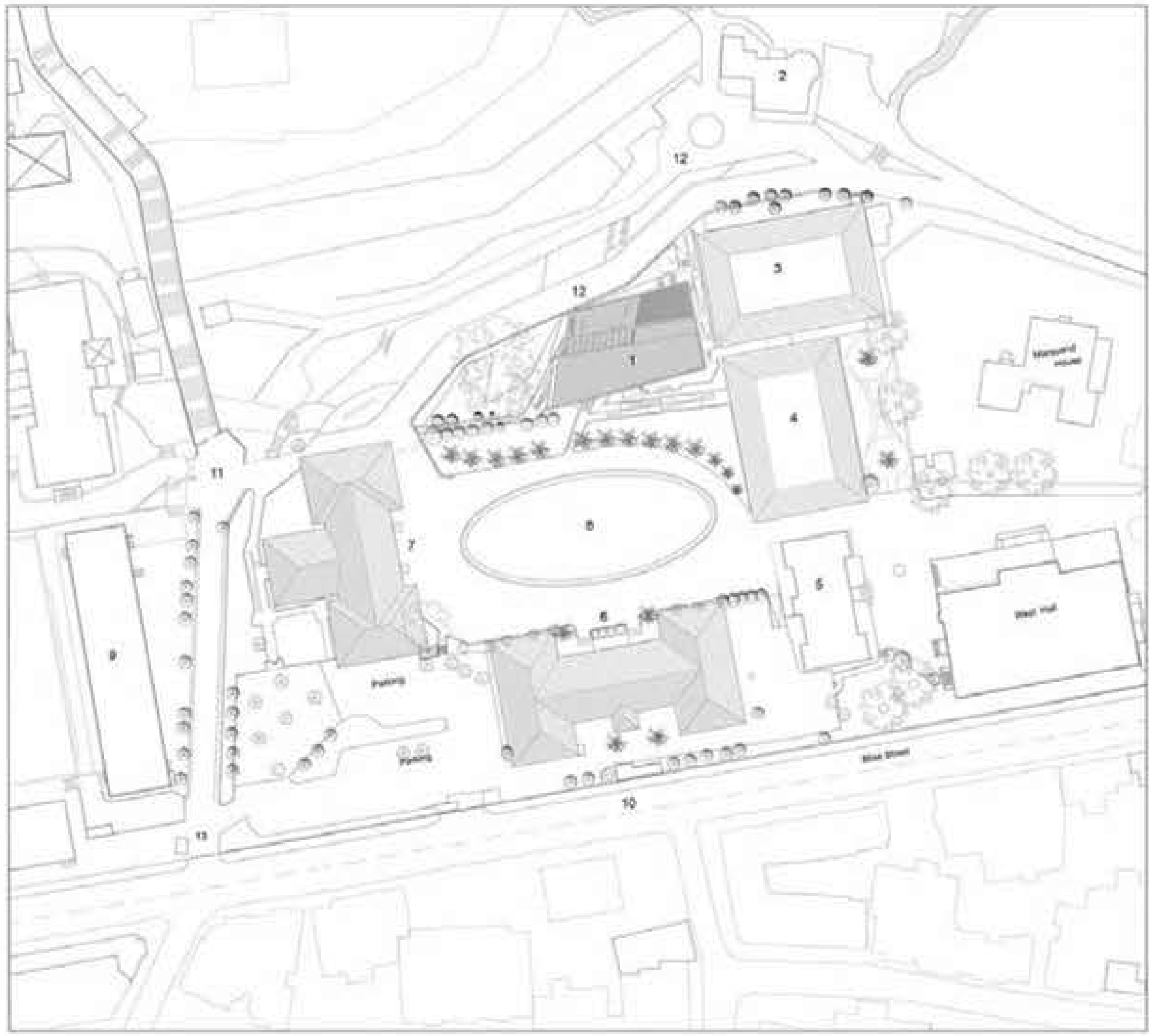
As the graphs suggest, Mixed Mode Natural Ventilation is crucial for the performance of this building. Not only does natural ventilation allow for the circulation of fresh air which benefits occupant health, but it also eliminates the need for cooling during the summer months. This savings can be an investment in vastly improving the efficiency of the building's heating coefficient of performance. Adding Radiant Heat to the system (Higher Cost Suite) improves the COP from 0.3 to 5.5. The difference is evident in the graphs.

Renewable Energy

In order for the building to reach net zero energy annually, PVs and a wind turbine are required to offset the use of energy. We recommend installing 244 PVs and a Windspire wind turbine for the Lower Cost Suite and 130 PVs and an Endurance wind turbine for the Higher Cost Suite.

Regarding Cost

Although the Lower Cost Suite is more affordable than the Higher Cost Suite (with or without the incorporation of renewables), we recommend the Lower Cost Suite with the addition of Radiant Heat. Radiant Heat is a worthy investment and, coupled with Mixed Mode Natural Ventilation, will cost less than the Higher Cost Suite and require less renewables to achieve net zero energy (contributing to an overall lower cost towards renewables).



ISSAM FARES INSTITUTE - Site Plan

1. Issam Fares Institute [IFI]
2. Lee Observatory
3. Nicely Hall 1
4. Nicely Hall 2
5. West Hall
6. Fisk Hall
7. Bliss Hall
8. The Oval
9. AUB Dorms
10. Bliss Street
11. Access to International College
12. Road
13. AUB Dorms Access Gate

0 1meter 5m 10m 20m

Issam Fares Institute for Public Policy and International Affairs

Architect: Zaha Hadid

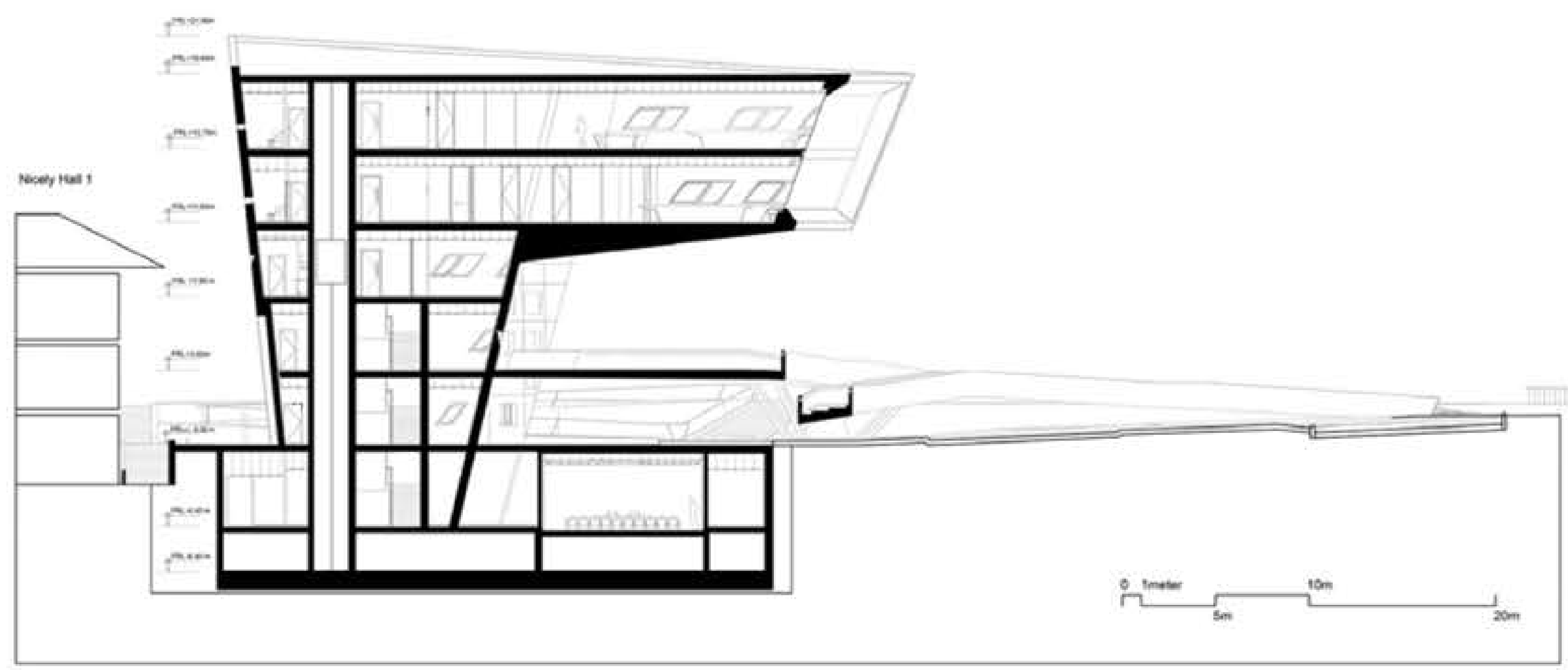
American University of Beirut
Bliss Street, Beirut, Lebanon

Constructed: 2011-2014

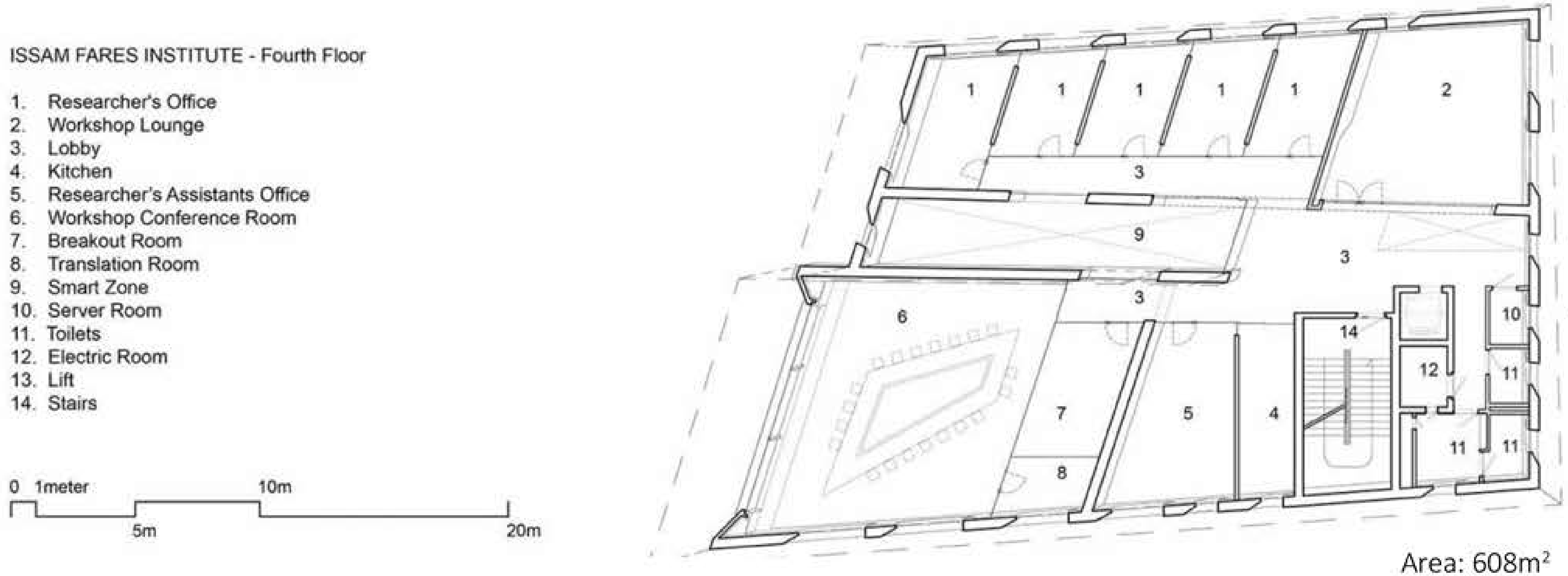
Total Built Floor Area: 3,000m^2
Total Site Area: 7,000m^2

Building Uses:

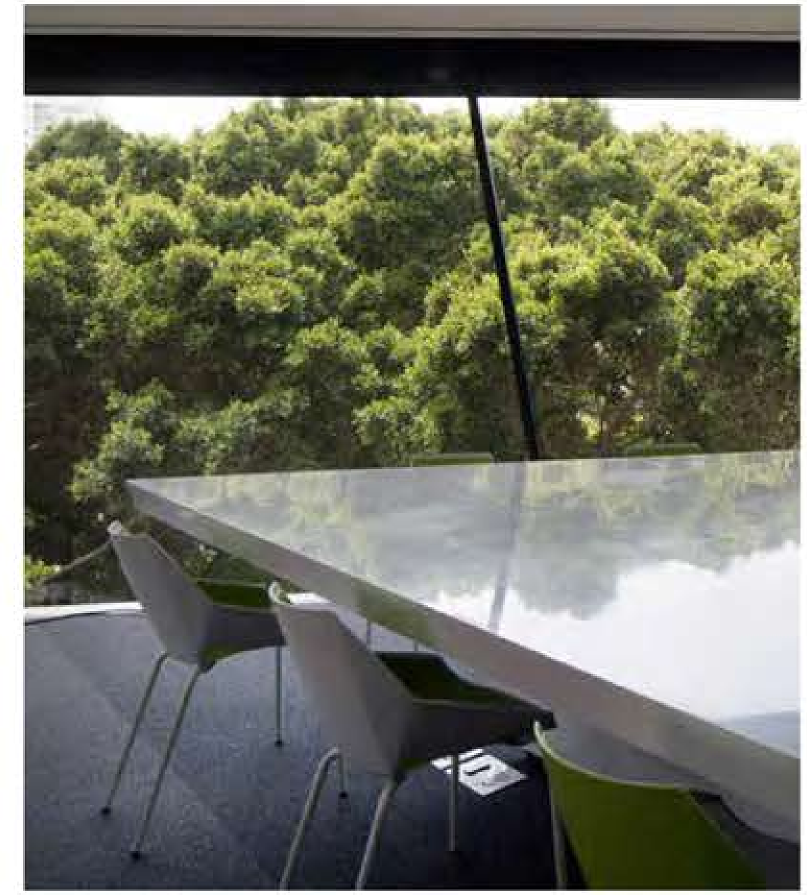
- Auditorium (100 seats)
- Classrooms
- Office Spaces
- Kitchenette
- Professional Meeting Rooms
- Lobby Areas
- TV Room



Fourth Floor Plan



Area: 608m^2
Height: 3.7m
Volume: 2,250m^3



Meeting Room

Office Space

General Building Assemblies

SURFACE	THICKNESS	MATERIALS
Ceiling	15cm	1.5cm furred and mounted false ceiling with gypsum board | 1.5cm plaster
Floors	40cm	30cm reinforced concrete slab | 5cm sand and mortar | 5cm tiles or screen to false finishing
Interior Walls	25cm	15cm CMU* | 2cm mortar | 8cm fair-faced concrete finish
Interior Mass	30 x 60cm	concrete columns
Exterior Walls	35cm	20cm CMU* | 10cm fair-faced concrete | 1.5cm plaster | 2cm mortar
Windows** & Doors		alumnium framing

*CMU = Concrete Masonry Units
** Windows are double-pane with clear glass and air fill.
U-Factor = 3.8 W/m^2-$^\circ$C
Solar Heat Gain Coefficient (SHGC) = 33%
Visible Transmittance (VT) = 52%

Lighting

Equipment

Notes on Internal Loads:
Lighting includes incandescent, LED, and halogen light bulbs.
Equipment consists of both office equipment and kitchen appliances.
A full list of internal loads, with their relative energy usage and consumption, can be found in the Appendix under Initial Energy Model.

Understanding the Weather

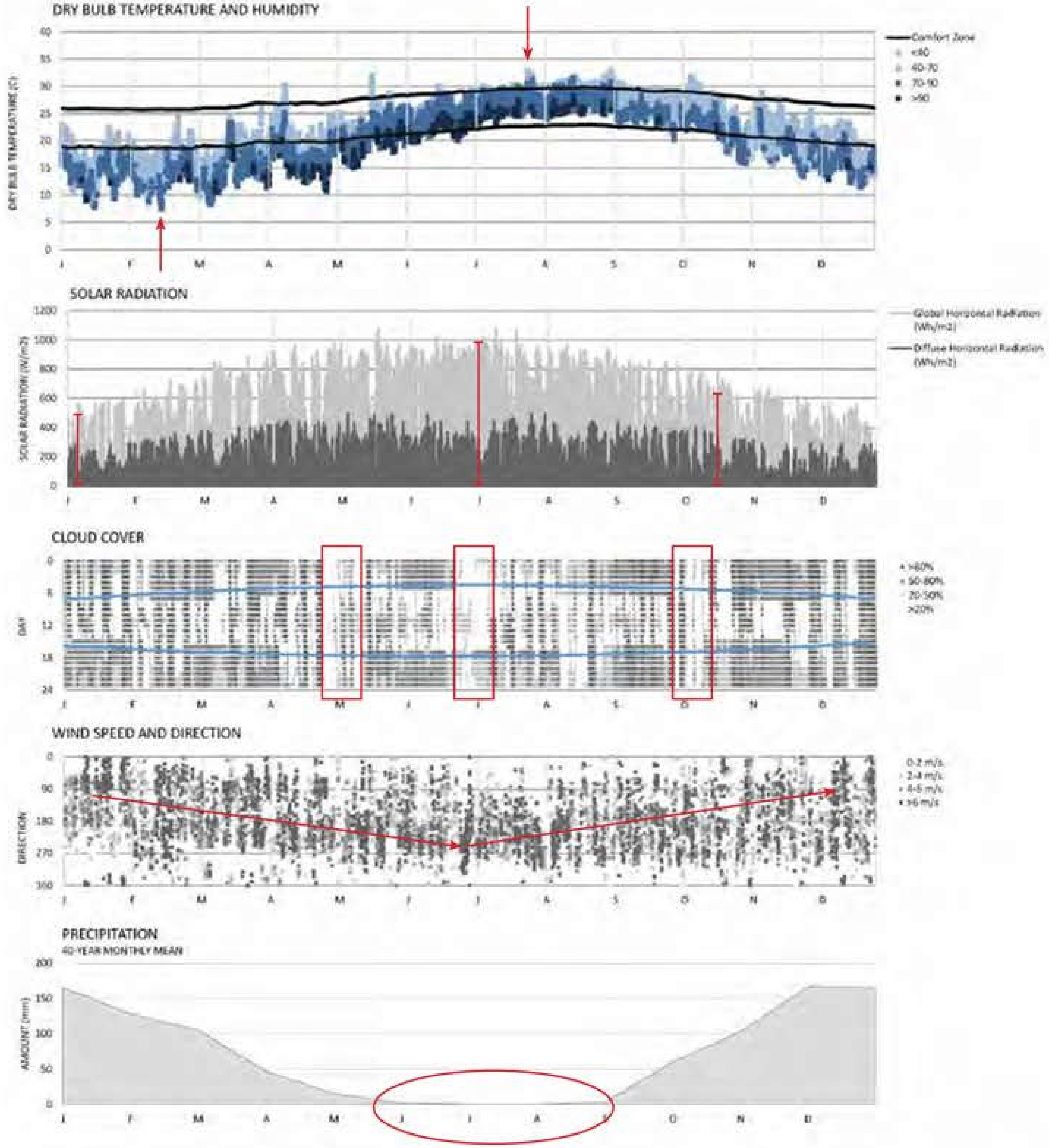
The climate is hot and dry in summer and is relatively cool and wet in winter. Temperature ranges between 7°C~33°C and it will typically it reach about 8°C in the winter and 28°C in the summer.

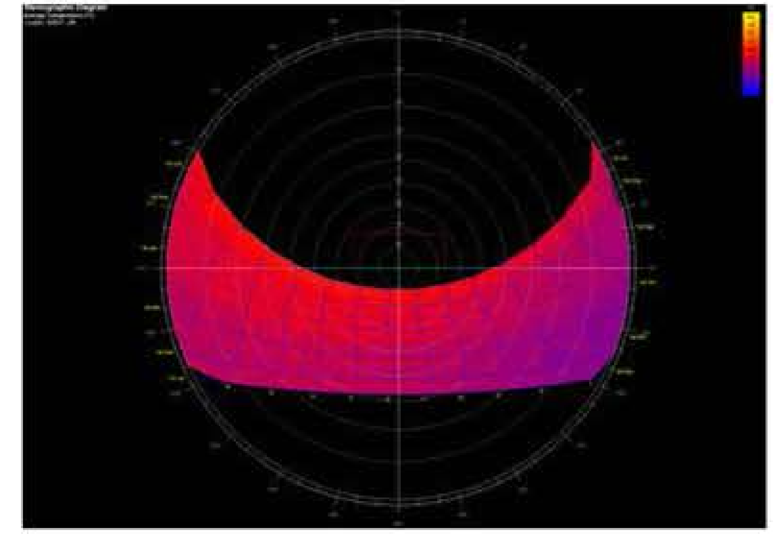
The sunshine condition here is optimal. Solar radiation reaches 1000W/m2 in the summer and 500W/m2 in the winter.

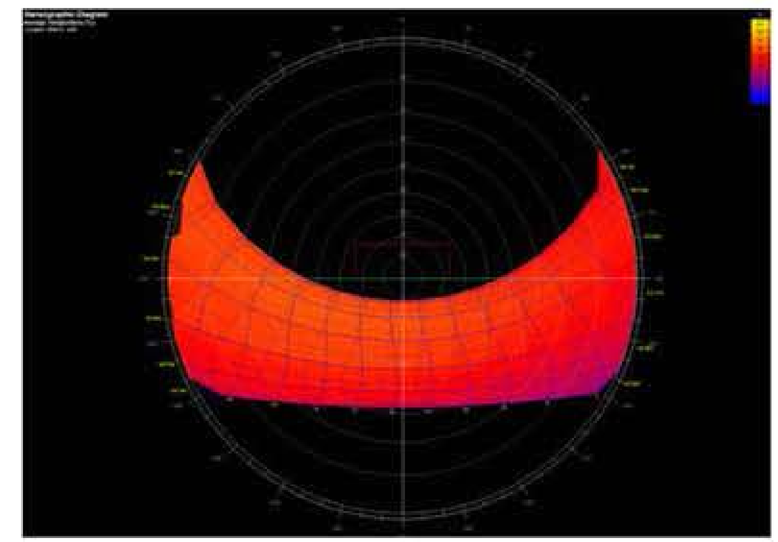
The probability of the cloud cover during the day is fairly low in Beirut; this will dictate the baselines for efficient PVs.

