Devang | devang@outlook.in
Master of Environmental Building Design-`13 | University of Pennsylvania

Skirkanich Hall

EnergyPlus Model with DesignBuilder

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Skirkanich Hall
Energy Simulation and Calibration with EnergyPlus

Project: Skirkanich Hall
Building Type: Institution
Function: Research Lab, Offices, Lounge, Meeting Spaces, Café
Area (Sq.Ft.): 58,425 new + 6478 renovated + 6000 C.yard
Construction Cost: $32 million
Owner: University of Pennsylvania
Completion: March 2007
Architect: Tod Williams Billie Tsien Architects
Contractor: Skanska USA
Project Manager: Kim Dengler/Chris Kern

1. Introduction

In 1960, the University of Pennsylvania famously fostered the notion that laboratory buildings should be architectural landmarks— emphatic physical statements about the place of advanced scientific thinking within the university. In designing Skirkanich Hall, which opened in 2006 for the university's bioengineering department in the School of Engineering and Applied Science, the New York firm of Tod Williams Billie Tsien Architects sought to create a lab building that would stand out but not compromise function. Emulating Kahn's particular solution was not part of Williams and Tsien's mission.

The building was to be inserted into a 18,500-square-foot site between two redbrick engineering buildings belonging to the university's historic district; one, Moore School, is devoted to the Department of Electrical and Systems Engineering. Flanking Skirkanich Hall on the south, Towne Building, designed by Cope and Stewardson in 1906, houses the Department of Mechanical Engineering and Applied Mechanics, and the Department of Chemical and Bio-molecular Engineering. Filling out the compound on the west is Kieran Timberlake's Levine Hall, completed in 2003 for computer sciences.

The building faces 33rd Street, and is situated between three-story Moore and Towne buildings, with Moore adjacent to the North and Towne to the South. The building is thus much more exposed on the West and East facades, but is heavily shaded on its West facade, by both Towne Hall and Levine Hall. The ground story of the building is well shaded by itself on both the West and East side, as the building is partially cantilevered above its ground floor.

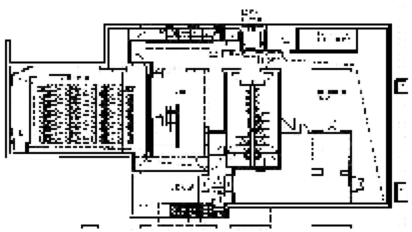
The building provides a laboratories, meeting spaces, lounges, and a cafe. The building contains 14-foot ceilings on six levels. Designed to be both a gateway and a connector, it connects horizontally to adjacent buildings, "providing a "street" in which pedestrians may traverse through from one end of the engineering campus to the next without having to endure the outside.

2. Energy Model Input

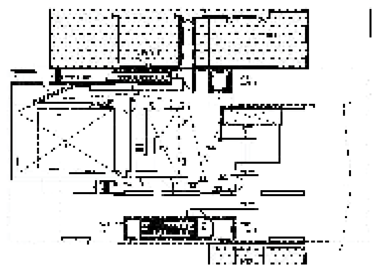
2A. Building Construction

Analysis of geometry was the first step in the process of developing a detailed energy model for Skirkanich Hall. CAD layouts were developed based on available schematics. Center line of the walls and floor to floor height was taken into consideration while developing the energy model.

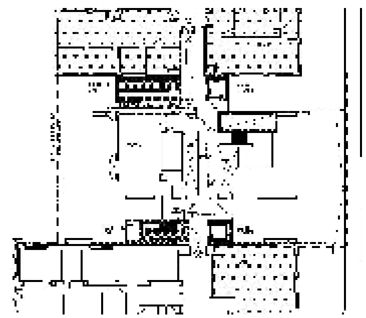
2A1. Geometry



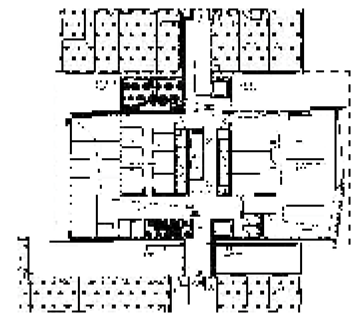
Basement Floor



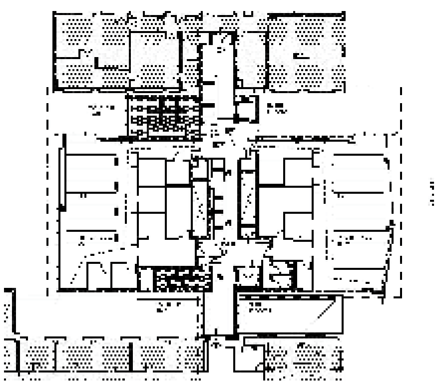
Ground Floor



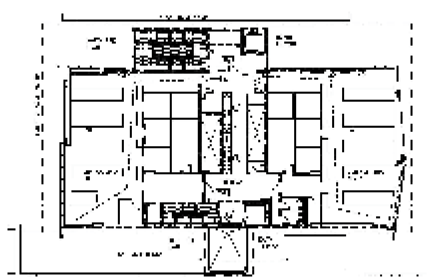
First Floor



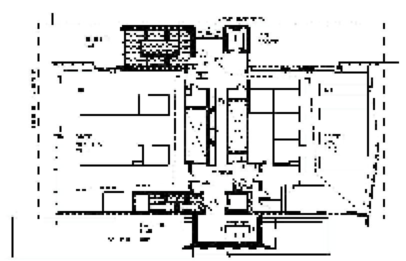
Second Floor



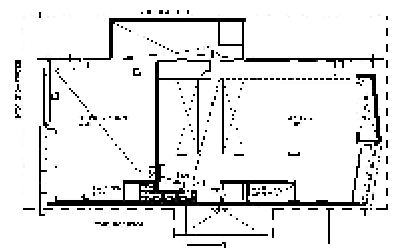
Third Floor



Fourth Floor



Fifth Floor



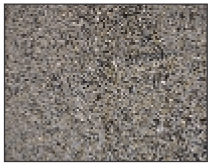
Sixth Floor

2A. Building Construction

Analysis of geometry was the first step in the process of developing a detailed energy model for Skirkanich Hall. CAD layouts were developed based on available schematics. Center line of the walls and floor to floor height was taken into consideration while developing the energy model.

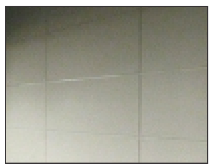
2A2. Materials

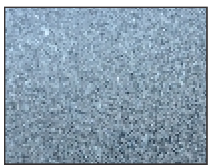
Materials used in Skirkanich Hall


Exposed Concrete


Ceramic Tile

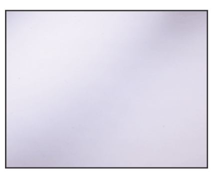

Honed Concrete

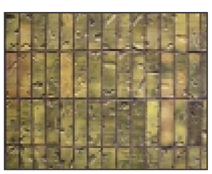

Gypsum Wall Board

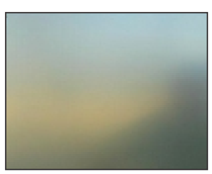

Stone Cladding


Acoustical Ceiling Tile


Stone Flooring


Clear Glass


Ceramic Tile

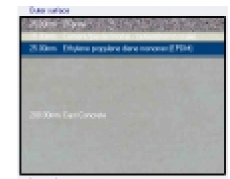

Clear Acid Etched

2A3. Construction

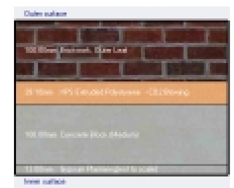
Construction assemblies developed for Energy Model

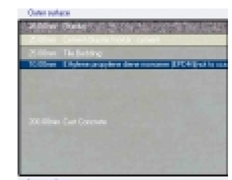

External Wall 01


Internal Wall

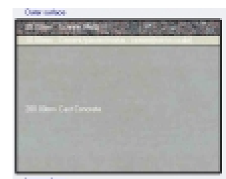

Ground Floor Slab

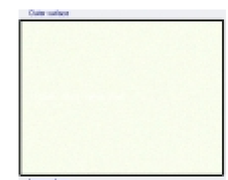

External Wall 02

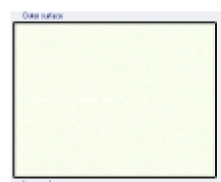

Semi-Exposed Wall 01


Semi-Exposed

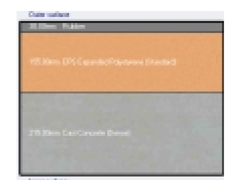

Glazing 01

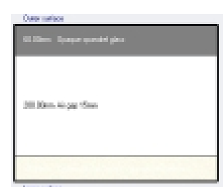

Semi-Exposed Wall

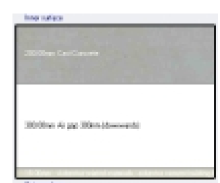

External Door


Glazing 02


Internal Door


External Slab


Sub Surface


Internal Slab

2B. Internal Loads

2B1. Lighting Loads

Lighting load was derived by summing up the wattage of all the lighting fixtures used in the building. Based on total square foot area of building (58041.7 ft2), general lighting power density for the building was derived and was used in energy model.

Bulb Type	Fixture Type	Watta/Bulb	# of Bulbs	Total # of Watts
Halogen	Track	150	106	15900
Compact Fluorescent	Ceiling Mounted	32	487	15584
Linear Fluorescent	4'F32	32	1140	36480
	3'F30	30	32	960
Additional	Exit Light	25	40	1000
	Ultraviolet Light	250	2	500
	Omnicure Lamp	100	1	100
Total Wattage (Watts)				**70524**
Total Usable Floor Area (ft2)				**58041.7**
Lighting Power Density (W/ft2)				**1.21505745**

2B2. Occupant Density

Occupant density for Skirkanich hall was determined based on ASHRAE Standard 62.1-2007

Facility	Occupant Desity (Person/1000 ft2)
Laboratory	25
Computer Lab	25
Auditorium	100
Corridors	20
Office	5
Conference	50

2B3. Equipment Loads

Similar to Lighting load calculation, Equipment Load was derived by summing up the wattage of all the equipment used in the office areas of the building. Based on total square foot area (11119 ft2), general equipment power density for the building was derived and was used in energy model.

Appliance	Avg. Wattage	# of Item	Total # of Watts
Coffee Maker Large	1660	1	1660
Coffee Maker Medium	1500	2	3000
Dishwasher	1800	1	1800
DVD Player	22.5	1	22.5
Fan-Small Desk	25	1	25
Handicap Door Opener	15	1	15
Microwave Small	450	7	3150
Paper Shredder	170	1	170
Personal Computer-Desktop CPU	120	92	11040
Personal Computer-Laptop	50	112	5600
Personal Computer-Flatscreen	50	89	4450
Personal Computer-Speakers	25	10	250
Printer-Ink Jet	48	7	336
Printer-Laser	576	12	6912
Radio (portable)	12	1	12
Refrigerator-Mini	120	3	360
Refrigerator	725	6	4350
Refrigerator (Lab Strength)	1840	27	49680
Router (large network)	36	2	72
Security Camera	50	6	300
Sound System	1900	1	1900
Space Heater	1500	7	10500
Television - 13"	80	1	80
Television - Flatscreen	120	2	240
Typewriter	300	1	300
VCR	19	1	19
Water Cooler	180	3	540
Water Fountain	400	1	400
Total Wattage (Watts)			**107183.5**
Total Office Area (ft2)			**11119**
Equipment Power Density (W/ft2)			**9.639670834**