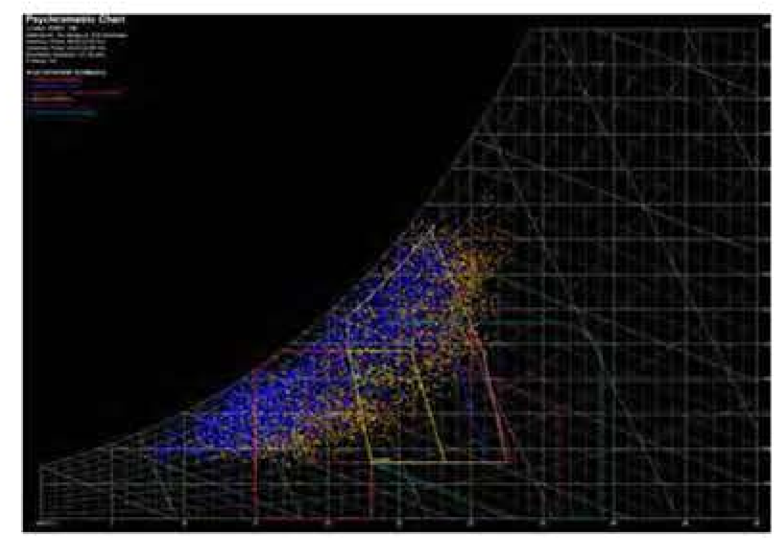
The main wind direction moves from east to west and west to east.. More specificially, it moves eastward when approaching winter and west when approaching summer. The wind speed is relatively high for the climate, which makes windspires wind turbine operation effective.

There is a large amount of precipitation from November to March which results in an increase in humidity. However, the summer months of June to August experience very little to no rain.

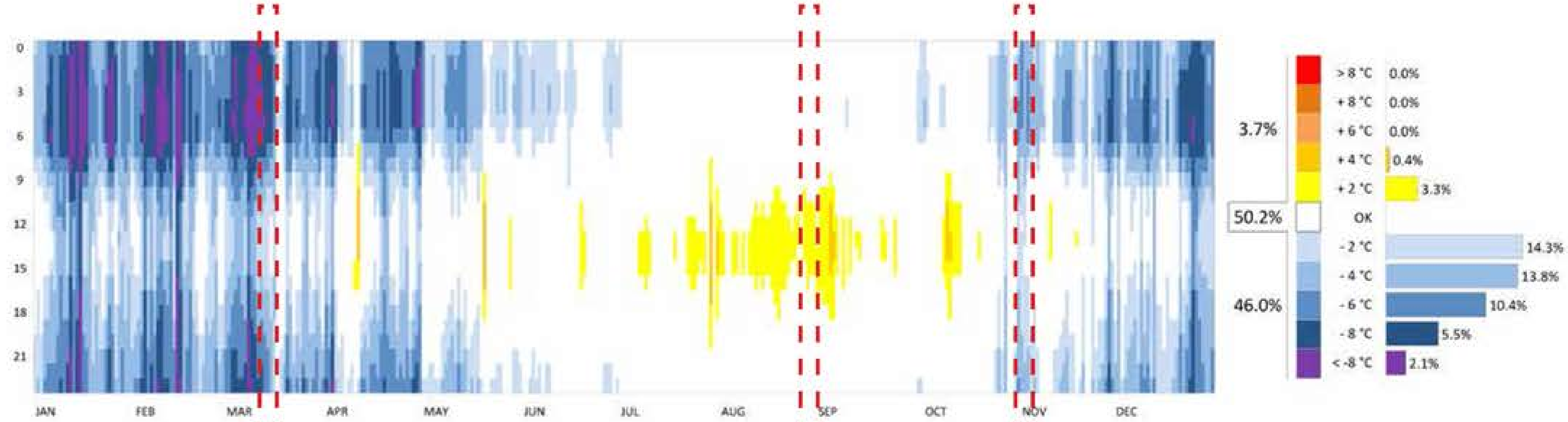



Solar Path Diagram from January to June

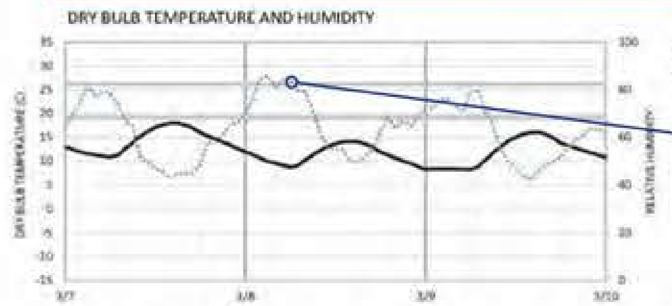

Solar Path Diagram from July to December


Psychrometric Chart

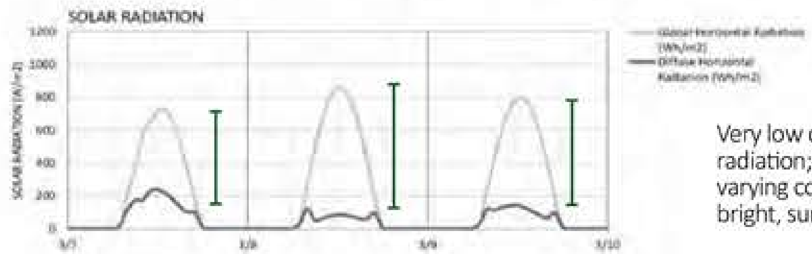
Degrees from Adaptive Comfort (°C)



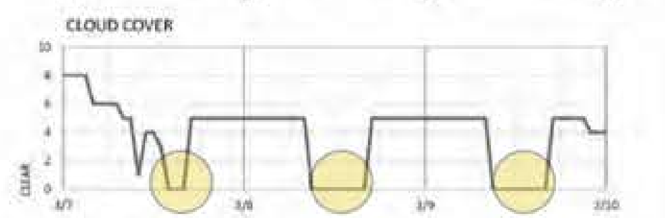
Cold Weather Extreme



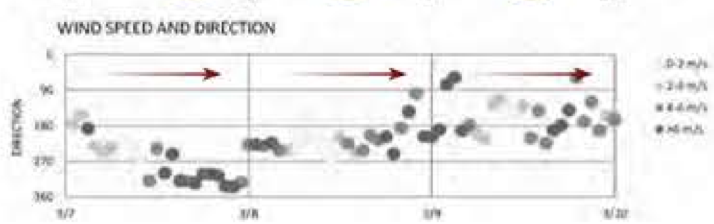
Cool days & colder nights; the relative humidity much higher than the dry bulb temperature.



Very low diffused radiation; some varying conditions of bright, sunny skies.

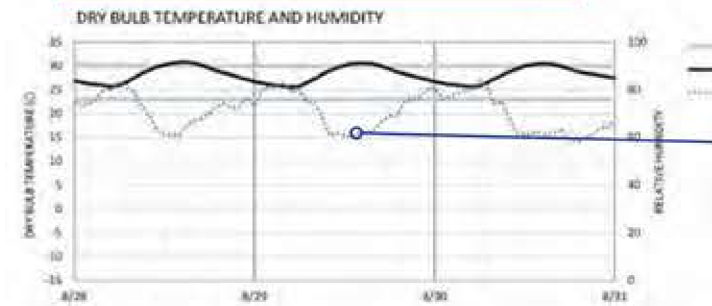


Clouds clear up during the day and return at night.

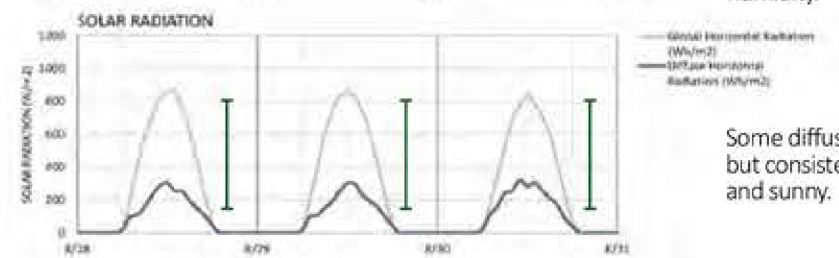


Wind speed decreases towards sunrise and increases towards night.

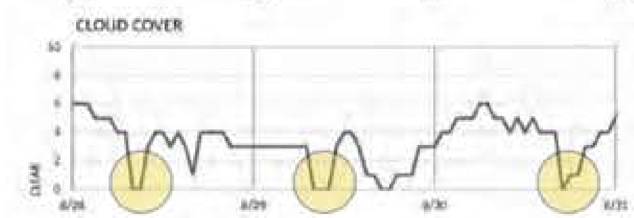
Hot Weather Extreme



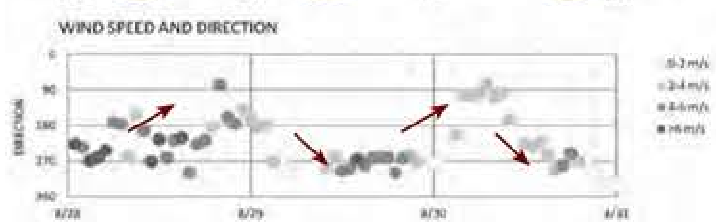
Hot days and warm evenings; the dry bulb temperature consistently fall in the comfort zone with lower relative humidity.



Some diffuse radiation but consistently bright and sunny.

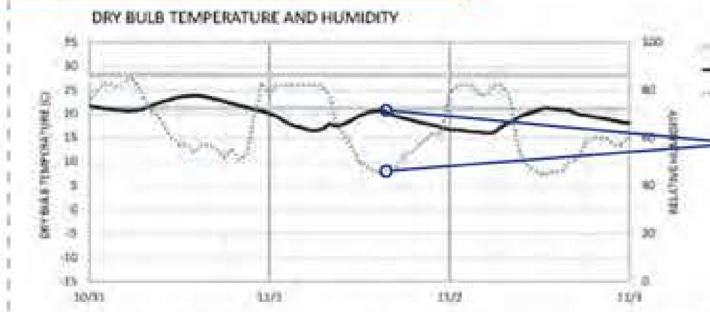


Scattered clouds but typically clear at sunrise.

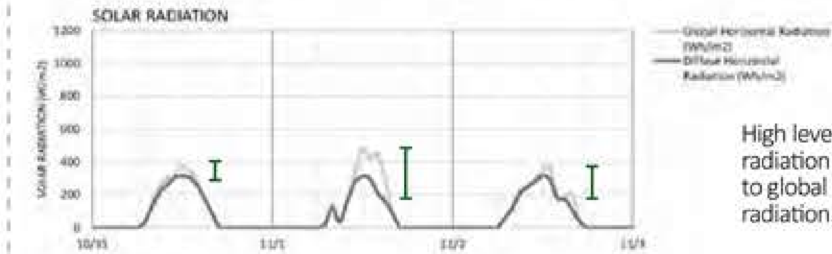


Wind blows from west to east throughout the day.

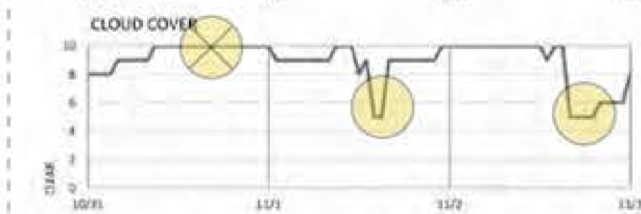
Typical Mild Weather



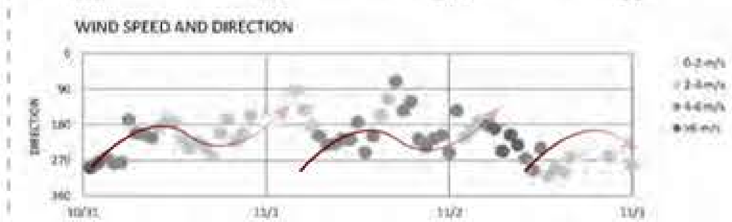
Warm days and cool nights; equal intervals of relative humdity and dry bulb temperature.



High levels of diffuse radiation in relation to global horizontal radiation.



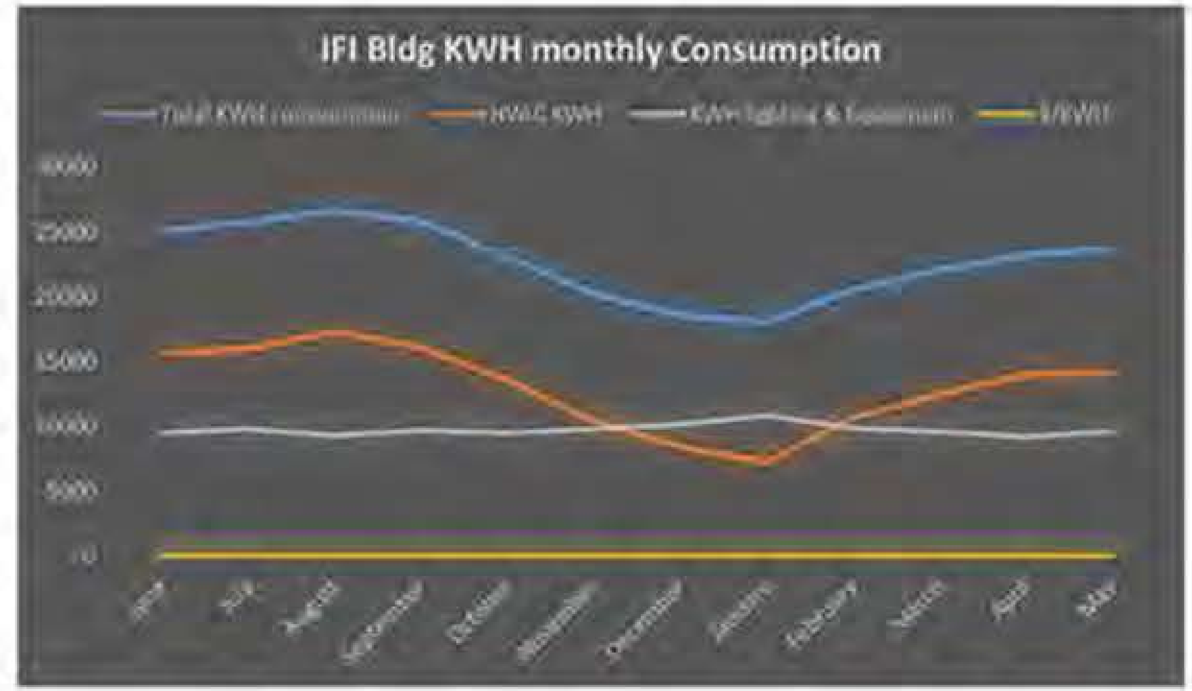
Clouds alternatively present during the day and lessen at night.



Wind blows from east to west and tends to be stronger in the morning and gradually weakens by night.

Monthly Electricity Consumption (kWh)

Month	Total KWH consumption	HVAC KWH	KWH lighting & Equipment	$/KWH
Jun-14	25117	15,573	9,544	0.17
Jul-14	25802	15,997	9,805	0.17
Aug-14	26632	17,311	9,321	0.17
Sep-14	25817	16,097	9,720	0.17
Oct-14	23077	13,561	9,516	0.17
Nov-14	20225	10,413	9,812	0.17
Dec-14	18595	8,435	10,160	0.17
Jan-15	18066	7,226	10,840	0.17
Feb-15	20537	10,667	9,870	0.17
Mar-15	22101	12,491	9,610	0.17
Apr-15	23197	13,989	9,208	0.17
May-15	23793	14,179	9,614	0.17



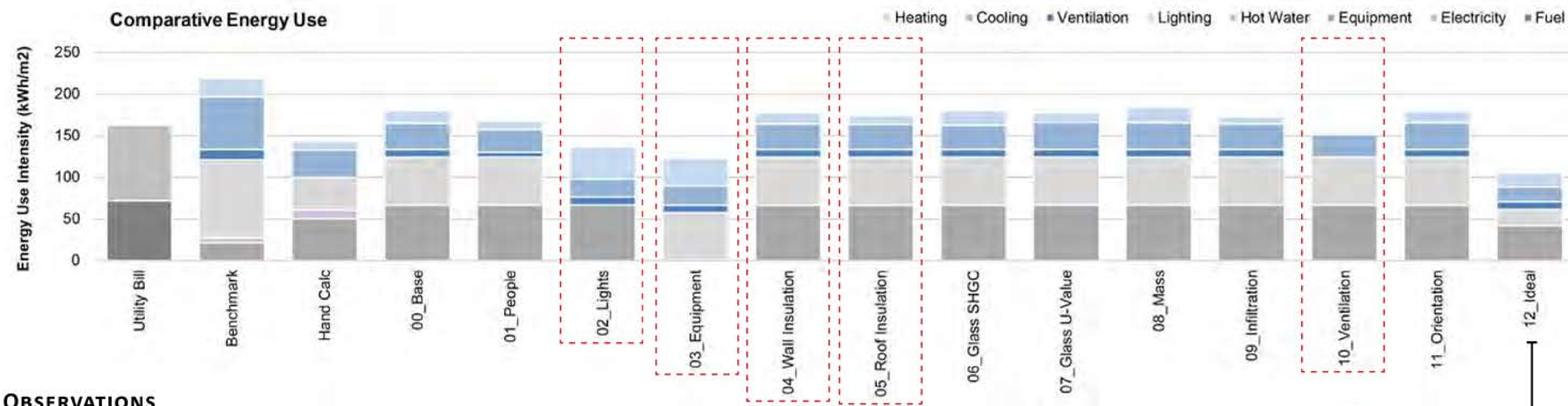
Monthly Steam Consumption (lbs)

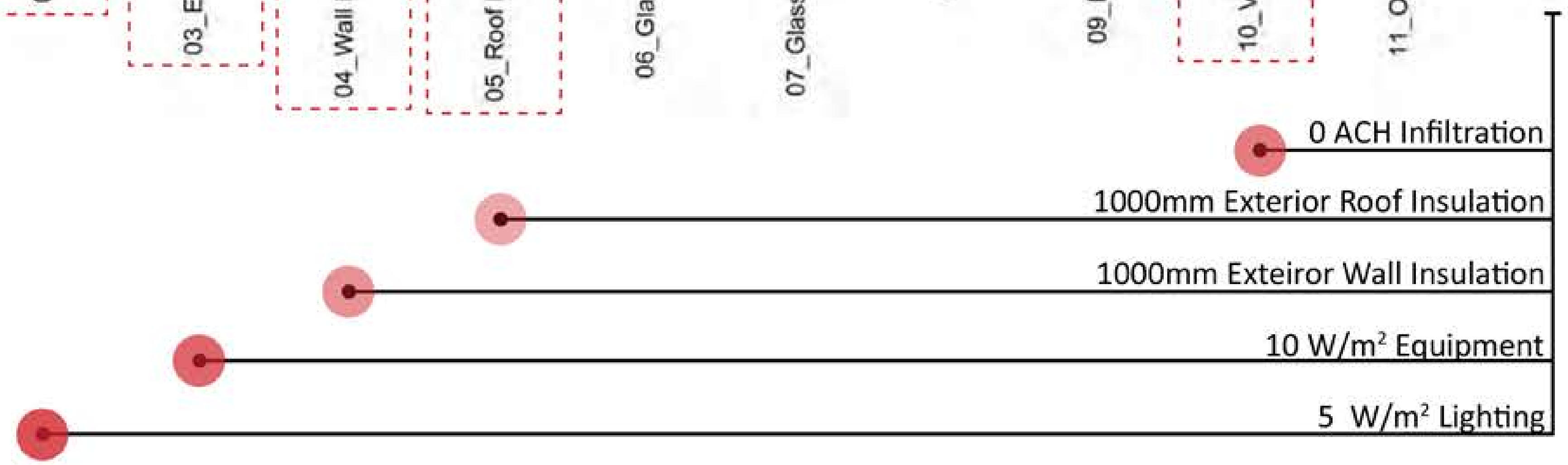
Month	Lbs of Steam	$/Lbs
Jun-14	15,000	0.027
Jul-14	15,000	0.027
Aug-14	15,000	0.027
Sep-14	16,000	0.027
Oct-14	16,000	0.027
Nov-14	20,000	0.027
Dec-14	22,000	0.027
Jan-15	22,000	0.027
Feb-15	24,000	0.027
Mar-15	20,000	0.027
Apr-15	16,000	0.027
May-15	15,000	0.027

Energy Use Intensity	
Electricity	92.0 kWh/m^2
Fuel	22.0 kWh/m^2
Total	114.0 kWh/m^2

Thermal Model Inputs

	Typical Values / Reference	Actual / Assumed	Benchmark	Hand Calc	00_Base	01_People	02_Lights	03_Equipment	04_Wall Insulation	05_Roof Insulation	06_Glass SHGC	07_Glass U-Value	08_Mass	09_Infiltration	10_Ventilation	11_Orientation	12_Ideal
Internal Loads																	
People	SWL12	44 people | 120 W/p 8am-6pm M-F			44 people | 120 W/p Bldg type defines schedule	0 people/m2											
Lights	SWL13	14.7 W/m2 8am-6pm M-F Manual Control | No Sensors			14.7 W/m2 Bldg type defines schedule Manual Control		0 Watts/m2										5 Watts/m2
Equipment	SWL14	16.053 W/m2 8am-6pm M-F			16.053 W/m2 Bldg type defines schedule			0 Watts/m2									10 Watts/m2
External Loads																	
Climate	—	Beirut, Lebanon			Beirut, Lebanon												
Orientation	—	12 degrees West of North			0 degrees North											270 deg. (West)	
Geometry	—	33.713m x 18.025m x 3.7m			See Screenshot												
Context Shade	—	Building to the east and trees to the west			Building to the east and trees to the west												
Ext. Shade	SWL16	Exterior wall provides massing around the window as the exterior shade.			0.3m x 1.5m x 2.5m eggcrate												
Int. Shade	SWL16	Operable fabric shades Manual Control			Operable fabric shades Down when incident solar												
Windows	SWL101	Double Pane Clear LoE (air) w/ Al Frame U-3.8 | SHGC- 0.33 | VT-0.52			Double Pane Clear LoE (air) w/ Al Frame U-3.8 | SHGC- 0.33 | VT-0.52						U-Value = 3.8 SHGC = 0.01	U-Value = 0.1 SHGC = 0.33					
Exterior Walls	SWL76	15mm Plaster + 200mm concrete + 20mm Mortar + 100mm Fair-Faced Concrete			250mm Concrete + 1mm Insulation + 30mm Concrete				250mm Concrete + 1000mm Insulation + 30mm Concrete								250mm Concrete + 1000mm Insulation + 30mm Concrete
Floors	SWL78	Adiabatic			Adiabatic												
Ceilings	SWL79	Adiabatic			Adiabatic					150mm Concrete + 1000mm Insulation + 30mm Concrete							150mm Concrete + 1000mm Insulation + 30mm Concrete
Mass	SWL83	0.18 m2 (estimation)			1 m2								800 m2 Mass				
Infiltration	0.1 = tight | 1.0 = leaky 0.3 = typ. new	0.3 ACH			0.4 ACH									0.0 ACH			0.0 ACH
Systems																	
Ventilation	SWL87	Fan - Unkown [8-6M-F] (1) 1.5 m2 + (4) 3.3 m2 window north, (4) 1.5 m2 + (2) 3.3 m2 north, (1) 1.5 m2 + (3) 2.25 m2 + (3) 3.75 m2 south, (1) 1.5 m2 + (1) 3.3 m2 west			Fan - 0.014218 m3/s/person | Bldg type and thermostat define schedule (1) 1.5 m2 + (4) 3.3 m2 window north, (4) 1.5 m2 + (2) 3.3 m2 north, (1) 1.5 m2 + (3) 2.25 m2 + (3) 3.75 m2 south, (1) 1.5 m2 + (1) 3.3 m2 west										No Cross Ventilation		
Heating		System Efficiency and Duct Loss Unknown Thermostat: unknown [8-6 M-F]			0.3 COP Thermostat: <21°C (School Sched), 16°C setback												
Cooling		System Efficiency and Duct Loss Unknown Thermostat: Unkown [8-6 M-F]			4.5 COP Thermostat: >24°C (School Sched), 27°C setback												
Hot Water		System Efficiency and Pipe Loss Unknown / Usage Unknown			Not modeled												
Energy Use Intensity																	
Lighting			94.0	36.1	57.3	57.3	-	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	19.5
Cooling			63.7	33.7	31.3	28.1	21.8	22.8	30.7	30.0	28.8	32.5	32.2	30.5	26.9	31.9	17.9
Ventilation			12.1		9.2	5.5	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	-	9.2	9.2
Equipment			21.2	50.7	67.0	67.0	67.0	-	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	41.7
Heating			21.2	10.0	15.1	9.7	38.8	33.8	13.0	10.3	17.4	11.5	18.0	8.9	2.6	13.9	16.8
Hot Water			6.1	10.4	-	-	-	-	-	-	-	-	-	-	-	-	-
Fuel		72.0															
Electricity		91.0															
Total (kWh/m2)		163	218.3	142.9	180.0	167.6	136.4	123.2	177.3	173.8	179.8	177.6	183.8	175.0	153.9	179.3	105.2





Observations

Parametrics that differ from reality: 0 people, 0 kWh of equipment, 0 ACH ventilation, alternate building orientation
There can be no building that has no people or equipment; ventilation is a human necessity; the building orientation typically remains consistent.

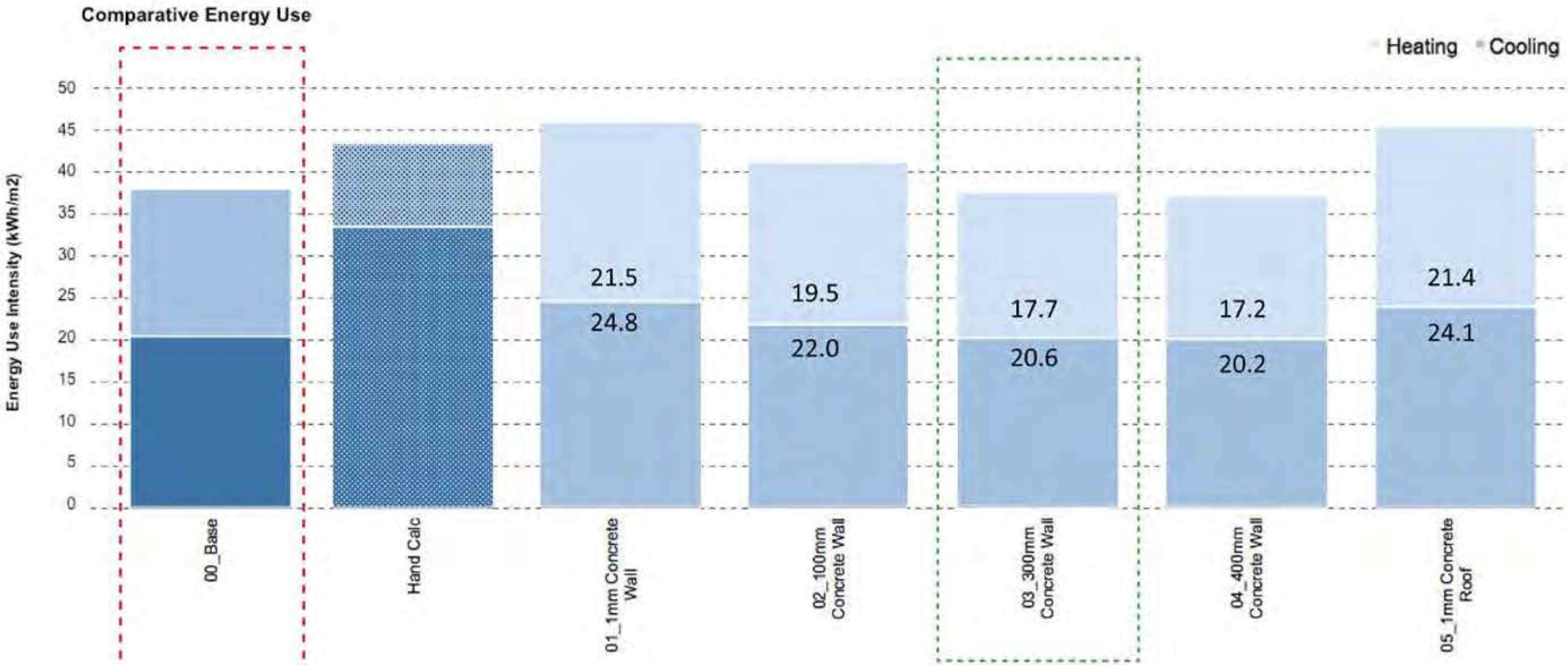
Most effectivie parametrics(s): Lights, Equipment, and Ventilation
These parametrics show the most noticeable decrease in energy use intensity. However, increasing wall insulation and roof insulation, as well as reducing infiltration, also were effective but they did not present drastic drops.

Least effective parametric(s): Glass SHGC, Glass U-Value, Mass, and Orientation
These parametrics are "lease effective" in comparison to the other parametrics. Generally these results are very similar to the base model, if not a little more energy consuming.

Differences in predictions: It was surprising that increasing the insulation for both the wall and the roof only slightly decreased the need for heating. Overall, it is surprising that the majority of the parametrics did not fluctuate as much as one would expect. This suggests that the building is primarily affected by internal loads and ventilation. However, ventilation is necessary to have a healthy environment so reducing the amount of energy consumption in lights and equipment is the most effective means to achieve enery efficiency.

Analysis

- The improvements do no change the building aesthetic as it is limited to the equipment inside it, wall insulation and infiltration. Also we could change the lights to energy saving lights with the same brightness/lumens.
- The building fits the pyramid category the most for it has low transparency and high mass, which is characterized by the high thermal mass of the concrete walls.
- We changed the insulation to 1000mm so that when it is warm inside the zone the wall will absorb the heat (and release that heat when the the zone becomes cooler). Additionally, changing the roof insulation to 1000mm allows it to act as a heat sink, which further dampens the peak loads and creates thermal lag.



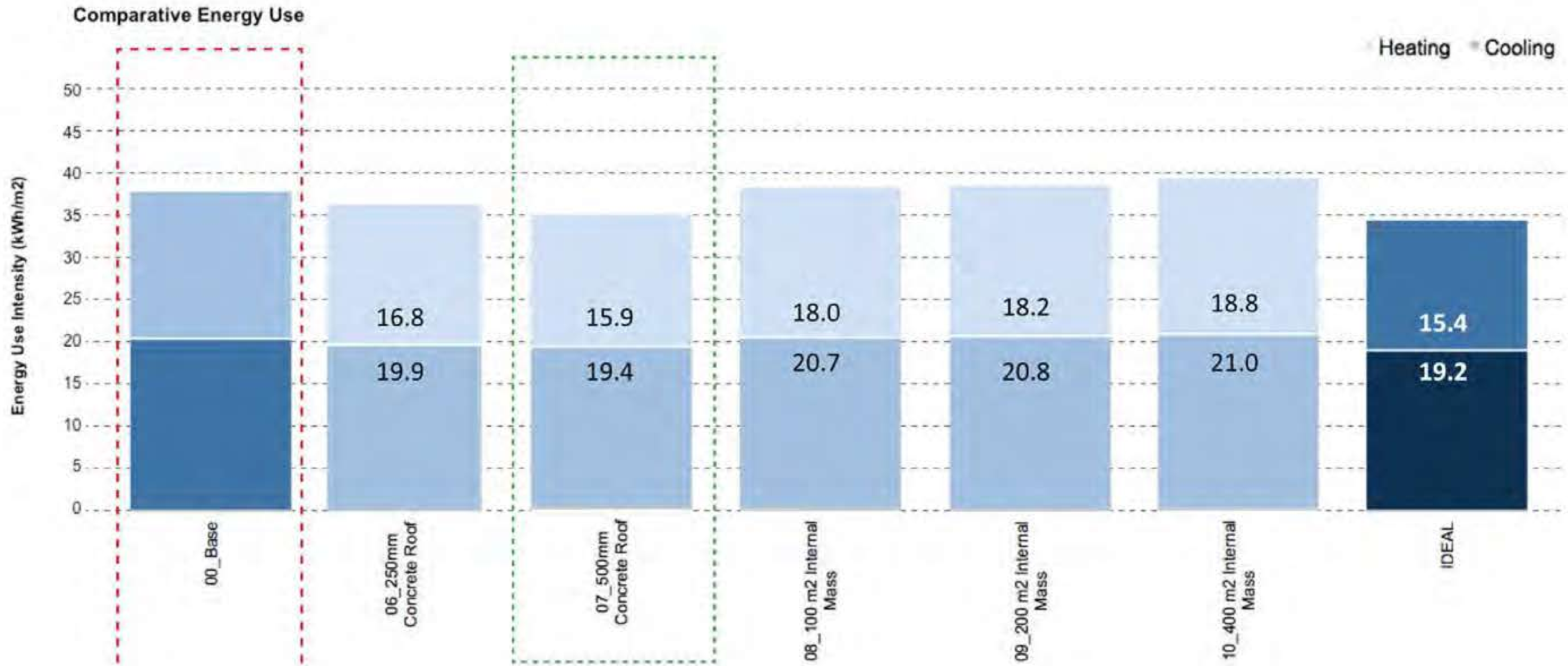
Energy Use Intensity	*Base*	*Hand Calc*
Lighting	23.0	38.1
Cooling	20.6	33.7
Ventilation	9.2	
Equipment	18.0	50.7
Heating	17.7	10.0
Hot Water	-	10.4
Fuel		
Electricity		
Total (kWh/m2)	88.5	142.9

Thermal Mass: Exterior Wall

When we reach 300mm Concrete for the wall massing, it does not make sense to further increase it do the incremental difference it makes. While 250mm and 300mm Concrete are similar amounts, the 300mm massing performed better. Additionally, increasing the width of the exterior walls beyond a total of ~350mm would not be efficient or look aesthetically pleasing.

Thermal Mass: Exteriror Ceiling

Commentary for the ceiling massing is on the following page.



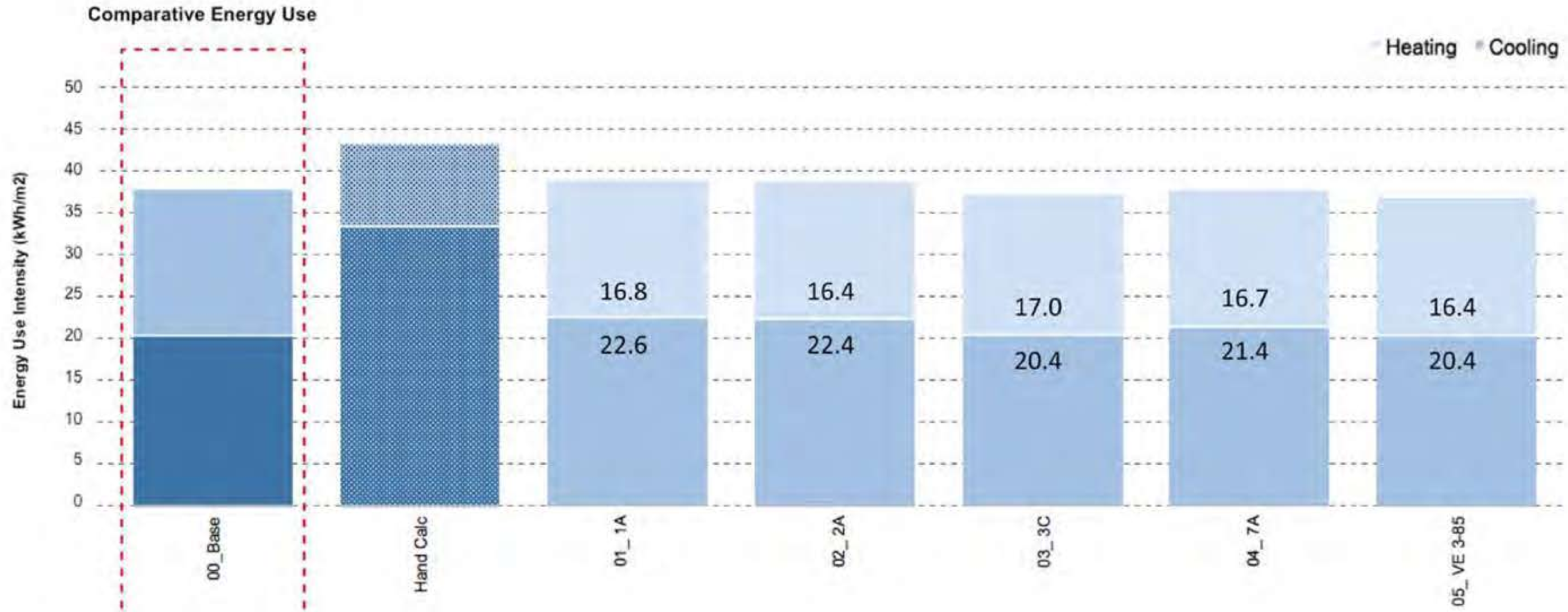
Energy Use Intensity	*Base*
Lighting	23.0
Cooling	20.6
Ventilation	9.2
Equipment	18.0
Heating	17.7
Hot Water	-
Fuel	
Electricity	
Total (kWh/m2)	88.5

Thermal Mass: Exteriror Ceiling

In contrast to the exterior wall, the ceiling benefitted from increasing its massing from 150mm Concrete to 500mm Concrete. This slightly lowered cooling, but it made a large difference in heating. Also, increasing the massing for the ceiling will not be as detrimental to the aesthetic of the building.

Internal Mass:

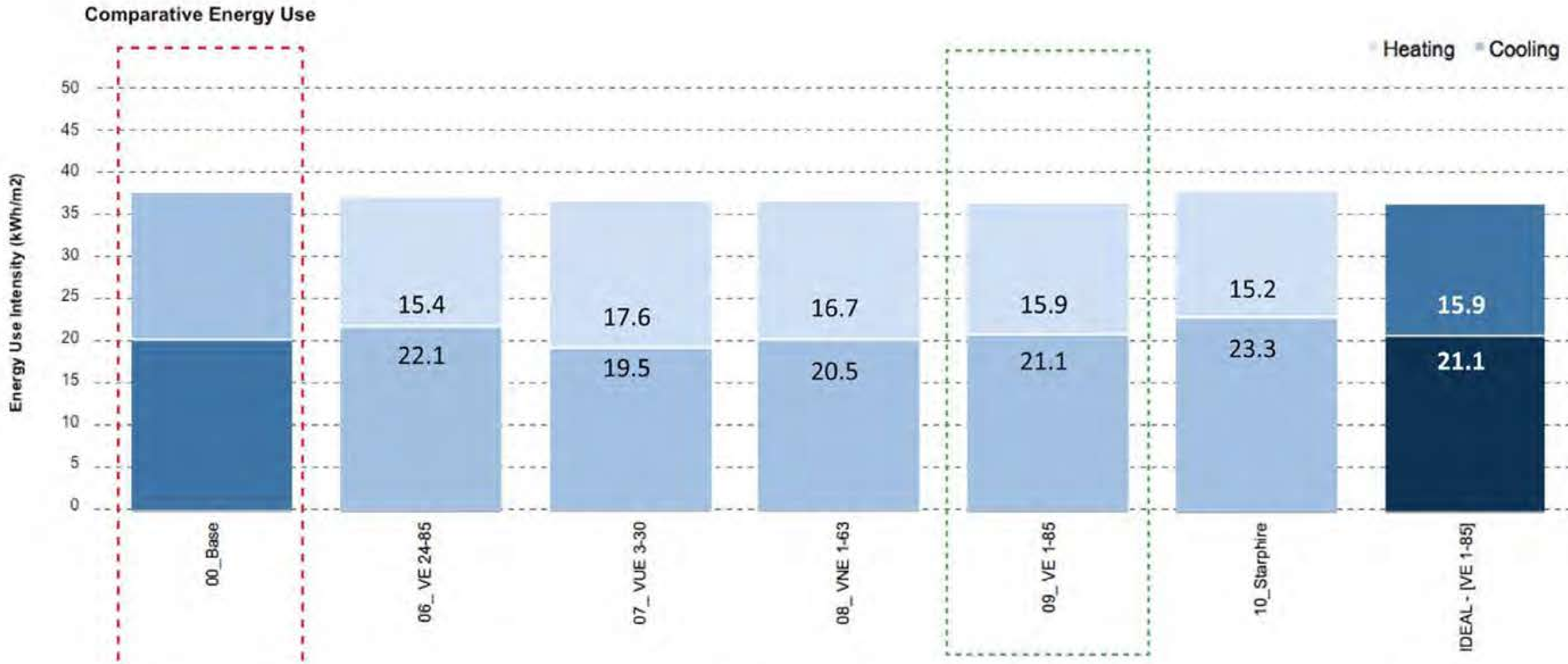
To our surprise, increasing the internal mass of the building was not as effective. Although there was little to no increase in levels of cooling, levels of heating increase noticeably. For this reason, we believed that maintaining an internal massing of 1m² (the original amount) would be more efficient for the building.



Energy Use Intensity	*Base*	*Hand Calc*
Lighting	23.0	38.1
Cooling	20.6	33.7
Ventilation	9.2	
Equipment	18.0	50.7
Heating	17.7	10.0
Hot Water	-	10.4
Fuel		
Electricity		
Total (kWh/m2)	88.5	142.9

Glass Types:	U-Value:	SHGC:	VLT:
1A	7.0	0.66	0.66
2A	6.5	0.59	0.59
3C	2.1	0.33	0.52
7A	3.0	0.52	0.52
VE 3-85	1.6	0.33	0.38

If we add more panes of glass, it does not make a great difference, as opposed to lessening the number of panes. However, changing the frame of the window affects the windows performance. For example, the wood frame in 3C performs better than the alumnium frame in 3A (all other factors remain the same).



Energy Use Intensity	*Base*
Lighting	23.0
Cooling	20.6
Ventilation	9.2
Equipment	18.0
Heating	17.7
Hot Water	-
Fuel	
Electricity	
Total (kWh/m2)	88.5

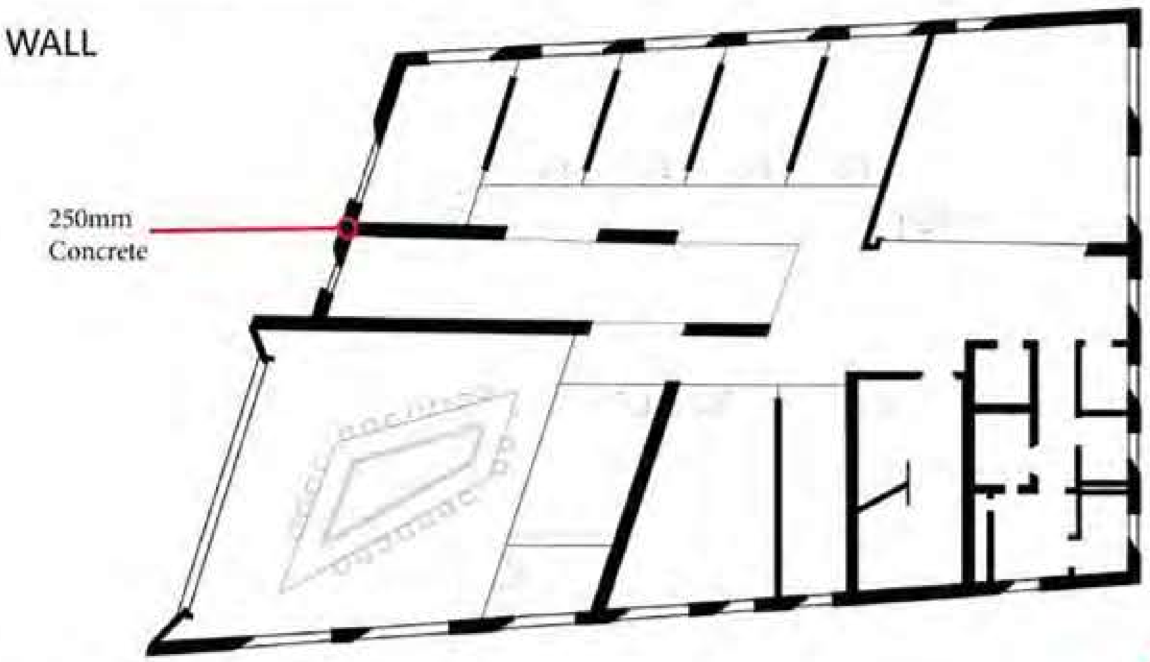
Glass Types:	U-Value:	SHGC:	VLT:
VE 24-85	**1.6**	**0.63**	**0.81**
VUE 3-30	**1.6**	**0.13**	**0.15**
VNE 1-63	**1.48**	**0.29**	**0.62**
VE 1-85	**0.96**	**0.44**	**0.65**
Starphire	**2.8**	**0.82**	**0.84**

Considering the climate in Beirut, we need a glass with high SHGC value and a lower U-value. The higher the SHGC value, the more the building requires cooling.

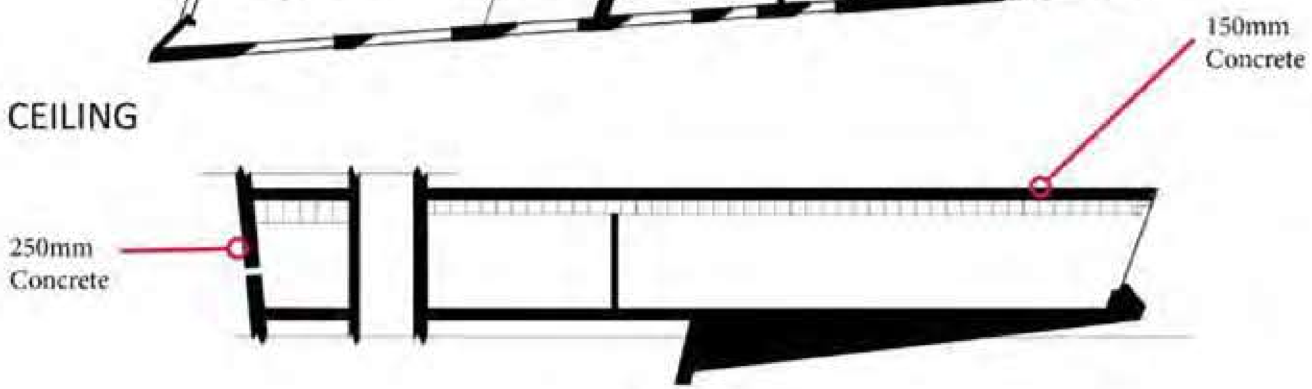
Given the results of our data, the glass type of VE1-85 performs better than all of the other types tested, including the origional in the base model.