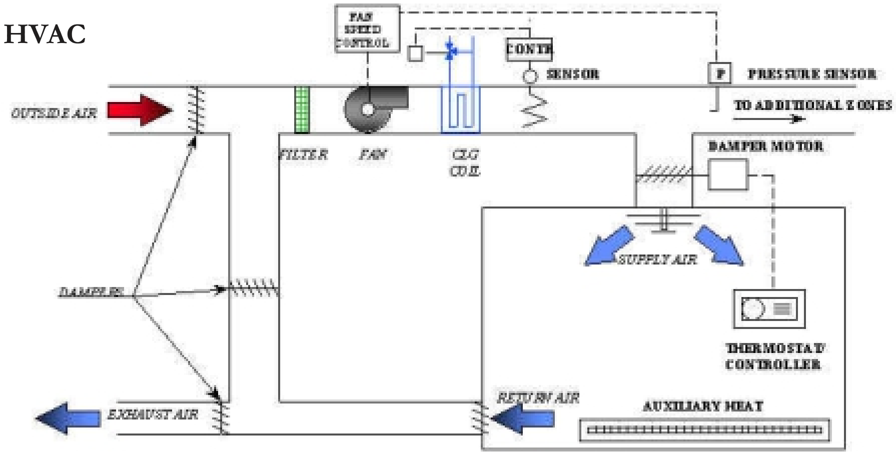
2B4. Lab Equipment Loads

Lab Equipment Load was derived by summing up the wattage of all the equipment used in the Labs of Skirkanich Hall. Based on total square foot area of Labs (13603 ft2), general Lab equipment power density was derived and was used in energy model.

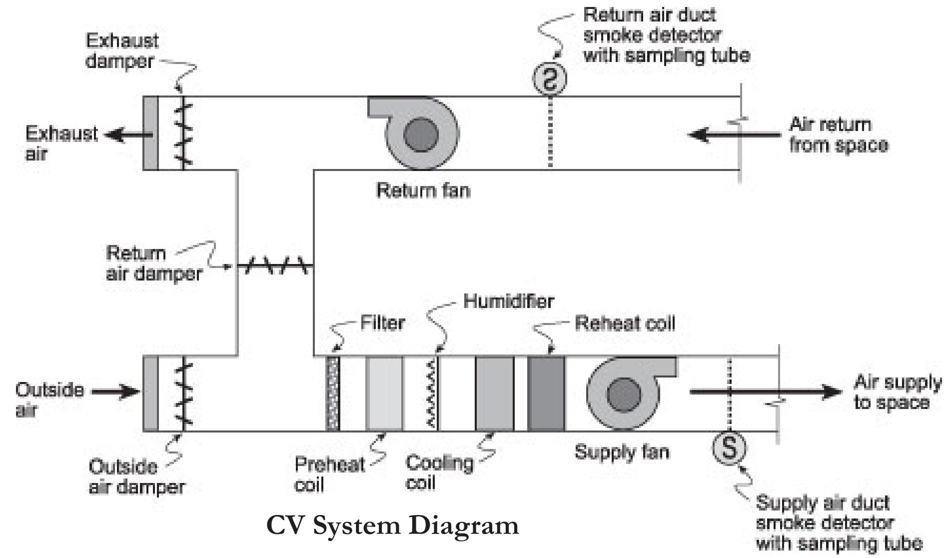
Lab Equipment	Avg. Wattage	# of Items	Total # of Watts
Exhaust Hood	600	31	18600
Leica CM 1850	3450	1	3450
Lab Camera	50	2	100
Binaray HPLC Pump	250	1	250
Sectronic 20D	115	3	345
Electrode Check	250	15	3750
Microscope	80	11	880
Copy Machine	400	4	1600
Centrifuge Beckman Coulter TJ-25	2000	10	20000
Medifuge	80	3	240
Incubator Shaker	600	2	1200
Incubator Shaker (lrg.)	1200	6	7200
Digital Dry	150	2	300
DNA Engine	850	2	1700
Odyssey Infra Red Imager	200	1	200
Unknown Machines	750	1	750
	450	1	450
	725	1	725
	1600	1	1600
	110	1	110
	300	1	300
	1600	1	1600
	700	1	700
	600	1	600
	160	1	160
	900	1	900
	360	1	360
Asmometer	120	1	120
Autoclave	1350	1	1350
Hot Plate	400	70	28000
Total Wattage (Watts)			97540
Total Lab Area (ft2)			**13603**
Equipment Power Density (W/ft2)			**7.170477101**

2C. HVAC Systems and Schedules

2C1. HVAC



VAV System Diagram



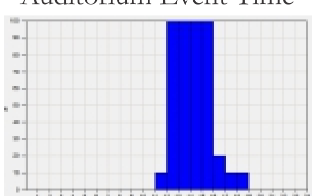
CV System Diagram

The building is supported by five AHUs serving different zones. The details about the zones the specific AHU serves was collected from HVAC specifications from mechanical engineer. In accordance with those details, in energy model, specific type of AHU was assigned to specific zone.

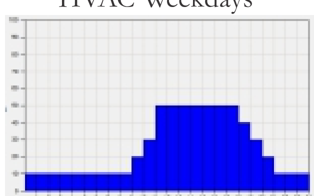
2C2. Schedules

Based on a week long activity monitoring at Skirkanich Hall, the schedules were configured. Different types of schedules were developed to reflect the activity profile as close as possible. Staff working at Laboratory and students were also interviewed to prepare a clearer activity profile of the building.

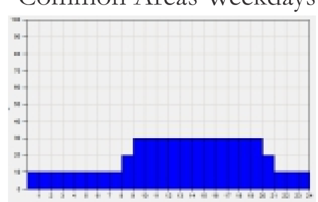
Auditorium Event Time



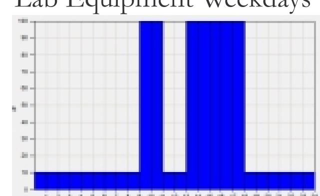
HVAC Weekdays



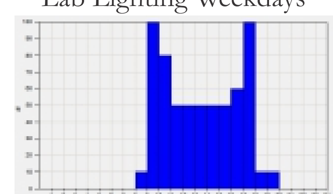
Common Areas Weekdays



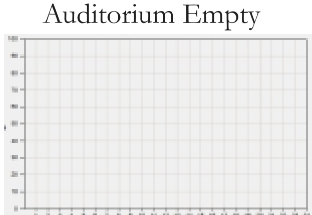
Lab Equipment Weekdays



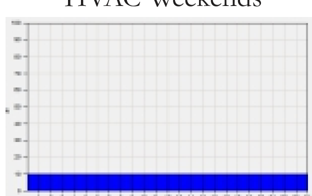
Lab Lighting Weekdays



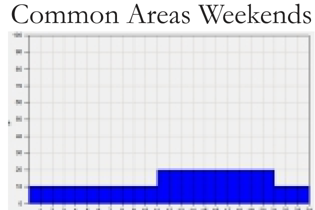
Auditorium Empty



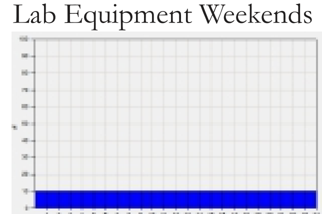
HVAC Weekends



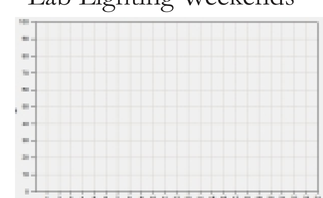
Common Areas Weekends



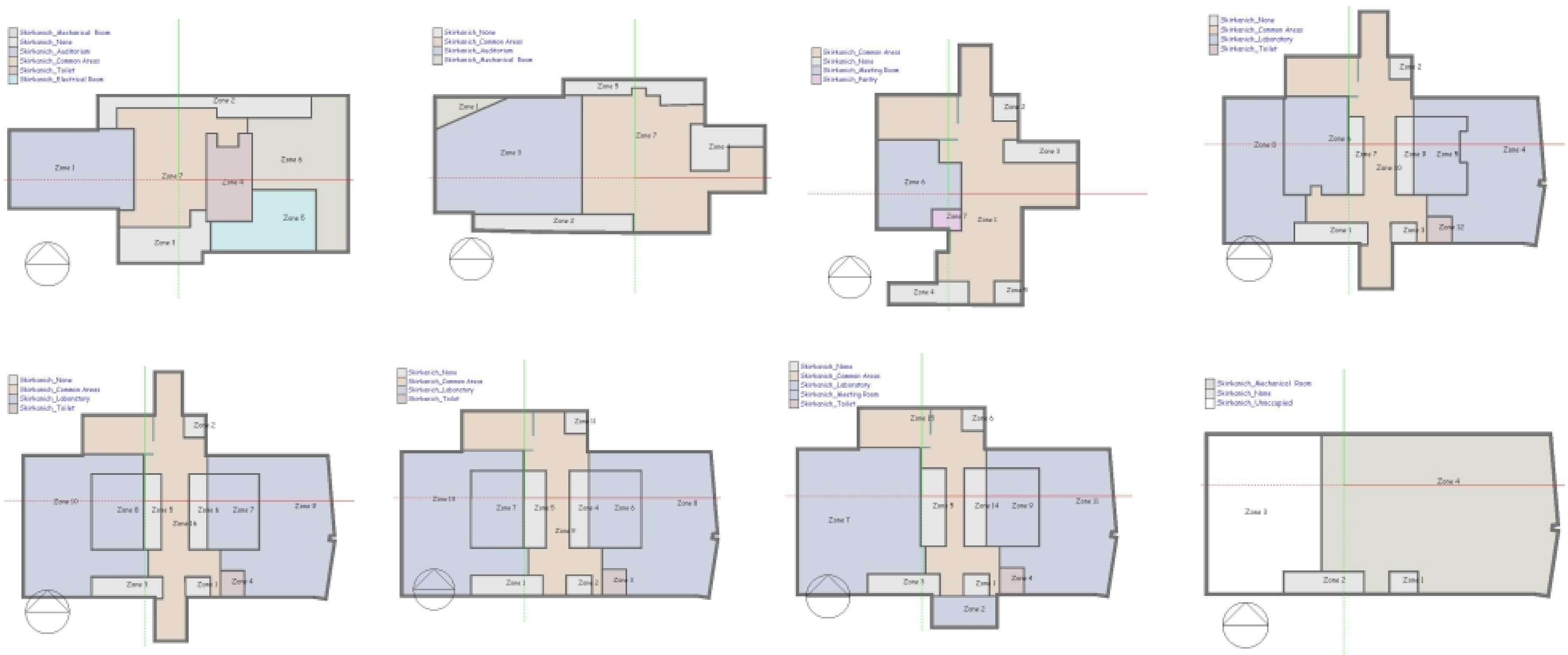
Lab Equipment Weekends



Lab Lighting Weekends



2D. Zoning



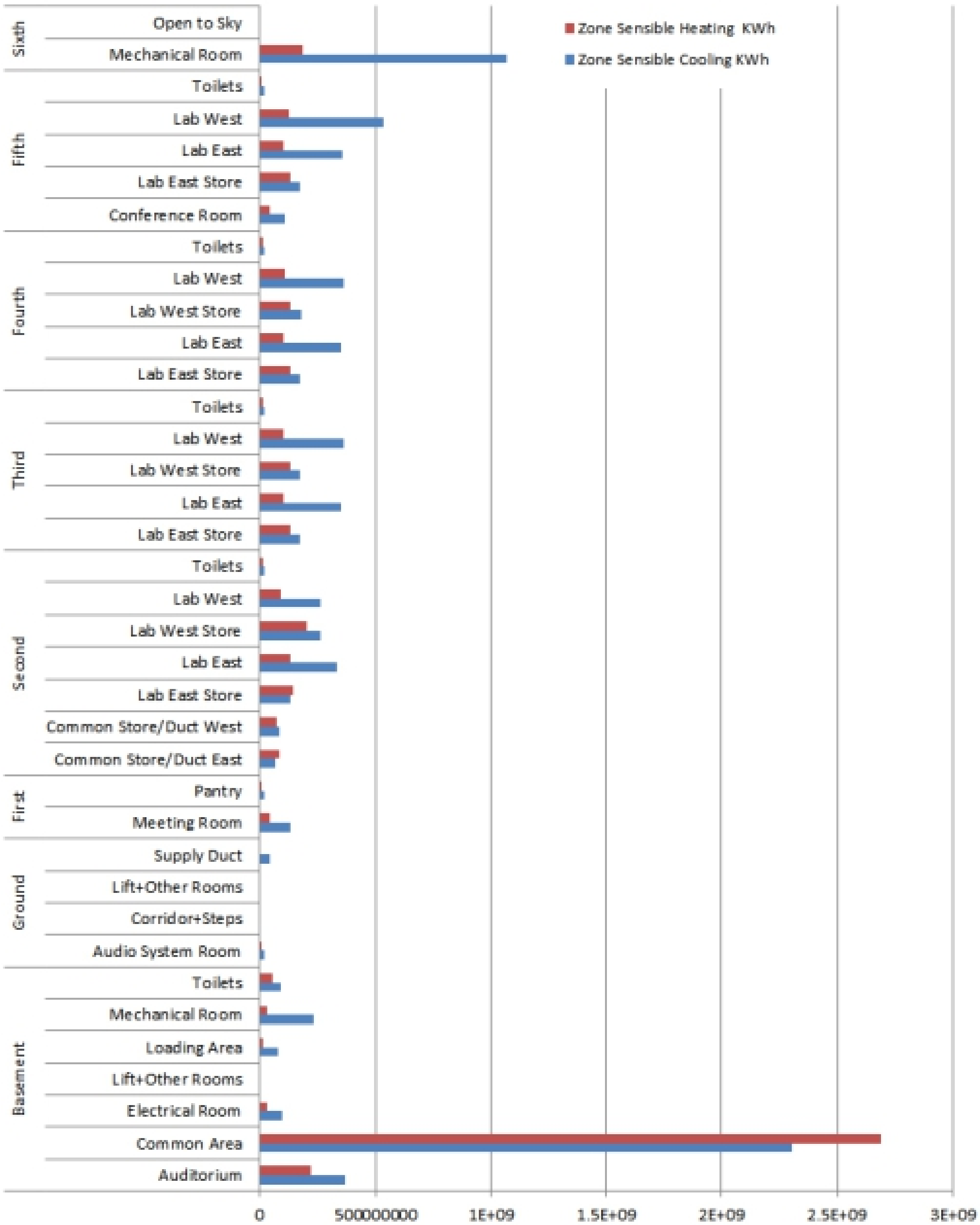