Base Model Massing:

WALL

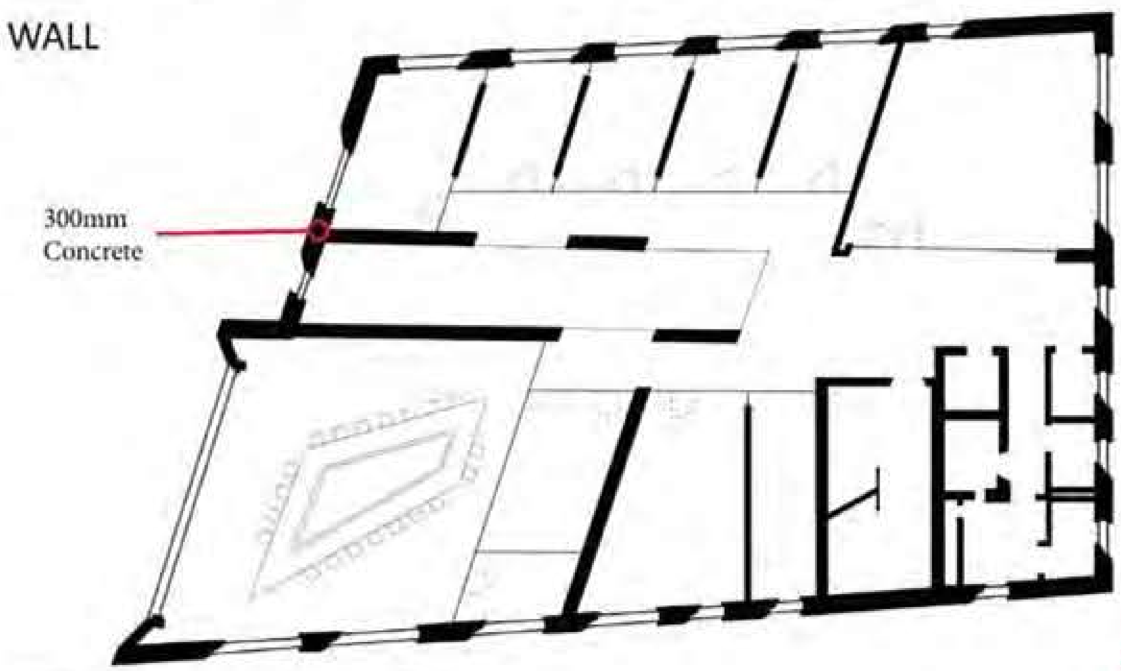


CEILING

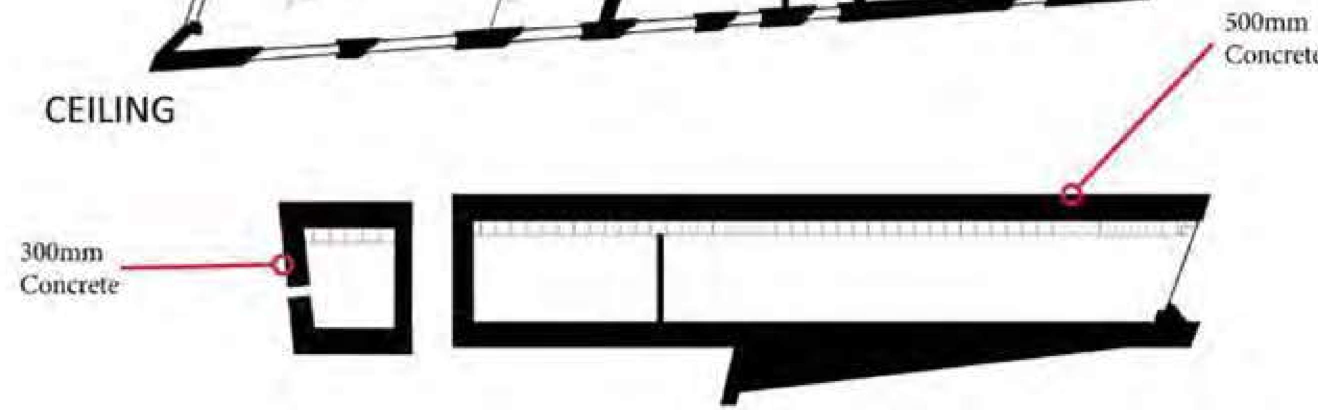


Suggested Massing:

WALL



CEILING



Base Model Glass:

Aluminum Framing
Double-Pane, Low-e
Clear Glass (Air Fill)
No Silk Screen

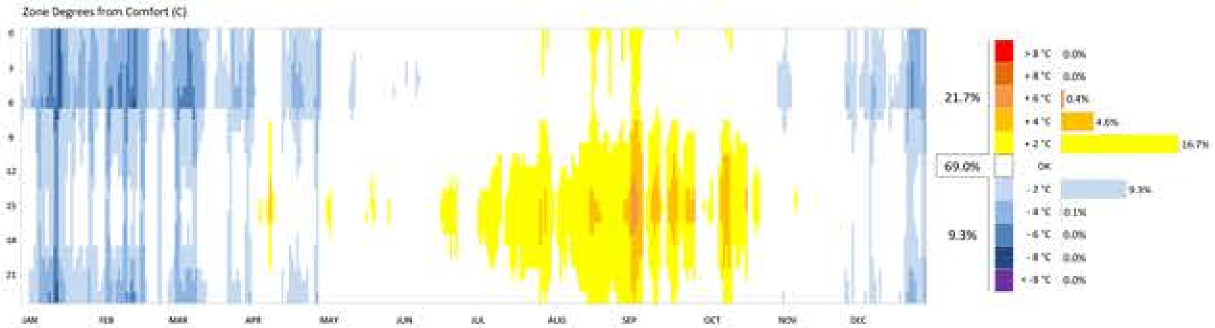
U-Value: 3.8
SHGC: 0.33
VLT: 0.52

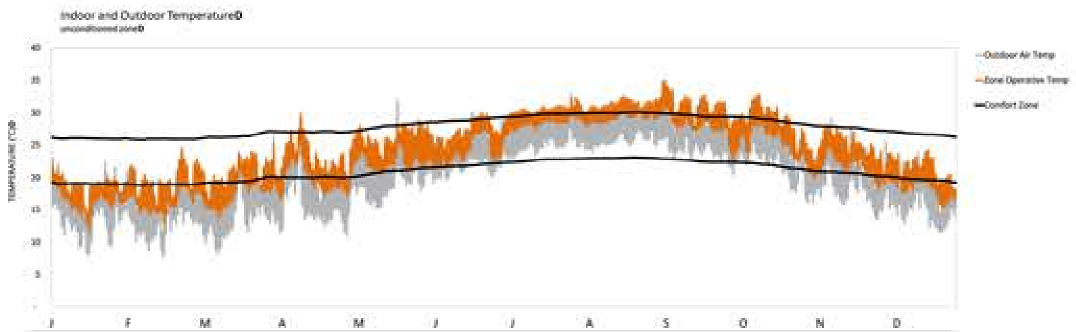
Suggested Glass:

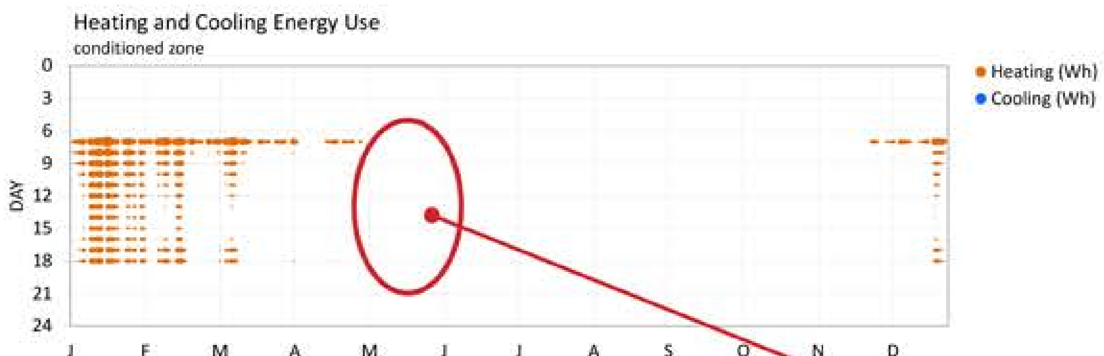
1-3/4" (44mm) VE 1-85
TRIPLE INSULATING
(DOUBLE COATING)
Clear Glass (Air Fill)
No Silk Screen

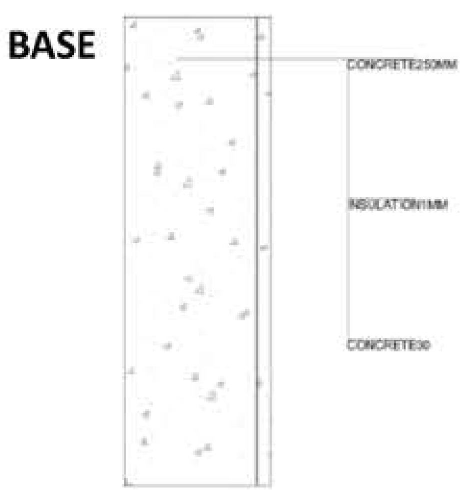
U-Value: 0.96
SHGC: 0.44
VLT: 0.65

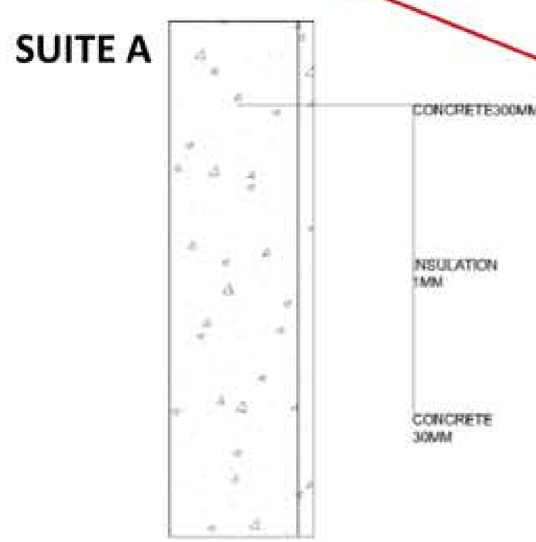
Thermal Autonomy and Energy Use



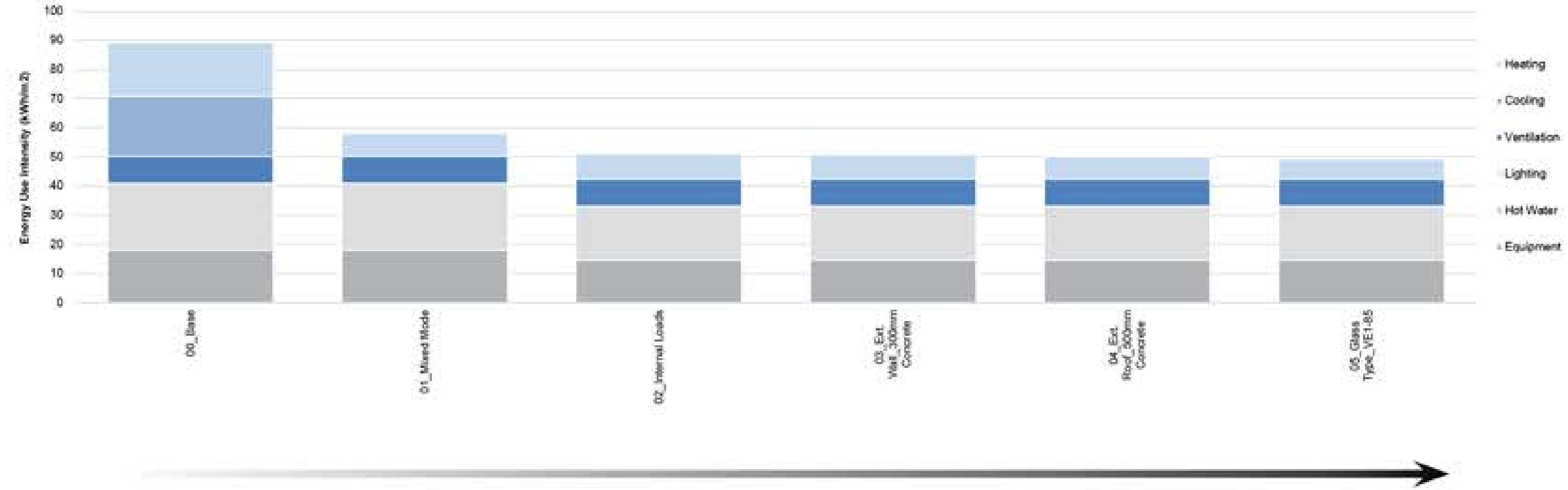








Comparative Energy Use



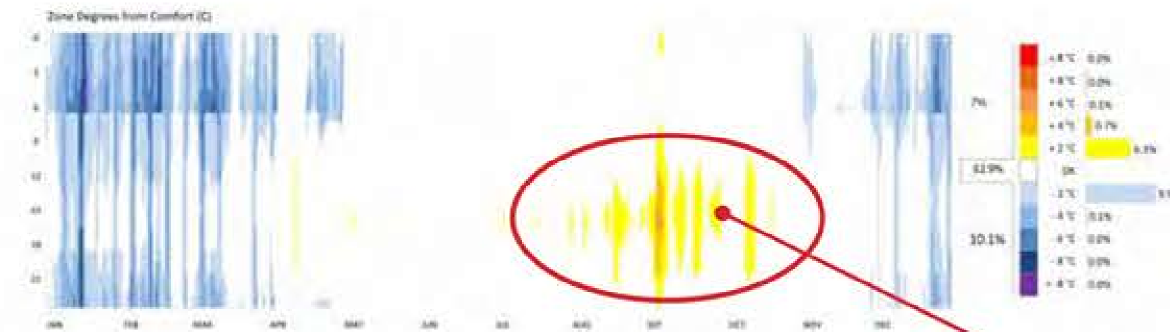
** Each new simulation is an add-on of the last simulation*

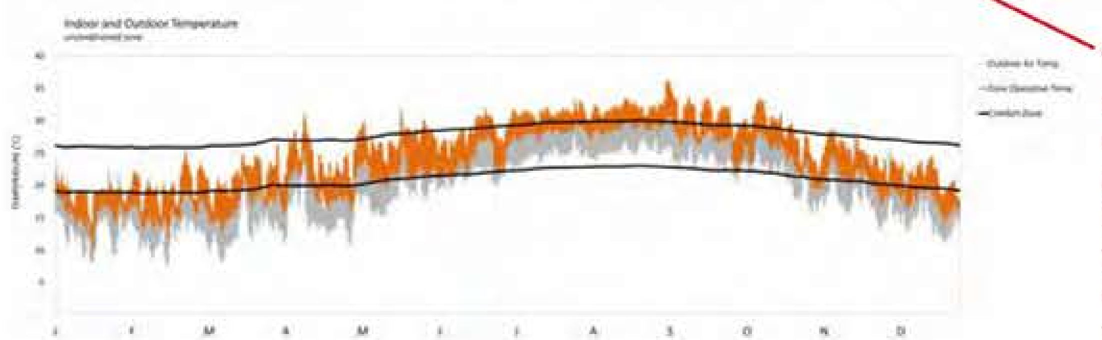
For Suite A, we redid the schedule for ventilation to decrease the cooling and heating which made a great difference. Cutting down the internal loads helped decrease the energy use but increased the need for heating. In an effort to reduce the heat, we made changes to the exterior roof (added 350mm concrete) and changed the glass type to be VE 1-85. Overall, the added insulation to the outside of the exterior wall made little to no difference.

Energy Use Intensity						
Lighting	23.0	23.0	18.4	18.4	18.4	18.4
Cooling	20.6	-	-	-	-	-
Ventilation	9.2	9.2	9.2	9.2	9.2	9.2
Equipment	18.0	18.0	14.7	14.7	14.7	14.7
Heating	18.5	7.9	8.7	8.6	7.7	6.9
Hot Water	-	-	-	-	-	-
Fuel						
Electricity						
Total (kWh/m2)	89.3	58.1	51.0	50.9	50.1	49.2

There are no longer dots in this area because the Mixed Mode schedule was corrected to begin on 05/22 instead of 05/15, allowing for the cool days to pass so that ventilation would not take place when the outside temperatures are much cooler, thus requiring more heating.

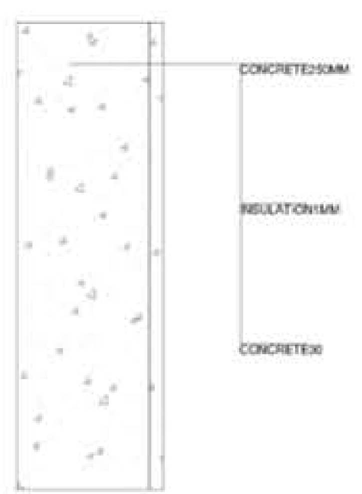
THERMAL AUTONOMY AND ENERGY USE



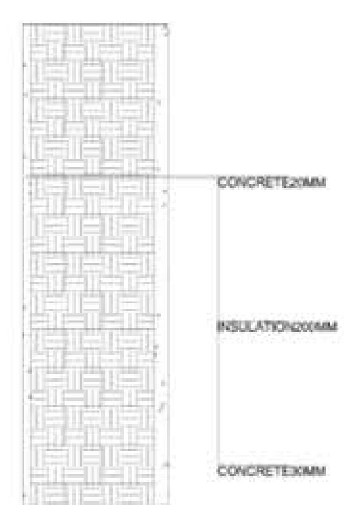


The ceiling fans make a big difference for Thermal Autonomy. This is due to the fact that air movement contributes to the preception of comfort.

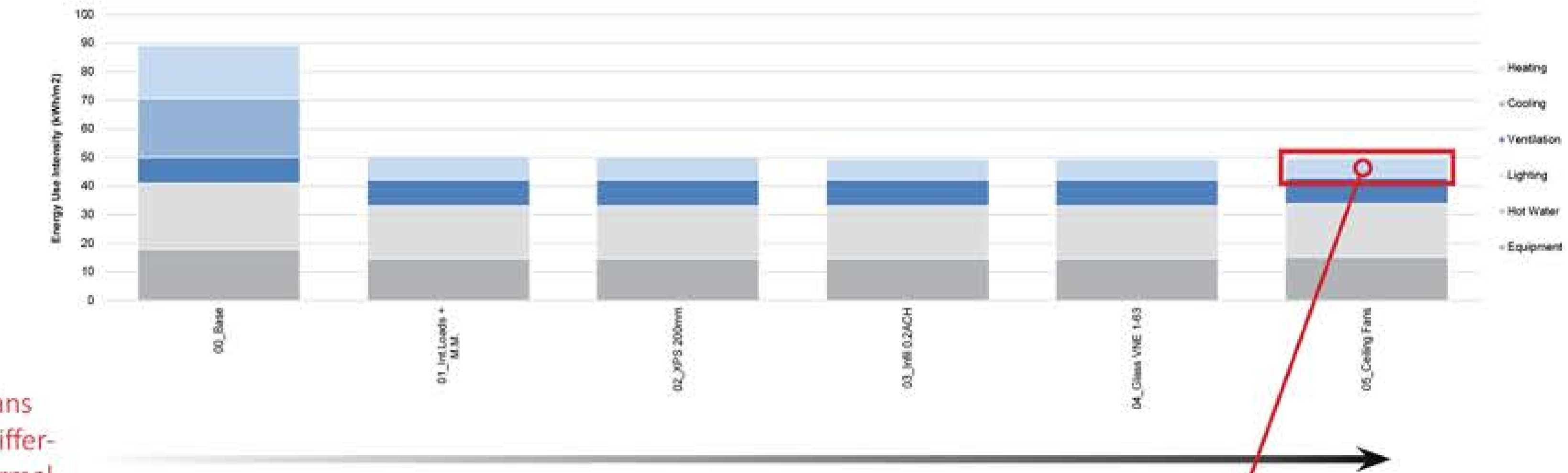
BASE



SUITE B



COMPARATIVE ENERGY USE



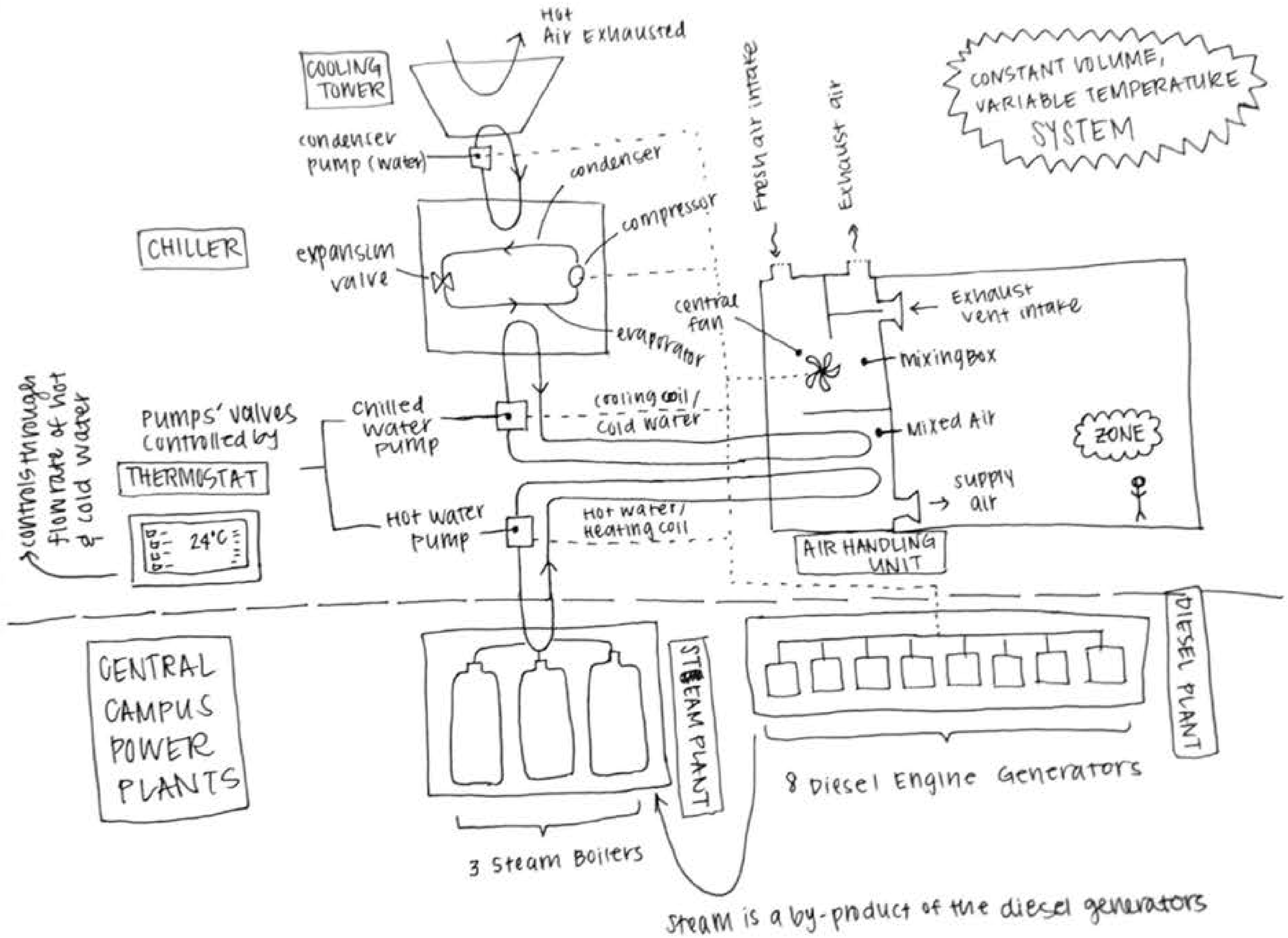
** Each new simulation is an add-on of the last simulation*

These simulations have the heating setpoint at 20 degrees Celsius from 7:00am - 7:00pm M-F and turned off at all other times; the cooling setpoints are all set to 40 degrees Celsius to allow for natural ventilation to cool the spaces. Interestingly enough, the energy decreases significantly when mixed mode ventilation is applied. While there isn't a significant energy difference in the application of XPS 200mm insulation, 0.2 ACH infiltration, and VNE 1-63 glass type, including ceiling fans is important to improve the thermal autonomy of the space (since adding air movement perceptually decreases the temperature by 2 degrees Celcius) while accounting for an increase in equipment energy use.