To be able to analyze zone wise energy consumption breakdown, care was taken to have only necessary merged zones. Atrium, stairs and lift blocks were connected vertically for simplification of data input.

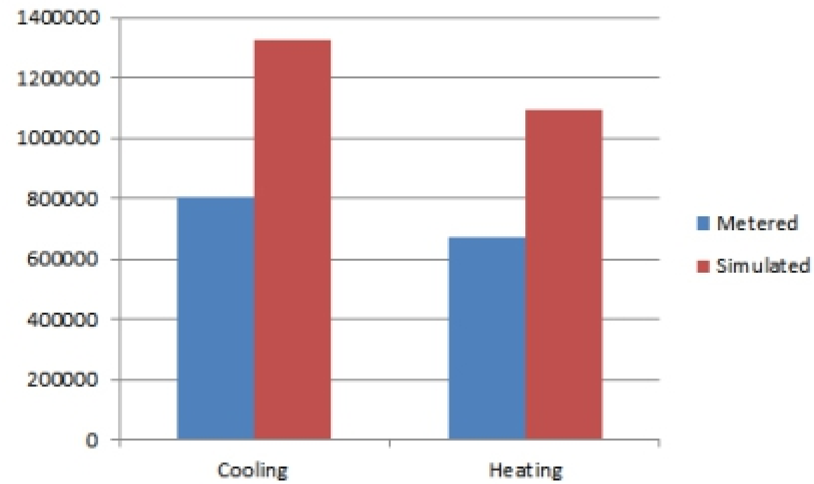
Zoning of the building is based on program of the space and function. Later on in the process, mechanical systems were applied to all the zones according to its use and system type.

Also, care was taken to keep areas such lift and stairs as separate zones, so that lighting, occupancy, equipment density, heating and cooling can be kept minimum or zero according to function of the space.