The existance of heating with the mixed mode schedule might suggest that investing in thermal mass instead of insulation might provide more desirable results to achieve little to no need for heating.

Energy Use Intensity						
Lighting	23.0	18.4	18.4	18.4	18.4	18.4
Cooling	20.6	-	-	-	-	-
Ventilation	9.2	9.2	9.2	9.2	9.2	9.2
Equipment	18.0	14.7	14.7	14.7	14.7	15.4
Heating	18.5	8.2	8.0	7.2	7.2	6.7
Hot Water	-	-	-	-	-	-
Fuel						
Electricity						
Total (kWh/m2)	89.3	50.6	50.3	49.5	49.5	49.8

HVAC Systems Diagram



Note on HVAC Systems Diagram:

This illustration does not accurately demonstrate the Air Handling Unit/Air Flow System. In the Issam Fares Institute, hot and cold air are supplied from the bottom and the top of the building floors, respectively. They feed into each zone through branches - this means that there is one central supply of hot and cold water that runs through the building and branches off in each floor, which branches off into each room (zone). In this diagram, the Air Handling Unit suggests that there is a mixing of fresh air and recovered heat when in reality there is no mixing box because each system is separate.

Base Model :: Cooling Setpoints, Heating Setpoints, No Natural Ventilation or Ceiling Fan Schedule

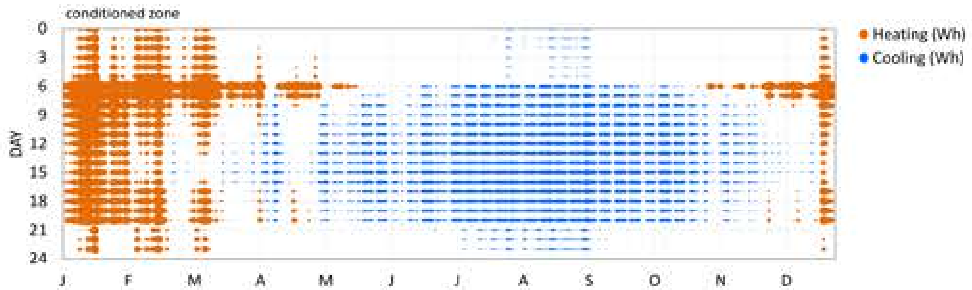
SCHOOL_CLGSETI	SCHOOL_HTGSET	Always Off
Temperature	Temperature	Fraction
Through: 12/31	Through: 12/31	Through: 12/31
For: WeekEnds	For: WeekEnds	For: AllDays
Until: 24:00	Until: 24:00	Until: 24:00
27	16	0
For: AllOtherDays	For: AllOtherDays	
Until: 06:00	Until: 06:00	
27	16	
Until: 21:00	Until: 21:00	
24	21	
Until: 24:00	Until: 24:00	
27	16	

Improved Model :: Cooling Setpoints, Heating Setpoints, Natural Ventilation Schedule, and Ceiling Fan Schedule

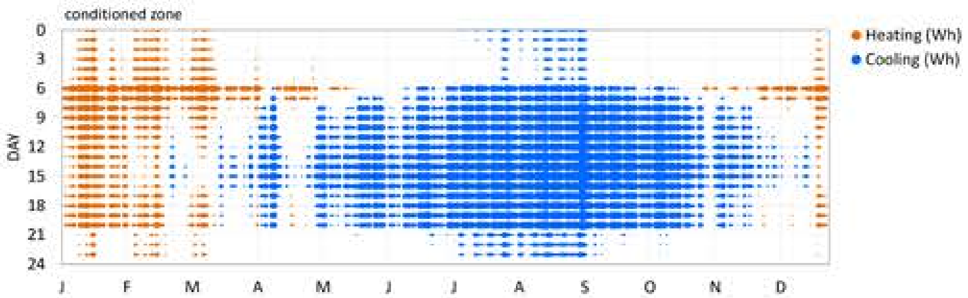
SCHOOL_CLGSETI	SCHOOL_HTGSET	NatVent_Schedule	SCHOOL_ClgFans
Temperature	Temperature	Fraction	Fraction
Through: 12/31	Through: 12/31	Through: 05/22	Through: 05/22
For: WeekEnds	For: WeekEnds	For: AllDays	For: AllDays
Until: 24:00	Until: 24:00	Until: 7:00	Until: 7:00
42	0	0	0
For: AllOtherDays	For: AllOtherDays	Until: 22:00	Until: 22:00
Until: 07:00	Until: 07:00	0	0
42	0	Until: 24:00	Until: 24:00
Until: 19:00	Until: 19:00	0	0
42	20	Through: 06/1	Through: 06/1
Until: 24:00	Until: 24:00	For: AllDays	For: AllDays
42	0	Until: 13:00	Until: 13:00
		1	1
		Until: 19:00	Until: 19:00
		1	1
		Until: 24:00	Until: 24:00
		1	1
		Through: 09/1	Through: 09/1
		For: AllDays	For: AllDays
		Until: 6:00	Until: 6:00
		1	1
		Until: 15:00	Until: 15:00
		0	1
		Until: 24:00	Until: 24:00
		1	1
		Through: 10/15	Through: 10/15
		For: AllDays	For: AllDays
		Until: 15:00	Until: 15:00
		1	1
		Until: 19:00	Until: 19:00
		1	1
		Until: 24:00	Until: 24:00
		1	1
		Through: 12/31	Through: 12/31
		For: AllDays	For: AllDays
		Until: 7:00	Until: 7:00
		0	0
		Until: 22:00	Until: 22:00
		0	0
		Until: 24:00	Until: 24:00
		0	0

Heating and Cooling Energy Use

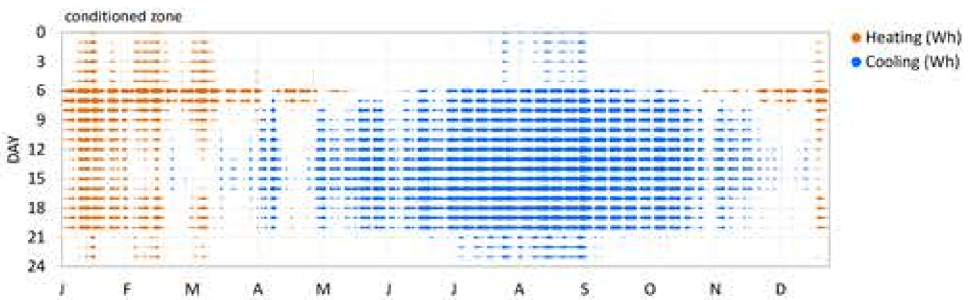
Improving the COPs for heating and cooling will primarily improve (lessen) the need for heating more than cooling. Since this is the Base Model, it is evident that incorporating a passive means to cool down the building, in conjunction to the HVAC system, will improve the energy use for cooling.



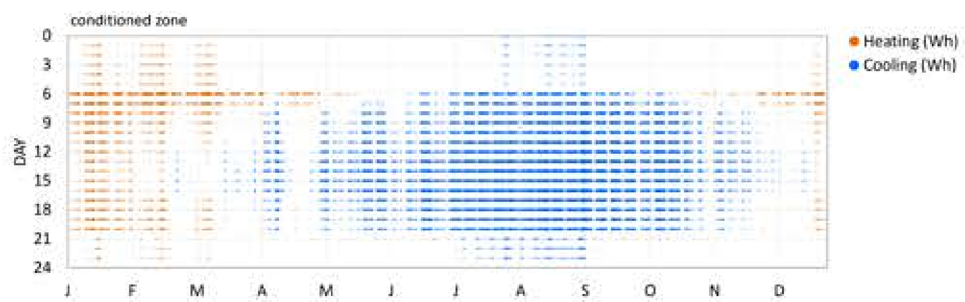
Existing
0.3 COP Heating
4.5 COP Cooling



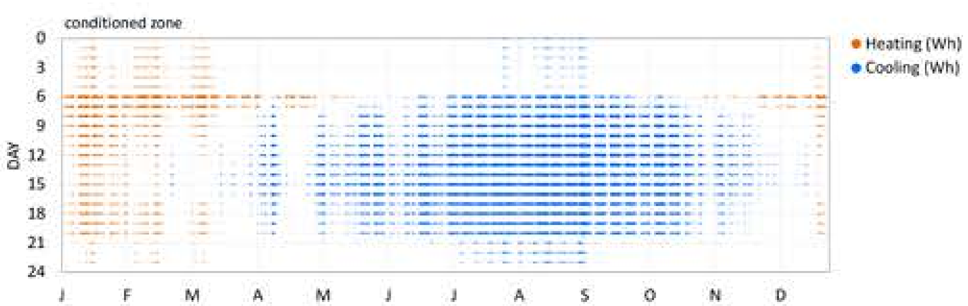
100% Efficiency
1.0 COP Heating
1.0 COP Cooling



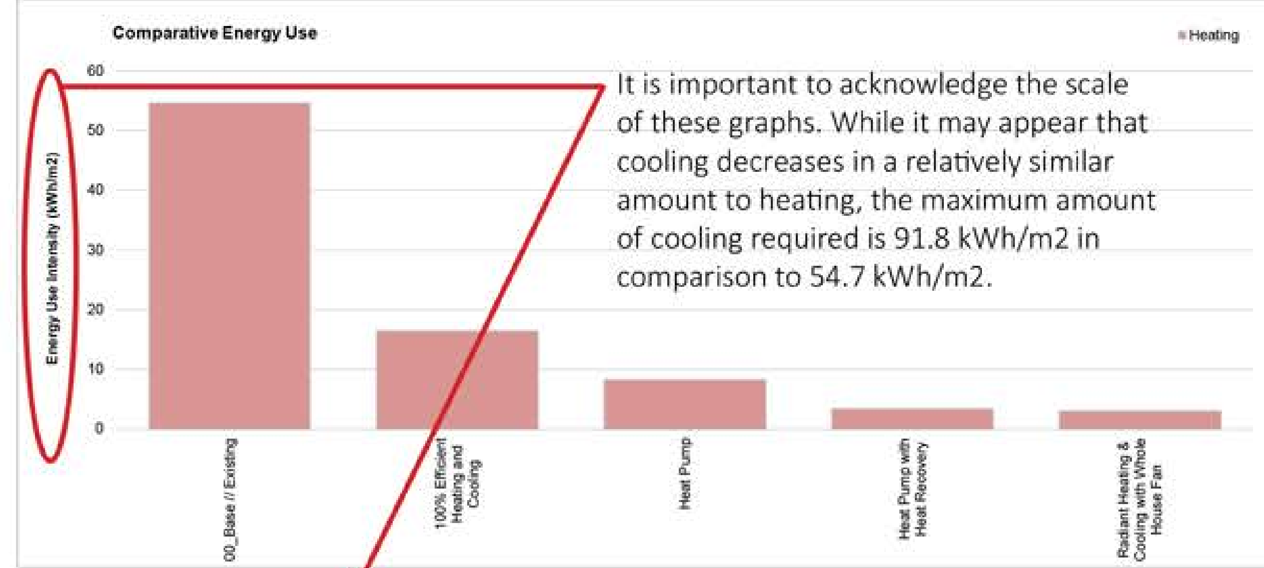
Heat Pump
2.0 COP Heating
3.0 COP Cooling



Heat Pump + Heat Recovery
5.0 COP Heating
6.0 COP Cooling



Radiant Heating/Cooling + Whole House Fan
5.5 COP Heating
6.5 COP Cooling



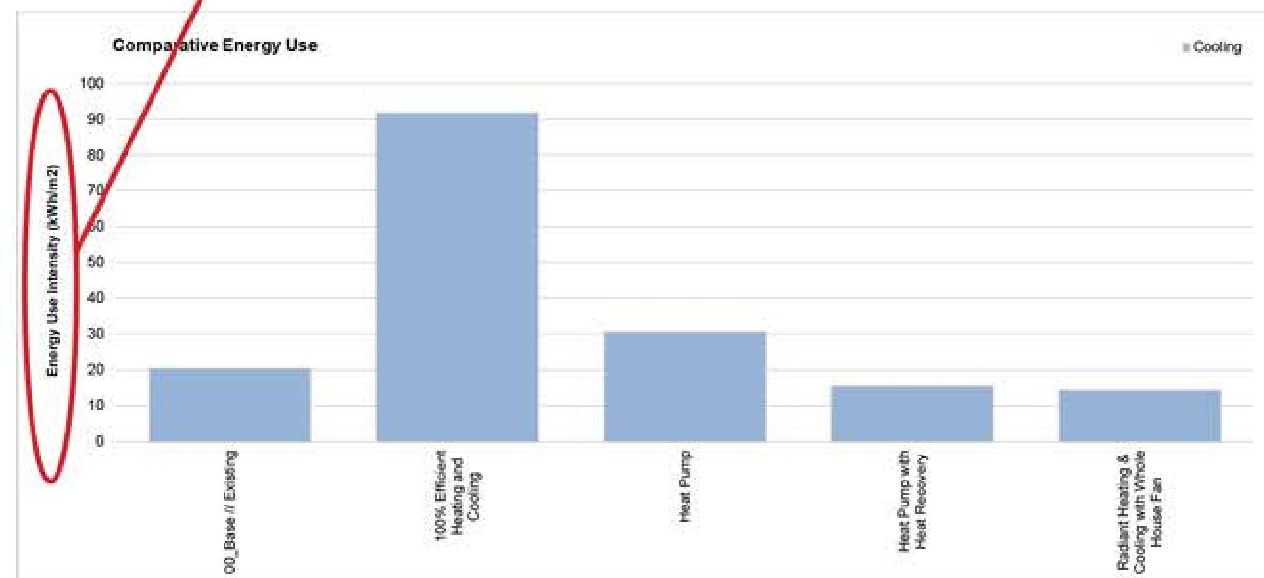
It is important to acknowledge the scale of these graphs. While it may appear that cooling decreases in a relatively similar amount to heating, the maximum amount of cooling required is 91.8 kWh/m2 in comparison to 54.7 kWh/m2.

BASE MODEL

Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	54.7	16.4	8.2	3.3	3
Cooling	20.4	91.8	30.6	15.3	14.1

IMPROVED MODEL

Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	20.8	6.2	3.1	1.2	1.1
Cooling	--	--	--	--	--



BASE MODEL

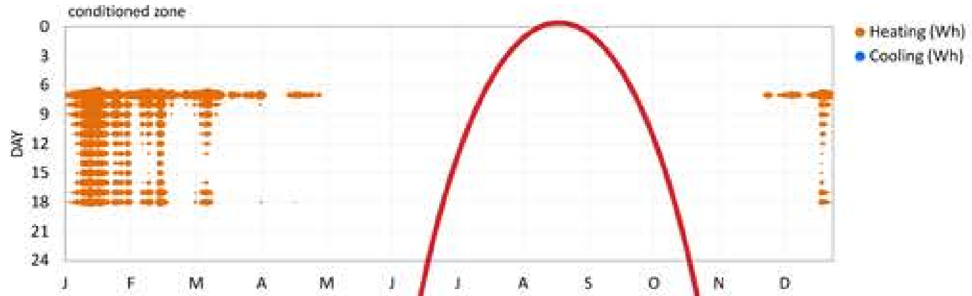
Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	54.7	16.4	8.2	3.3	3
Cooling	20.4	91.8	30.6	15.3	14.1

IMPROVED MODEL

Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	20.8	6.2	3.1	1.2	1.1
Cooling	--	--	--	--	--

Heating and Cooling Energy Use

Existing
0.3 COP Heating
4.5 COP Cooling

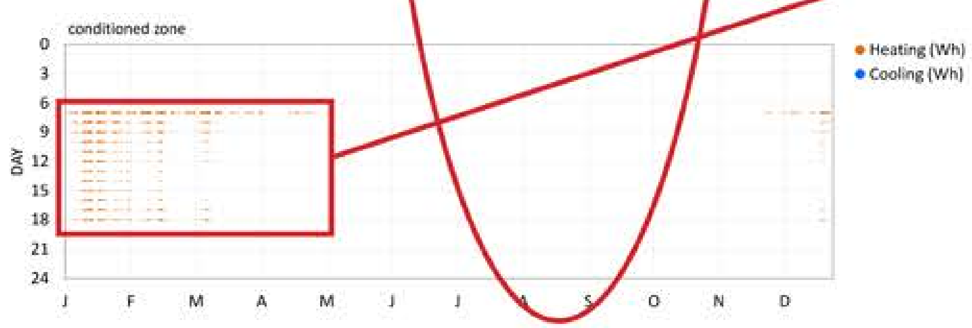


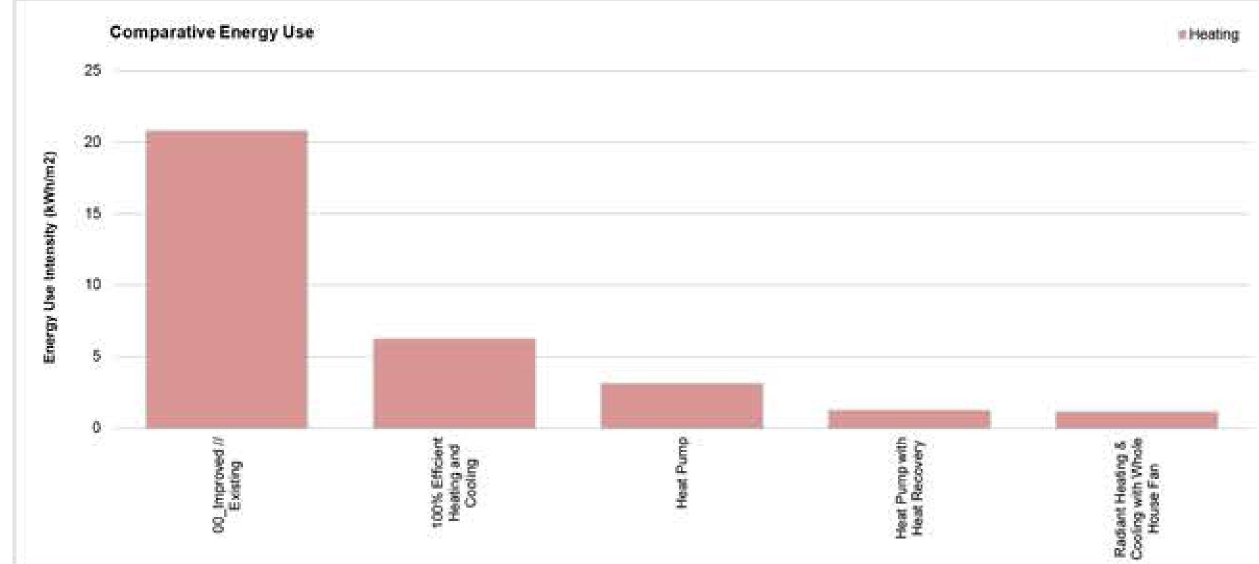
100% Efficiency
1.0 COP Heating
1.0 COP Cooling

Heat Pump
2.0 COP Heating
3.0 COP Cooling

Heat Pump +
Heat Recovery
5.0 COP Heating
6.0 COP Cooling

Radiant Heating/Cooling +
Whole House Fan
5.5 COP Heating
6.5 COP Cooling





BASE MODEL

Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	54.7	16.4	8.2	3.3	3
Cooling	20.4	91.8	30.6	15.3	14.1

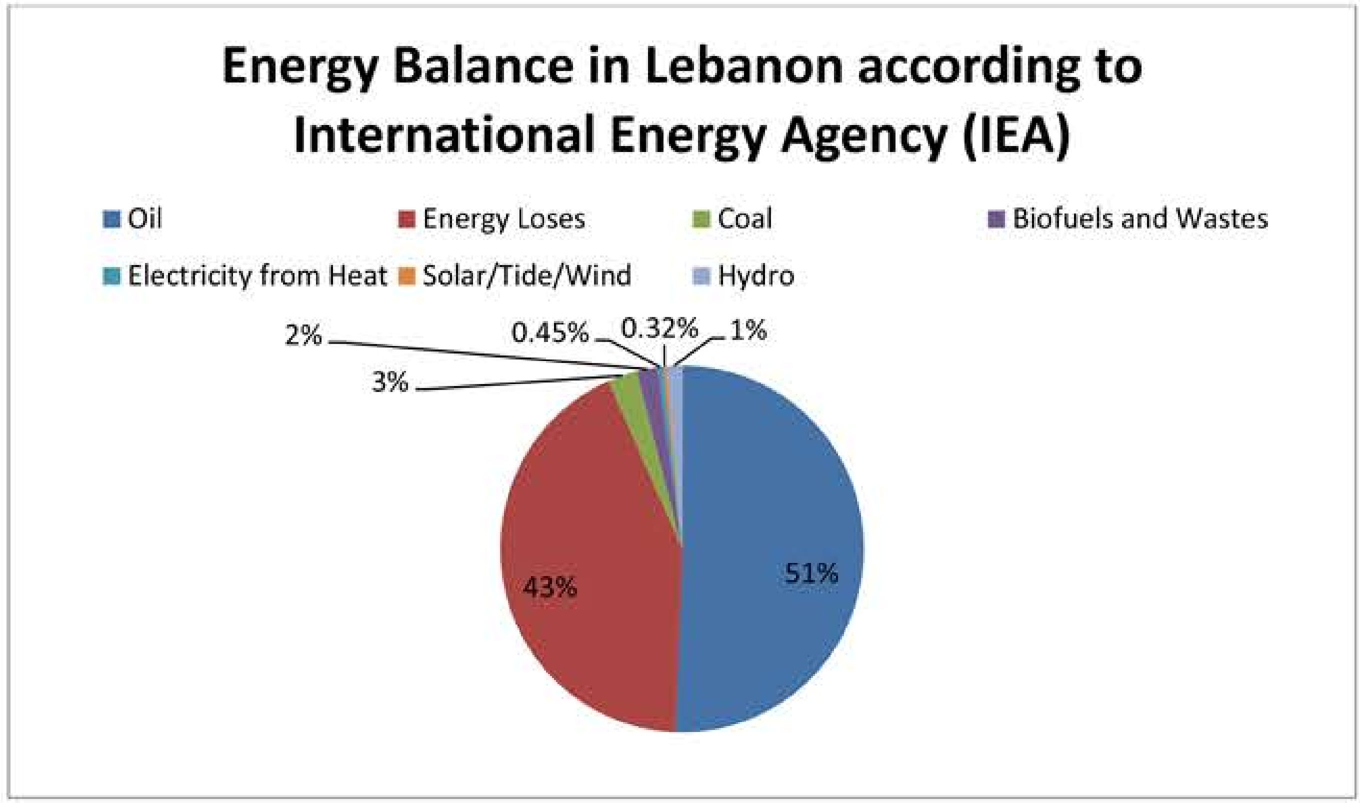
IMPROVED MODEL

Energy Use	Exisitng	100 % Efficiency	Heat Pump	Heat Pump + Heat Recover	Radiant Heating + Cooling
Heating	20.8	6.2	3.1	1.2	1.1
Cooling	--	--	--	--	--

In regards to cooling:
There are no effects of improving the cooling COP because improving the Base Model with natural ventilation as part of the mixed mode schedule (coupled with the HVAC system) elminates the need for cooling the Improved Suite.

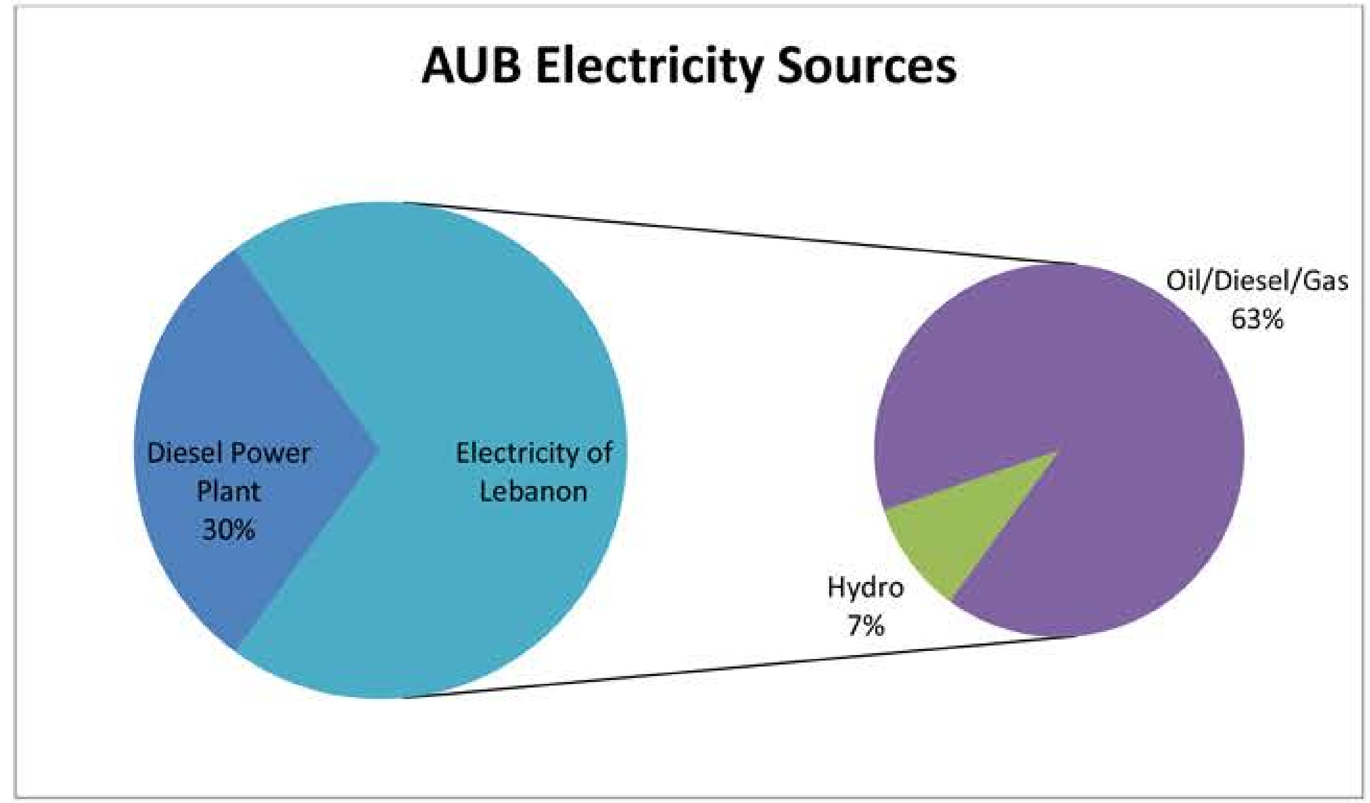
In regards to heating:
It is apparent that improving the heating COP greatly reduces the need for heating in the building. This efficiency can be expanded upon by incorporating renewable energy to "elminate" the rest of the this energy consumption, in addition to the energy consumption from ventilation and internal loads (lighting and equipment).

Energy Source in Lebanon



- The total of produced and imported energy is 7423 ktoe
- 63% of the energy produced is consumed in transport

Energy Source in American University of Beirut



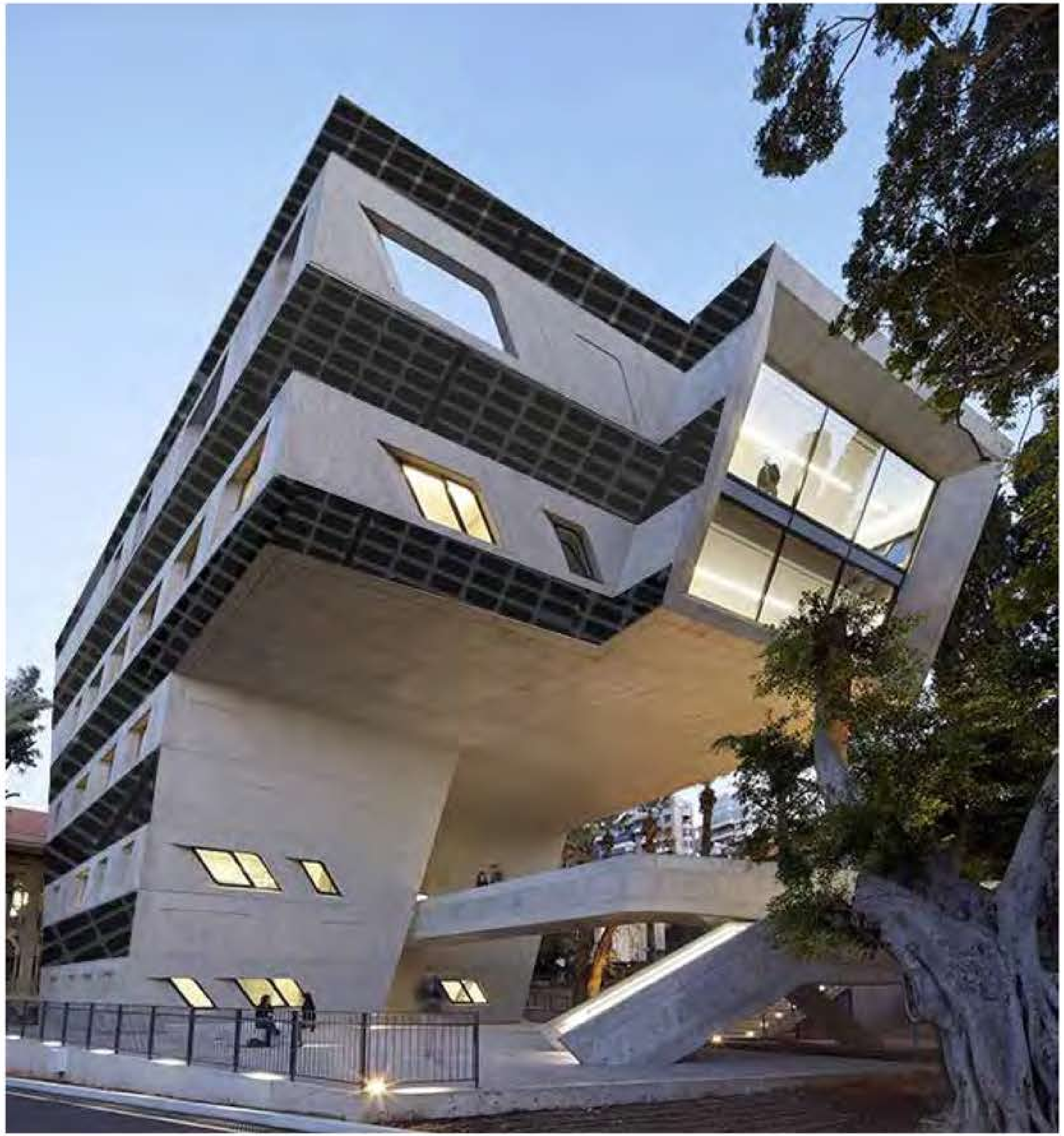
- The power plant is equipped with diesel engine generators. Electrical power is generated at 3,300 volts and distrubted on campus
- Electricity of Lebanon (EDL - Electricite du Liban) is the main governmental provider of electricity in lebanon
  >> Produces 2083 MW through thermal power plants that use oil, diesel, and gas
  >> Produces 220.6 MW through hydro power plants

American University of Beirut enery settings (campus wide):

- Setting of campus buildings temperature at 76 F (24 C) and 86 F (30 C) during summer occupied and unoccupied periods, respectively
- Setting of campus buildings temperature at 70 F (21 C) and 60 F (15 C) during winter occupied and unoccupied periods, respectively
- Replacement of low efficiency equipment with new high efficiency ones such as motors, air-conditioning equipment, electrical transformers heating boilers, etc.
- Installing aerating, low-flow faucets and showerheads to reduce water consumption

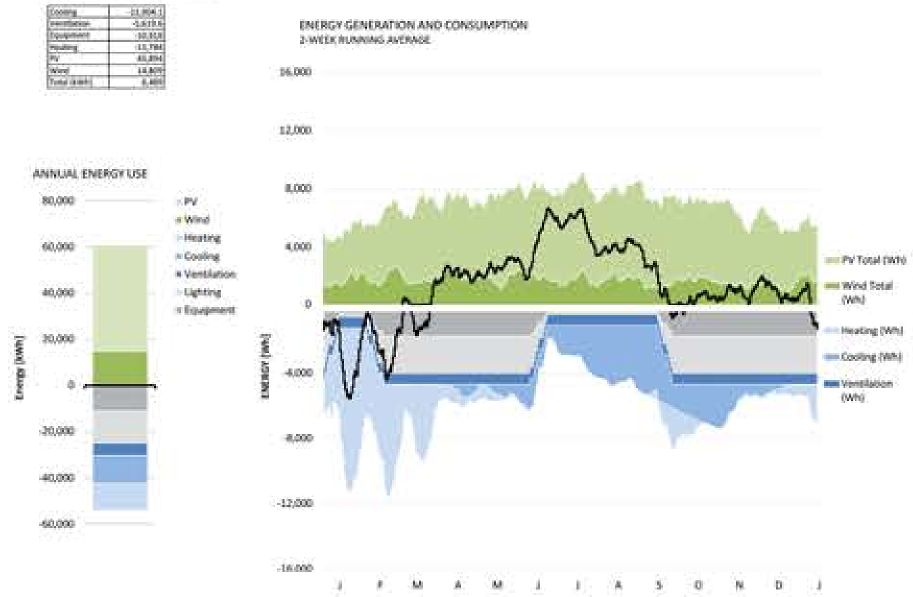
Hydro Power Plant, Lebanon

Thermal Power Plant, Lebanon



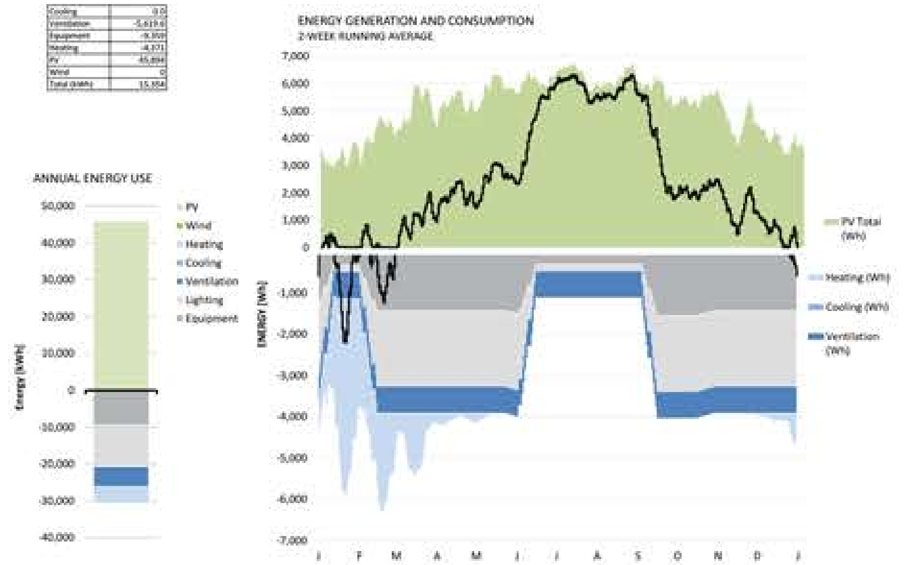
Base Model

Cooling	[illegible]
Ventilation	[illegible]
Equipment	[illegible]
Heating	[illegible]
PV	[illegible]
Wind	[illegible]
Total (kWh)	[illegible]



Improved Model

Cooling	[illegible]
Ventilation	[illegible]
Equipment	[illegible]
Heating	[illegible]
PV	[illegible]
Wind	0
Total (kWh)	[illegible]



The Aesthetic of the Building:

We changed the PVs to emphasis the cantilever as well as the division of the floor plates. These lines create a ribbon around the building to create an overall aesthetic unique to the building. Additionally, creating this ribbon allows for maxium coverage of the building without sacrificing the original design by Zaha Hadid.

COMPARTIVE SUITES

	EXISTING BUILDING | BASE	LOWER COST SUITE	HIGHER COST SUITE
CAPITAL COST	$	$$	$$$
BASIC UPGRADES	None None Existing Internal Loads	Mixed Mode Operations Ceiling Fans Internal Loads Lighting: Circle Lights Long Lights Equipment: Microwaves Coffee Makers Water Dispenser Water Kettle Printer Computers Refrigerators	Mixed Mode Operations Ceiling Fans Internal Loads Lighting: Circle Lights Long Lights Equipment: Microwaves Coffee Makers Water Dispenser Water Kettle Printer Computers Refrigerators
ADDITIONAL UPGRADES	2-Pane, Low-e, Air, Low-SHGC 150mm Concrete Ext. Roof Heat Pump (COP: 0.3)		VE 1-85 Window Glass Add 350mm Concrete for Ext. Roof Thermal Mass Radiant Heating (COP: 5.5)
RENEWABLE UPGRADES	None	Photovoltaics Wind Turbine - Windspire	Photovoltaics Wind Turbine - Endurance

COST & PERFORMANCE IMPLICATIONS

Renewable energy heavily impacts the value and performance of each suite. Over time, the renewable greatly contribute to the overall energy savings of the suites. However, this can only be seen over large intervals of time, such as 20 or 30 years down the line (around the same time that the suites payback their capital costs.

The primary difference between Suite A + Renewables and Suite B + Renewables are the Additional Upgrade machines and appliances that are added as energy efficient replacements. These added machines and appliances increase the costs dramatically (within $100,000) but offer slightly less energy savings. Based on this trend, the clients can opt for the lower cost suite with the option to add one of the Additional Upgrade machines or appliances if they prefer.

Cost Savings Over Time

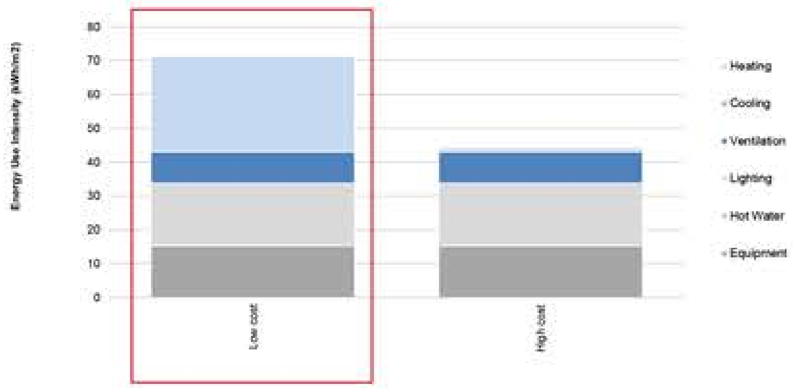
current base electricity rate	$ 0.17	$/kWh
current base fuel rate	$ 0.01	$/kWh
energy escalation rate	4.0%	

existing annual electricity use	42,930	kWh
existing annual fuel use	33,263	kWh

ECM A annual electricity use	26,169	kWh
ECM A annual fuel use	17,204	kWh
ECM A annual on-site electricity offset	45,714	kWh
ECM A annual on-site fuel offset	780	kWh

ECM A annual energy savings	32,820	kWh
ECM A + Renewables annual energy savings	79,314	kWh

ECM A payback	4	years
ECM A + Renewables payback	14	years



	Low cost	High cost
Lighting	18.4	18.4
Cooling	-	-
Ventilation	9.2	9.2
Equipment	15.4	15.4
Heating	28.3	1.3
	-	-
Total	71.3	44.3

Capital Investment

This analysis assumes:

1. Costs derived from NREL National Residential Efficiency Measures Database (http://www.nrel.gov/ap/retrofits/group_listing.cfm)

2. Cost of Living Factor derived from Consumer Pricing Index (http://www.numbeo.com/cost-of-living/comparison.jsp)

84% *Cost of Living Factor (Chicago - Beirut)*

Suite A

Number or Area (m2)	Energy Efficient Replacement	Unit Price ($/no. or $/m2)	Standard Replacement	Unit Price ($/no. or $/m2)	Net Price	Cost of Living Adjustment	Adjusted Total Price
19	Mixed Mode/Automatic Window Opener	$ 465.10	None	$ -	$ 8,837	100%	$ 8,837
15	Ceiling Fans	$ 140.00	None	$ -	$ 2,100	100%	$ 2,100
16	Fluorescent GE Super Long Life	$ 13.99	Lighting :: Circle Lights	$ 1.40	$ 204	84%	$ 171
34	150W Halogen Light Bulb	$ 4.13	Lighting :: Long Lights	$ 3.98	$ 5	84%	$ 4
2	Microwave | Energy Savings	$ 139.99	Equipment :: Microwave	$ 89.96	$ 100	84%	$ 84
2	Coffee Maker | Energy Star	$ 99.95	Equipment :: Coffee Maker	$ 38.94	$ 122	84%	$ 102
1	Water Dispenser | Eco	$ 200.00	Equipment :: Water Dispenser	$ 148.00	$ 52	84%	$ 44
1	SmartKettle | Eco	$ 135.00	Equipment :: Electric Water Kettle	$ 30.00	$ 105	84%	$ 88
1	All-in-One Printer | Energy Star	$ 499.00	Equipment :: Printer	$ 250.00	$ 249	100%	$ 249
9	Dell Optiplex 3030 All-in-One	$ 884.29	Equipment :: Computers	$ 430.00	$ 4,089	100%	$ 4,089
2	Mini Refrigerator | Energy Star	$ 159.00	Equipment :: Refrigerator	$ 189.00	$ (60)	100%	$ (60)
	ECM Capital Cost				$ 15,803		**$ 15,709**
244	Photovoltaic Panels	$ 770	None	$ -	$ 187,880	100%	$ 187,880
1	Windspire Wind Turbine	$ 9,900	None	$ -	$ 9,900	100%	$ 9,900
-	Endurance Wind Turbine	$ 41,200	None	$ -	$ -	100%	$ -
	On-site Renewables Capital Cost				$ 197,780		**$ 197,780**
	Suite B Total Capital Cost				$ 213,583		**$ 213,489**

Note on Equipment:

Some of the existing machines and appliances for lighting and equipment were not replaced because of they were either already energy effcicienet or consumed very low levels of energy (these were typically less than 10 Watts).

Note on Ceiling Fans:

The number of ceiling fans were estimated to be 15 under the presumption that a typical office space area would require 1 ceiling fan and that larger spaces would have additional fans based on the number of office spaces the room would be able to hold. This is due to the uncertainty of the ceiling fan sizes/diameters.