Skirkanich_Mechanical Room
Skirkanich_None
Skirkanich_Auditorium
Skirkanich_Common Area
Skirkanich_Toilet
Skirkanich_Electrical Room
Skirkanich_Meeting Room
Skirkanich_Pantry
Skirkanich_Laboratory
Skirkanich_Unoccupied

3. Initial Results





Based on initial results, it was inferred that Skirkanich hall is primarily a cooling dominated building, and even though the labs which are primary areas in the building, are located on periphery, and are heating zone, the common area, which is the circulation/corridor zone in the thermal model, consumes more energy for cooling and ventilation purpose.

Also, form the zone break down, it can be deduced that the storage spaces for labs, which are located towards core and are completely detached from outside environment, mostly require cooling.

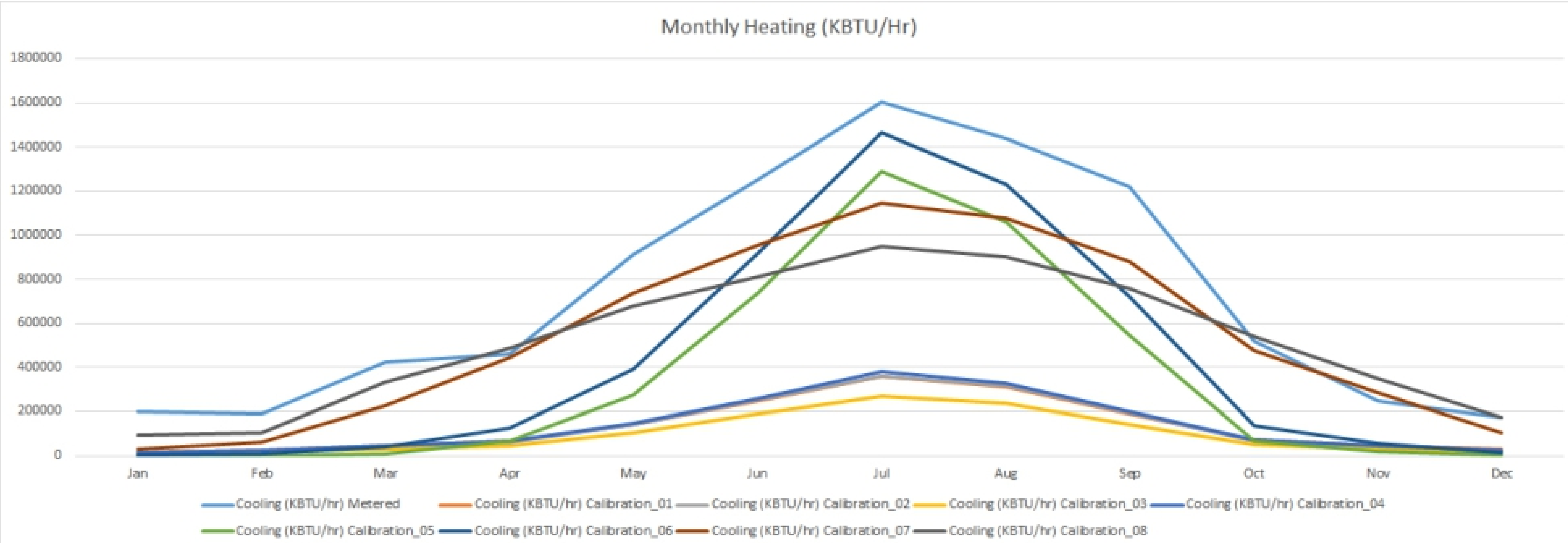
This analysis was helpful in goal setting for future simulations and calibrations.

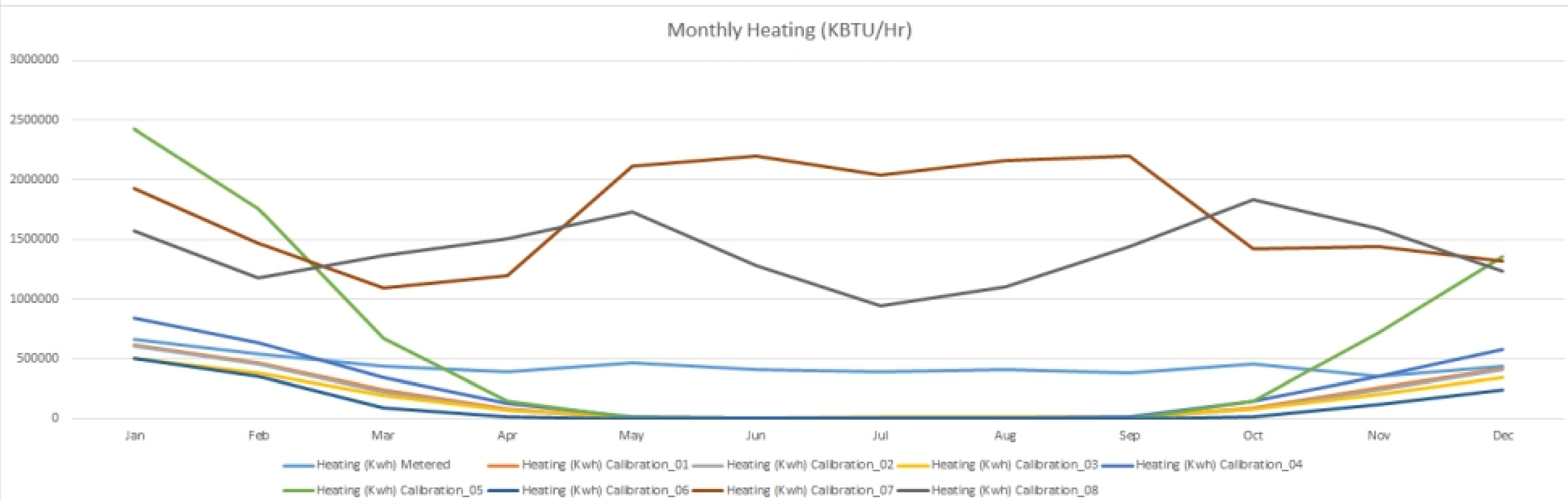
The defined goals for future calibrations were:

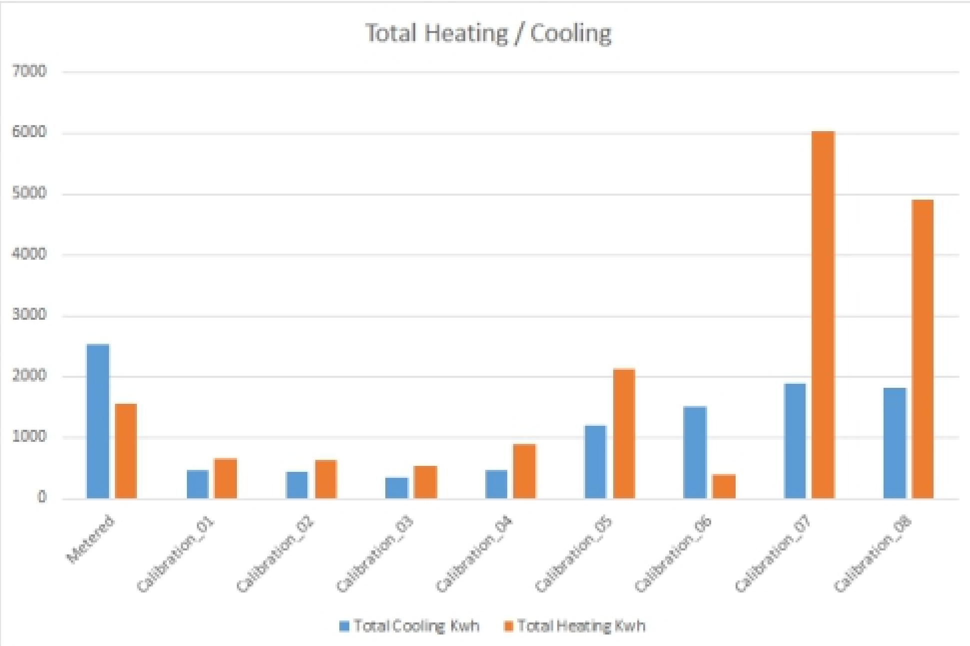
- To carry monthly analysis and compare the results with monthly metered data.
- To find out variables that affect the cooling load in the building
- To find out the variables that affect the heating load in the building

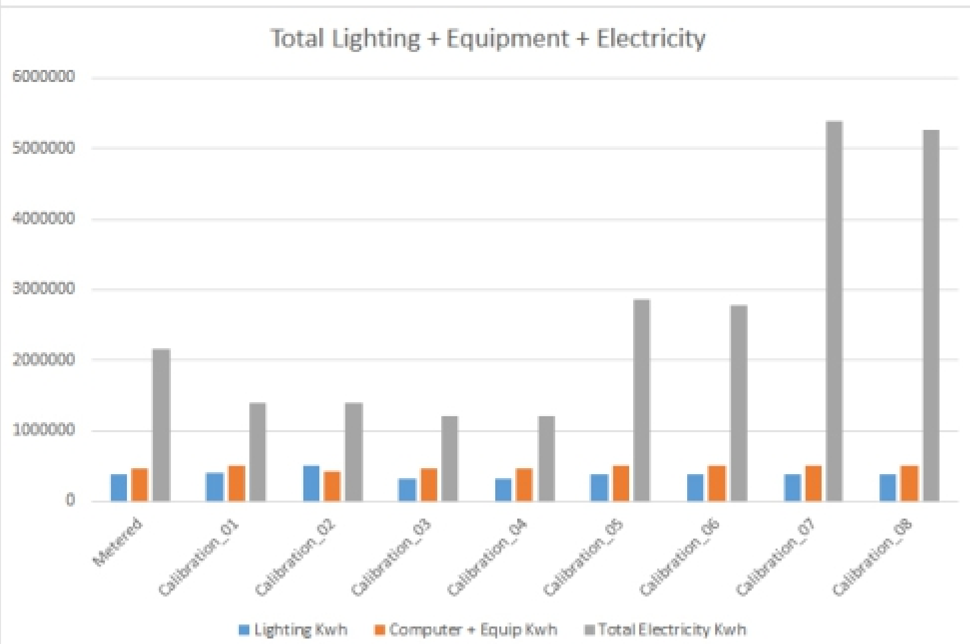
4. Calibrations and Corrections

Comprehensive Plot of Calibration Results









During the calibration process, variable such as; **Occupancy Schedule, Heating Setpoint, Cooling Setpoint, VAV Turn down ration, Ac/h Ratio, Humidification Setpoints, Dehumidification Setpoints, Lighting power density, Occupant desnsity, U-value of envelope, U-value of openings** were explored.

From this process, it is learned that, in the early stages of calibration, the variable concerning entities such as; lighting, computers, and office equipment shall be explored, and the loads related to these entities shall be made accurate and be brought close to the metered data earlier in the process. This allows opportunity to focus on less number of variables in the later stages of calibration process, and thus can reduces number of calibrations.