Cost Savings Over Time

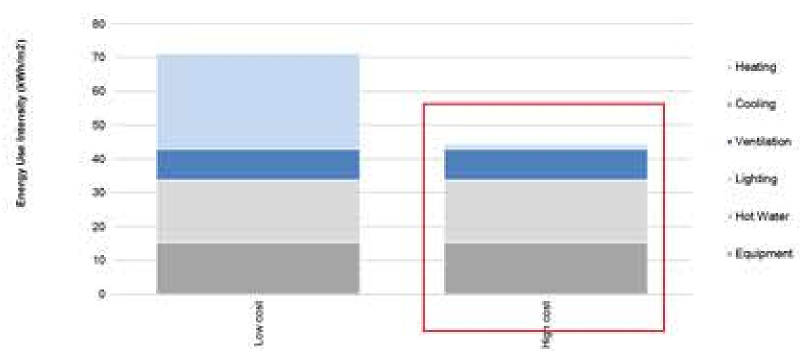
current base electricity rate	$ 0.17	$/kWh
current base fuel rate	$ 0.01	$/kWh
energy escalation rate	4.0%	

existing annual electricity use	42,930	kWh
existing annual fuel use	33,263	kWh

ECM B annual electricity use	26,169	kWh
ECM B annual fuel use	760	kWh
ECM B annual on-site electricity offset	36,581	kWh
ECM B annual on-site fuel offset	780	kWh

ECM B annual energy savings	49,264	kWh
ECM B + Renewables annual energy savings	86,625	kWh

ECM B payback	18	years
ECM B + Renewables payback	17	years



	Low cost	High cost
Lighting	18.4	18.4
Cooling	-	-
Ventilation	9.2	9.2
Equipment	15.4	15.4
Heating	28.3	1.3
	-	-
Total	71.3	44.3

Capital Investment

This analysis assumes:

1. Costs derived from NREL National Residential Efficiency Measures Database (http://www.nrel.gov/ap/retrofits/group_listing.cfm)

2. Cost of Living Factor derived from Consumer Pricing Index (http://www.numbeo.com/cost-of-living/comparison.jsp)

84%	*Cost of Living Factor (Chicago - Beirut)*

Suite B

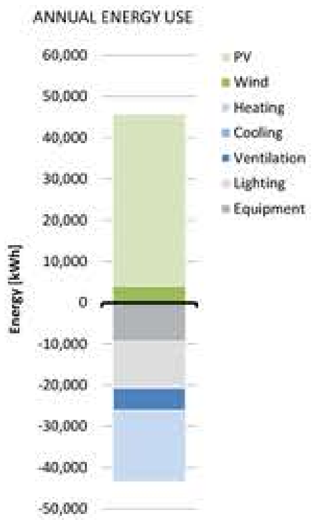
Number or Area (m2)	Energy Efficient Replacement	Unit Price ($/no. or $/m2)	Standard Replacement	Unit Price ($/no. or $/m2)	Net Price	Cost of Living Adjustment	Adjusted Total Price
19	Mixed Mode/Automatic Window Opener	$ 465.10	None	$ -	$ 8,837	100%	$ 8,837
608	Add 350mm concrete (roof)	$ 44.41	None	$ -	$ 26,998	84%	$ 22,679
608	Radiant Heating	$ 70.00	None	$ -	$ 42,560	100%	$ 42,560
15	Ceiling Fans	$ 140.00	None	$ -	$ 2,100	84%	$ 1,764
19	VE 1-85 Window Glass	$ 85.38	2-Pane, Low-e, NM, Air, Low-SHGC	$ 14.14	$ 1,354	84%	$ 1,137
16	Fluorescent GE Super Long Life	$ 13.99	Lighting :: Circle Lights	$ 1.40	$ 204	84%	$ 171
34	150W Halogen Light Bulb	$ 4.13	Lighting :: Long Lights	$ 3.98	$ 5	84%	$ 4
2	Microwave | Energy Savings	$ 139.99	Equipment :: Microwave	$ 89.96	$ 100	84%	$ 84
2	Coffee Maker | Energy Star	$ 99.95	Equipment :: Coffee Maker	$ 38.94	$ 122	84%	$ 102
1	Water Dispenser | Eco	$ 200.00	Equipment :: Water Dispenser	$ 148.00	$ 52	84%	$ 44
1	SmartKettle | Eco	$ 135.00	Equipment :: Electric Water Kettle	$ 30.00	$ 105	84%	$ 88
1	All-in-One Printer | Energy Star	$ 499.00	Equipment :: Printer	$ 250.00	$ 249	100%	$ 249
9	Dell Optiplex 3030 All-in-One	$ 884.29	Equipment :: Computers	$ 430.00	$ 4,089	100%	$ 4,089
2	Mini Refrigerator | Energy Star	$ 159.00	Equipment :: Refrigerator	$ 189.00	$ (60)	100%	$ (60)
	ECM Capital Cost				$ 86,715		**$ 81,748**
130	Photovoltaic Panels	$ 770	None	$ -	$ 100,100	100%	$ 100,100
-	Windspire Wind Turbine	$ 9,900	None	$ -	$ -	100%	$ -
1	Endurance Wind Turbine	$ 41,200	None	$ -	$ 41,200	100%	$ 41,200
	On-site Renewables Capital Cost				$ 141,300		**$ 141,300**
	Suite B Total Capital Cost				$ 228,015		**$ 223,048**

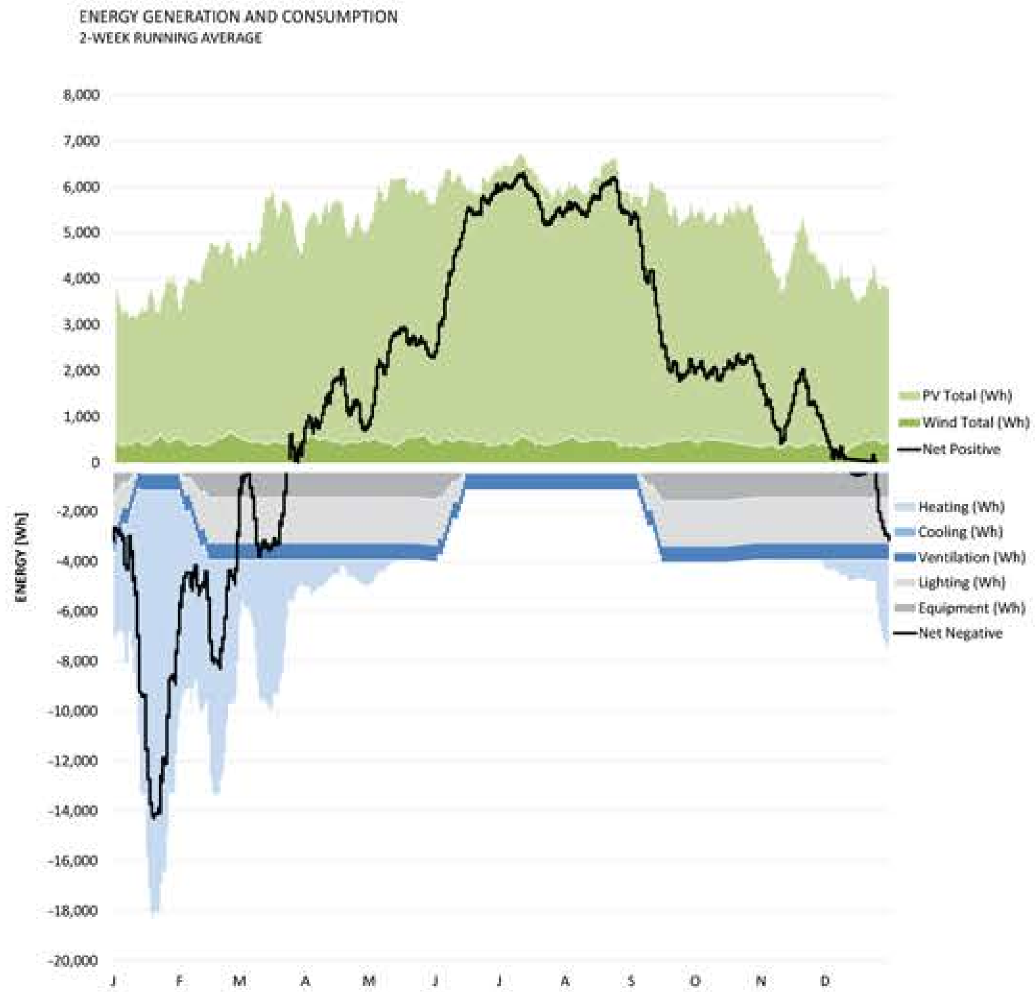
Cost estimates for thermal mass (concrete), radiant heating, and mixed mode operations were found outside of the cost retrofit samples and adjusted to the cost of living from the sites/locations there were gathered. For example, information for mixed mode operations cost (represented by automatic window openers) was found by Chinese standards. That cost was then appropriated to reflect USD currency as well as the cost of living in Beirut.

It was difficult to find costs for window glass type in regards to both standard replacement and energy efficient replacement. The listed costs are estimations -- the actual products were subtituted for producted with SHGCs and u-values that were within the same range. However, this is not an accurate representation.

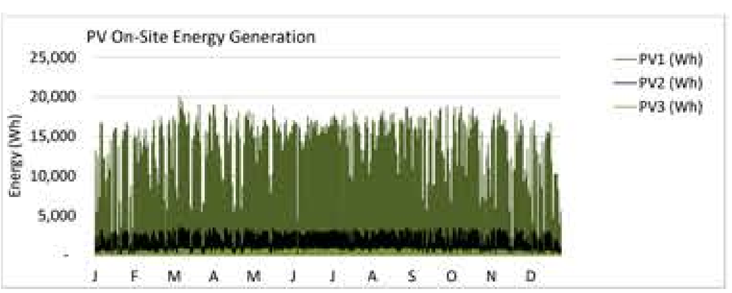
Lower Cost Suite

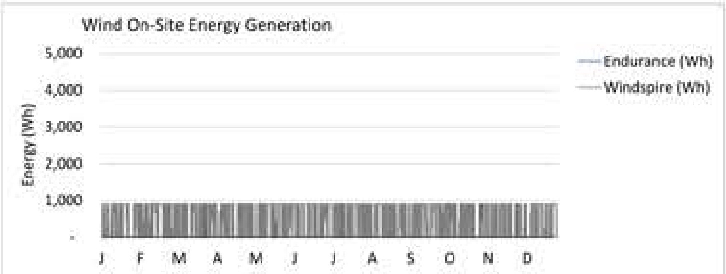
	Energy Use
Formula	kWh
Lighting	-11,190.2
Cooling	0.0
Ventilation	-5,619.6
Equipment	-9,359
Heating	-17,204
PV	41,749
Wind	3,965
Total (kWh)	2,341





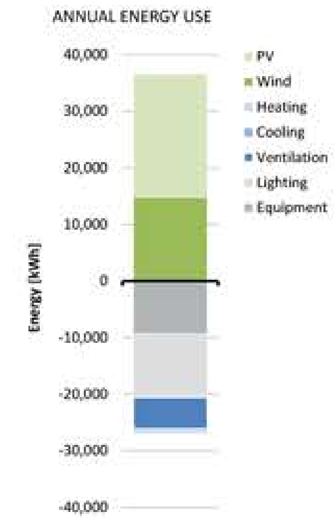
For the Lower Cost Suite, there are a total of 244 PVs and 1 wind turbine (the Windspire). Despite having a large number of PVs, not enough energy can be generated during the winter months, mainly from December to March.

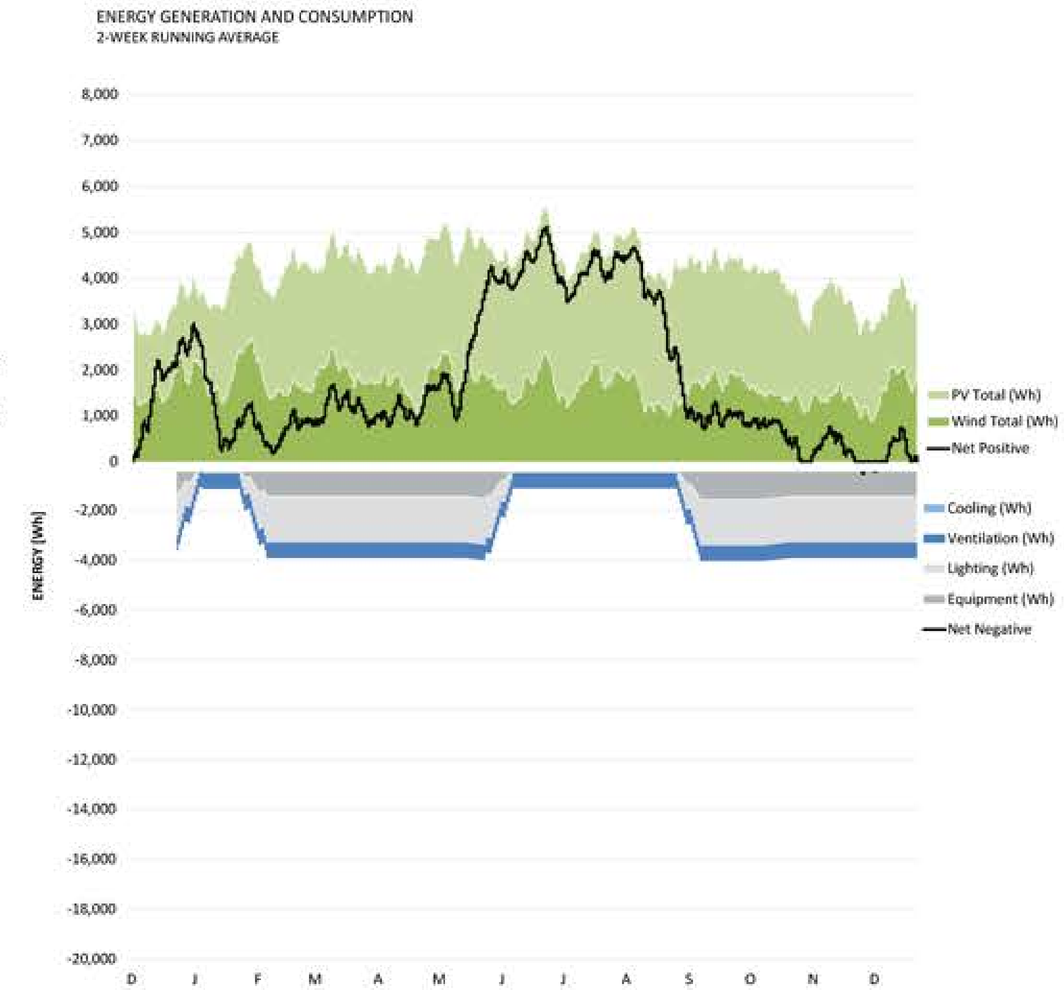




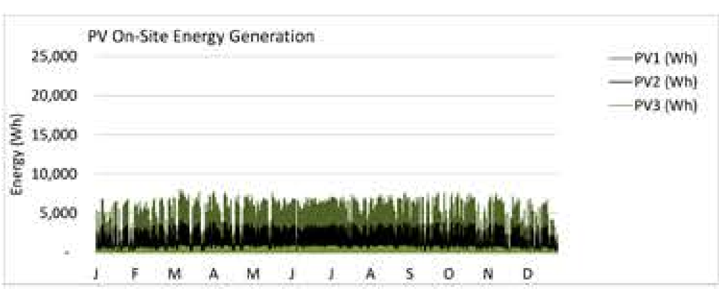
Higher Cost Suite

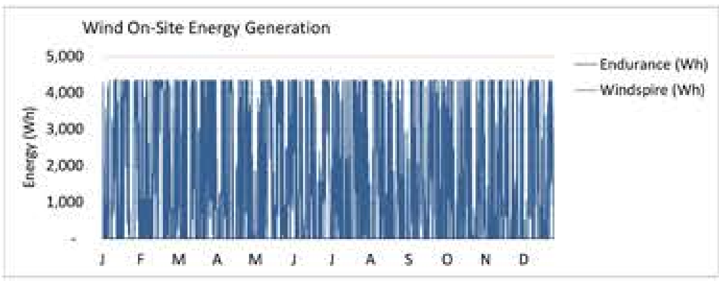
	Energy Use
Formula	kWh
Lighting	-11,190.2
Cooling	0.0
Ventilation	-5,619.6
Equipment	-9,359
Heating	-760
PV	21,772
Wind	14,809
Total (kWh)	9,652





For the Higher Cost Suite, there are a total of 130 PVs and 1 wind turbine (the Endurance). This wind turbine generation nearly 2.5x more energy, which allows for less PVs. There is only a short period during the year that not enough energy is generated (November to mid-December).

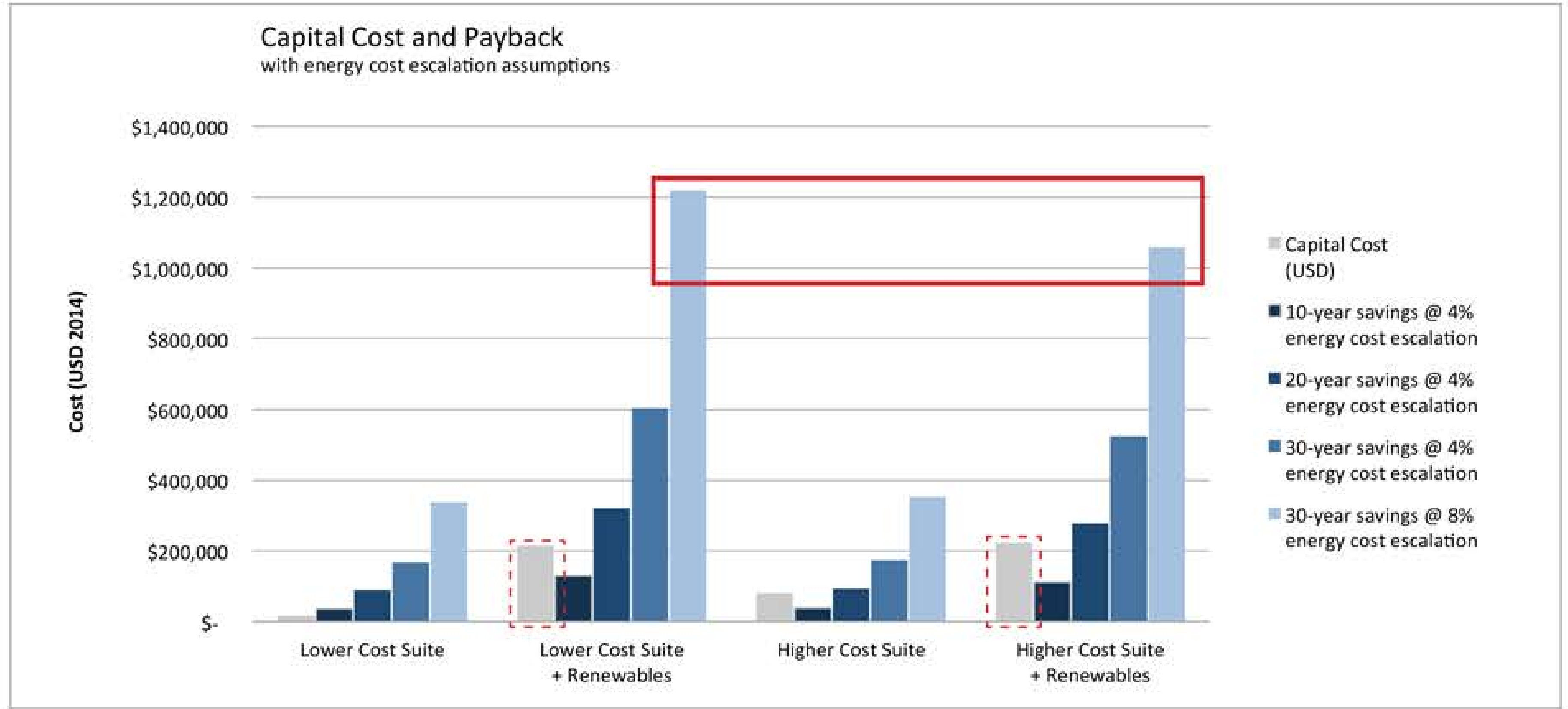




Cost Summary

This analysis assumes:

1. *No Discount Rate (opportunity cost of capital over time)*
2. *No rebates or incentives*
3. *No inflation - all costs are in 2013 dollars*
4. *No loan or mortgage payments (capital is available)*
5. *Appliances and machines to be replaced are at end of life*
6. *No depreciation of value or performance over time*
7. *No additional operations and maintenance costs for ECMs*
8. *Energy calculations use flat rates-they do not consider time of use or other rate structures*



	Capital	*Cost*	*Cost*	*Formula*	*Cost*	*Cost*	*Cost*	*Cost*	*Cost*	*Cost*
ECM Suites	**Capital Cost (USD)**	**Energy Savings (kWh/year)**	**Flat Rate Year 1 Energy Savings (USD)**	**Flat Rate Simple Payback (years)**	**Payback @ 4% energy cost escalation (years)**	**Payback @ 8% energy cost escalation (years)**	**10-year savings @ 4% energy cost escalation**	**20-year savings @ 4% energy cost escalation**	**30-year savings @ 4% energy cost escalation**	**30-year savings @ 8% energy cost escalation**
Lower Cost Suite	$ 15,709	32,820	$ 2,978	5	4	4	$ 35,752	$ 88,674	$ 167,012	$ 337,340
Lower Cost Suite + Renewables	$ 213,489	79,314	$ 10,755	20	14	12	$ 129,131	$ 320,277	$ 603,219	$ 1,218,413
Higher Cost Suite	$ 81,748	49,264	$ 3,109	26	18	14	$ 37,332	$ 92,592	$ 174,390	$ 352,242
Higher Cost Suite + Renewables	$ 223,048	86,625	$ 9,334	24	17	13	$ 112,070	$ 277,961	$ 523,519	$ 1,057,431

The Renewables in the Lower Cost Suite average about $197,780.00 in cost, while the Higher Cost Suite average about $141,300.00. This is primarily because there are significantly less PVs required to install in the Higher Cost Suite to reach net zero energy. However, the capital cost for renewables in both suites is similar in range (about $10,000) but the Lower Cost Suite produces higher savings in about the same range of time.

Energy Model and Benchmark

1. Basic Information

Whole Building Area		3000	m2
Analysis Area		75	m2
Electricity Cost	$	0.17	US$/kWh
Fuel Cost	$	0.01	US$/kWh
Annual Horizontal Solar Radiation		2,300	kWh/m2
Annual Horizontal PV Generation		345	kWh/m2

2. Energy Use from Utility Bill

Category	Annual Energy Use Therms / Year	Conversion Kilowatt-Hours / Therm	Annual Energy Use Kilowatt-Hours / Year	Energy Use Intensity Kilowatt-Hours / Sq. meter / Year	Annual Energy Cost US$	ZNE PV Area per Bldg Area PV m2 / Bldg m2
Fuel		29.3	272,959	90.99	$ 2,184	0.26
Electricity			216,000	72.00	$ 36,720	0.21

3. Energy Use from Benchmark

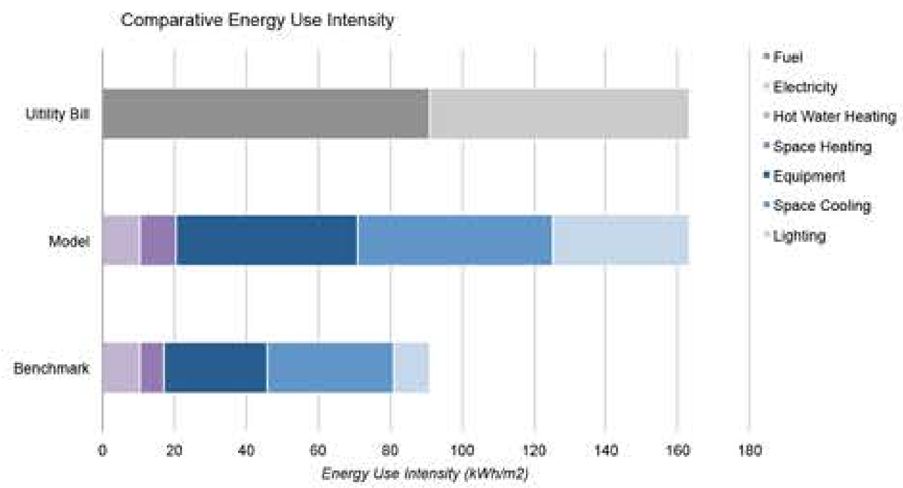
Category	Annual Energy Use Therms / Year	Conversion Kilowatt-Hours / Therm	Annual Energy Use Kilowatt-Hours / Year	Energy Use Intensity Kilowatt-Hours / Sq. meter / Year	Annual Energy Cost US$	ZNE PV Area per Bldg Area PV m2 / Bldg m2
Equipment			87,020	29.01	$ 14,793	0.08
Lighting			30,000	10.00	$ 5,100	0.03
Space Cooling			105,000	35.00	$ 17,850	0.10
Space Heating		29.3	20,000	6.67	$ 160	0.02
Hot Water Heating		29.3	30,939	10.31	$ 248	0.03

4. Energy Model

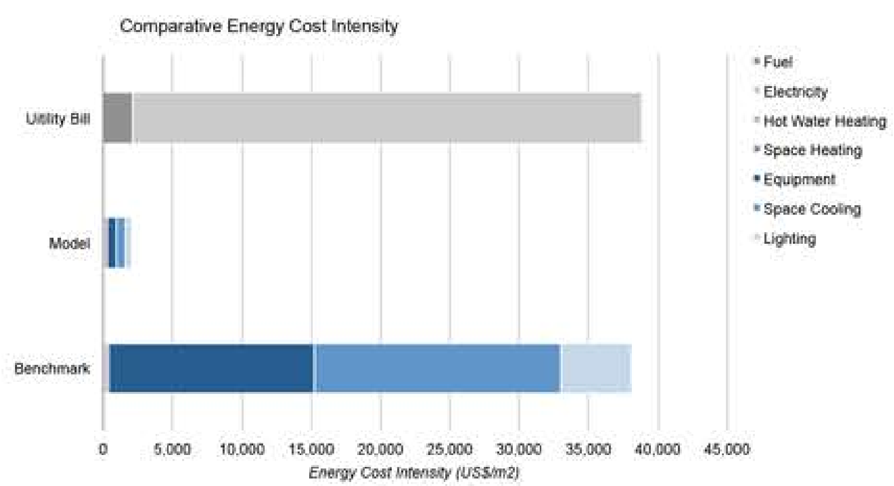
Category	Item	Power Watts	Daily Use Hours	Annual Use Days / Year	Annual Energy Use Watt-Hours / Year	Annual Energy Use Kilowatt-Hours / Year	Energy Use Intensity Kilowatt-Hours / Sq. meter / Year	Annual Energy Cost US$	ZNE PV Area per Bldg Area PV m2 / Bldg m2
Equipment					**3,800,460**	**3,800.46**	**50.67**	**$ 646**	**0.15**
	Refrigerator	120	24.00	365	1,051,200				
	Microwaves	375	2.00	260	195,000				
	Water Dispenser	80	24.00	235	451,200				
	Coffee Maker	1,800	2.00	260	936,000				
	Water Heater	1,000	2.00	260	520,000				
	Computer(on)	180	9.00	260	421,200				
	Computer(sleep)	54	1.00	260	14,040				
	Telephone	8	24.00	365	70,080				
	Printer (on)	40	4.00	260	41,600				
	Printer (sleep)	16	3.00	260	12,480				
	Wi-Fi Router	6	24.00	365	52,560				
	Phone Charger	45	3.00	260	35,100				
					-				
Lighting					**2,860,000**	**2,860**	**38.13**	**$ 486**	**0.11**
	Circle Light	420	10.00	260	1,092,000				
	Tiny LED Light	80	10.00	260	208,000				
	Long Line Light	600	10.00	260	1,560,000				
					-				
Space Cooling					**4,048,000**	**4,048**	**53.97**	**$ 688**	**0.16**
	Central Air Conditioner	2,200	8.00	230	4,048,000				
Space Heating					**750,000**	**750**	**10.00**	**$ 128**	**0.03**
	Heating(Boiler+Pump)	5,000	5.00	30	750,000				
Hot Water Heating					**780,000**	**780**	**10.40**	**$ 133**	**0.03**
	Kitchen Sink Hot Water	300	10.00	260	780,000				
					-				
TOTAL					**12,238,460**	**12,238**	**163.18**	**$ 2,081**	**0.47**

5. Summary Chart

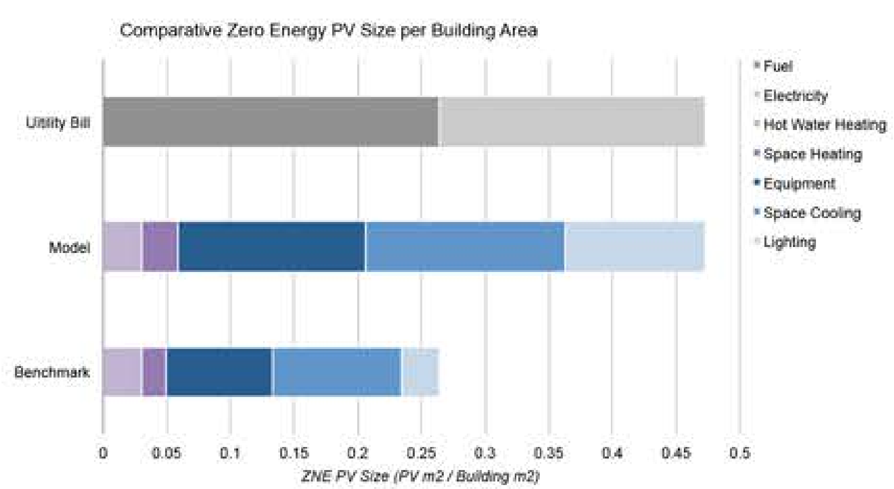
Energy	Benchmark *kWh/m2*	Model *kWh/m2*	Uitility Bill *kWh/m2*
Fuel			90.99
Electricity			72.00
Equipment	29.01	50.67	
Lighting	10.00	38.13	
Space Cooling	35.00	53.97	
Space Heating	6.67	10.00	
Hot Water Heating	10.31	10.40	



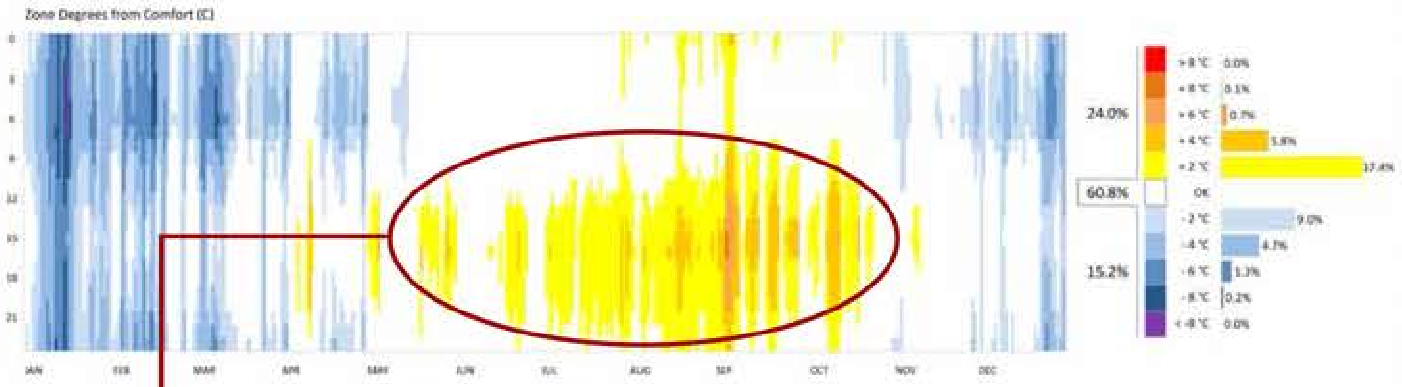
Cost	Benchmark *US$*	Model *US$*	Uitility Bill *US$*
Fuel			$ 2,184
Electricity			$ 36,720
Equipment	$ 14,793	$ 646	
Lighting	$ 5,100	$ 486	
Space Cooling	$ 17,850	$ 688	
Space Heating	$ 160	$ 128	
Hot Water Heating	$ 248	$ 133	

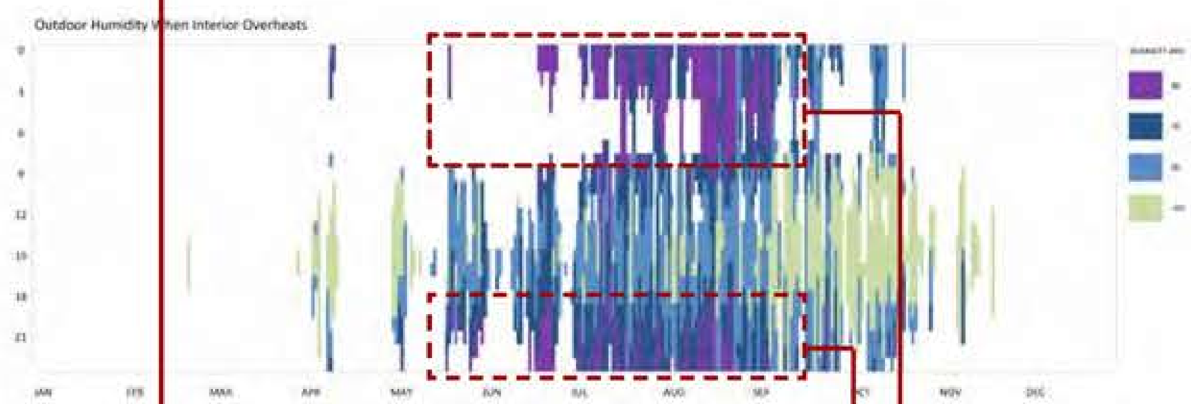


PV Area	Benchmark *PV m2*	Model *PV m2*	Uitility Bill *PV m2*
Fuel			0.26
Electricity			0.21
Equipment	0.08	0.15	
Lighting	0.03	0.11	
Space Cooling	0.10	0.16	
Space Heating	0.02	0.03	
Hot Water Heating	0.03	0.03	

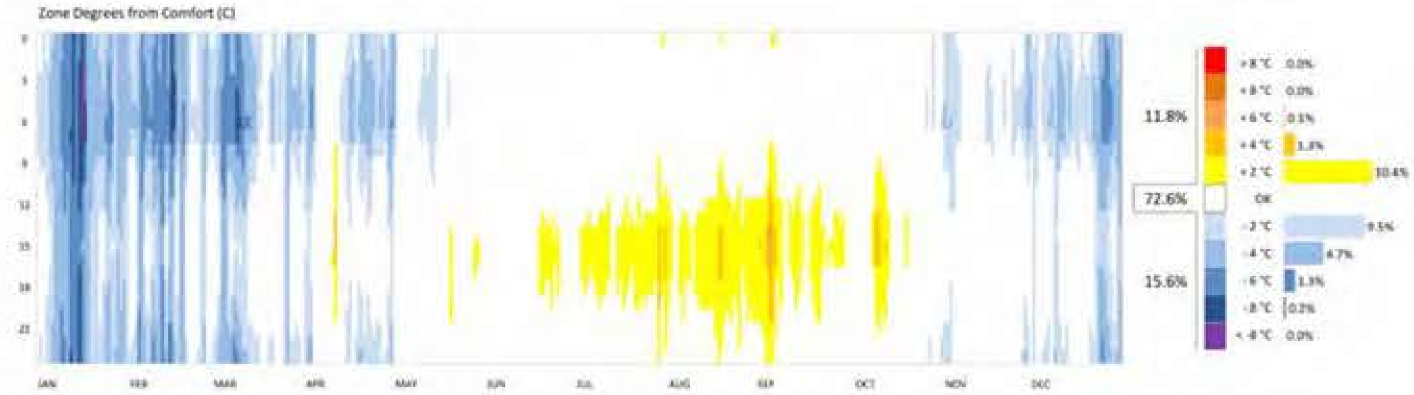


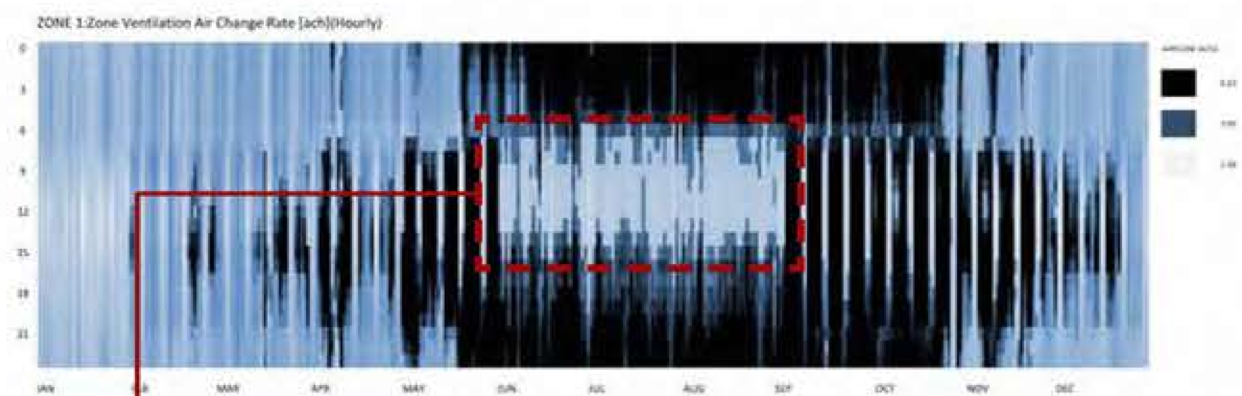
HUMIDITY





VENTILATION





<u>Periods of Overheating:</u>
May 1 - October 15
9:00 am - 9:00 pm

<u>Periods of High Humidity:</u>
May 1 - September 15
12:00 am - 9:00 am
-&-
7:00 pm - 12:00 am

<u>Periods when Natural Ventilation is not available because outdoor temperatures are higher than indoor temperatures:</u>
June 1 - September
6:00 am - 3:00 pm

Avail ABILITY SCHEDULES

<u>Heating:</u>
January 1 - May 1
-&-
November 1 - December 31
12:00 am - 12:00 am

<u>Cooling:</u>
May 1 - September 15
12:00 am - 9:00 am
-&-
7:00 pm - 12:00 am

<u>Natural Ventilation:</u>
May 1 - July 1
12:00 am - 12:00 am

July 1 - September 1
12:00 am - 6:00 am
-&-
3:00 pm - 12:00 am

September 1 - October 15
12:00 am - 12:00 am

Mixed Mode Schedule

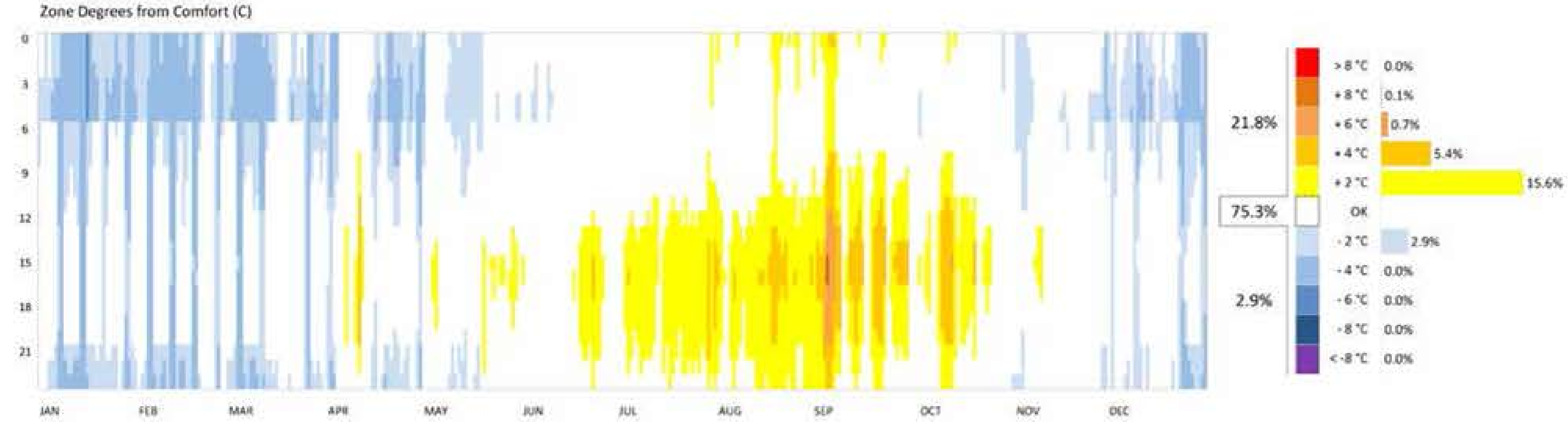
January 1 - May 1
[All Days]
12:00 am - 12:00 am
No Ventilation

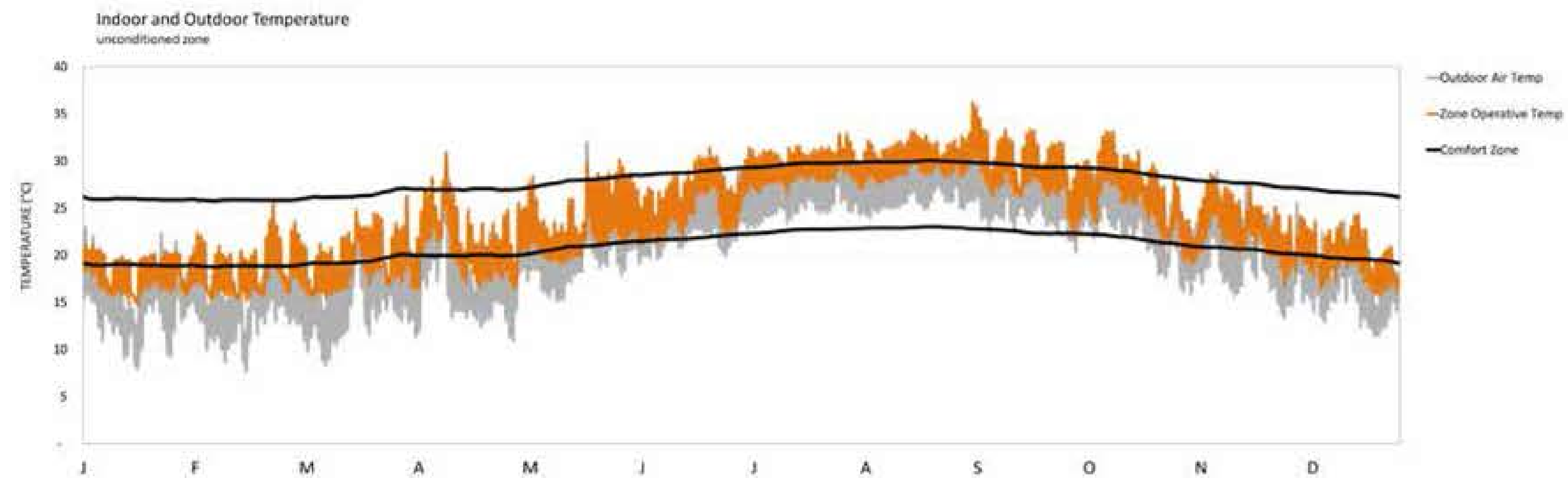
May 1 - June 1
[All Days]
12:00 am - 12:00 am
Ventilation

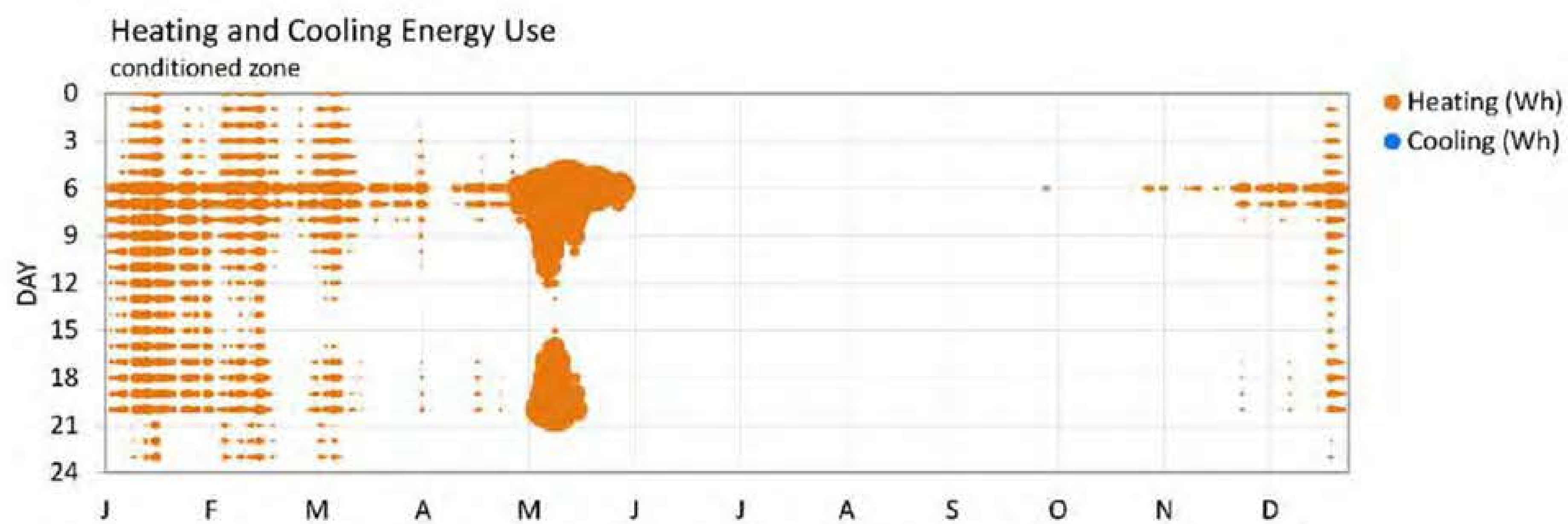
June 1 - September 1
[All Days]
12:00 am - 6:00 am
No Ventilation
6:00 am - 3:00 pm
Ventilation
3:00 pm - 12:00 am
No Ventilation

September 1 - October 15
[All Days]
12:00 am - 12:00 am
Ventilation

October 15 - December 31
[All Days]
12:00 am - 12:00 am
No Ventilation







Notes on the Base Model:

After the simulations completed in the Building Analysis portion of this report, the Base Case was updated to better represent the schedules and internal loads of the building. Also included in the update was the $30m^2$ west-facing window. In the initial base model, this window was not calculated in Energy Plus, which produced lower energy use intensity levels. After its incorporation, levels for cooling spiked up -- this demonstrated that the large west-facing window was a big contributor to the low percentage of thermal autonomy.

Notes on the Schedules:

The schedule updates that were coupled with Mixed Mode Natural Ventilation were completed as accurately as possible, but more can be altered to make sure that the building is not using energy when there are no occupants in the space. Since we only have a basic understanding of how the building is used by its occupants, the next step would be to document the hours of usage and when the building experiences reduced hours to no usage (i.e. summer and winter breaks). Afterwards, we can sculpt the schedules to accomodate these changes and maintain heating, lighting, and equipment so that they are not in use when there is no one in the building.