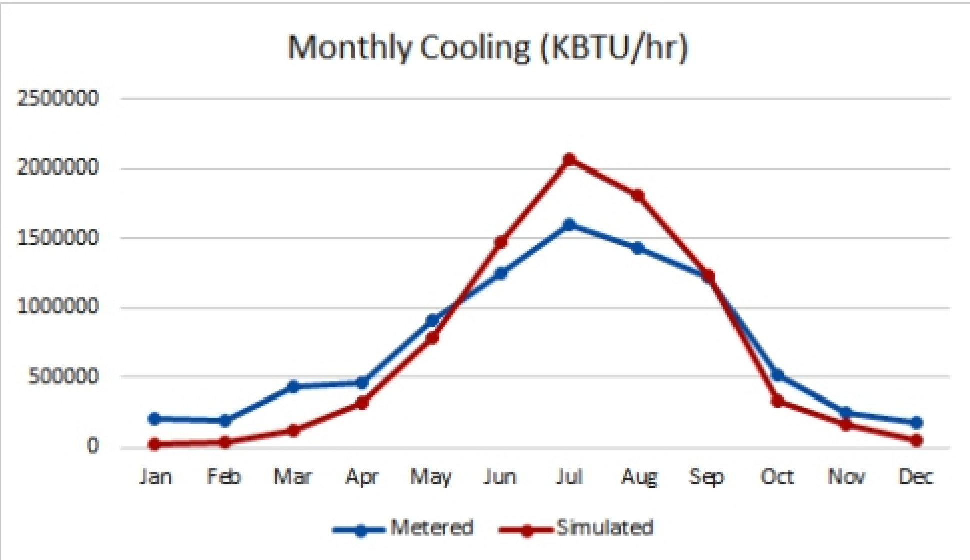
In Philadelphia climate, a commercial building predominantly requires heating in its peripheral zones and cooling in its core zones, therefore the U-value of envelope and glazing have greater effects on heating load of the building, which usually occurs in the peripheral zones.

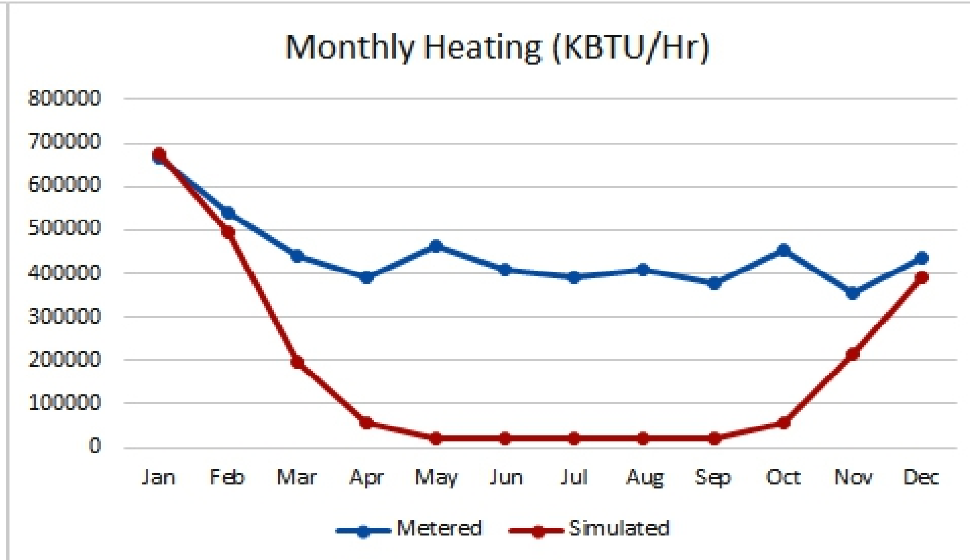
Air flow rate (ac/h) significantly affect the cooling load of the building. In DesignBuilder, since there is no schedule applied to ac/h, system uses as significant amount of outside air in summer season as it uses during the winter season for free cooling. This results in higher cooling load in summer months.

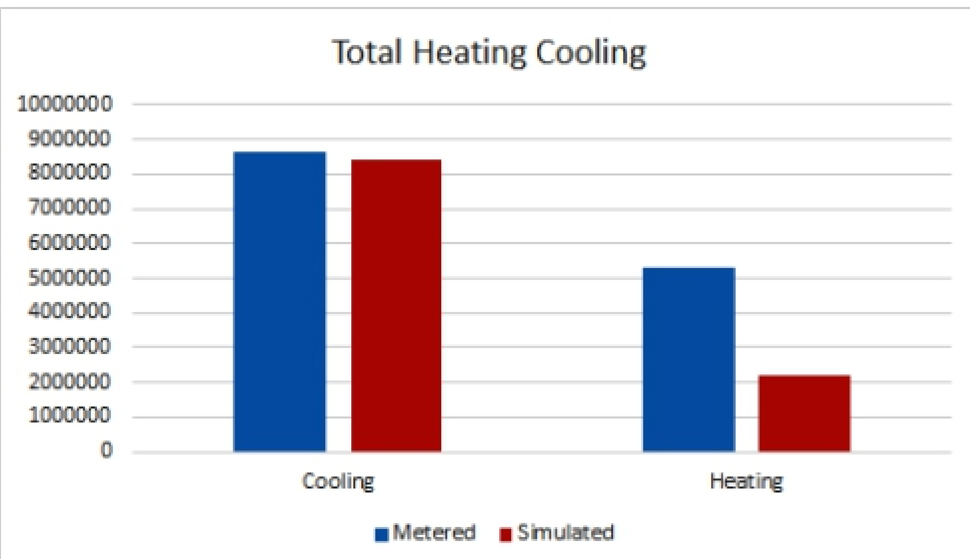
Increase or reduction in indoor set point temperature results change in heating and cooling load. However, the effect of ac/h on heating and cooling load was relatively significant.

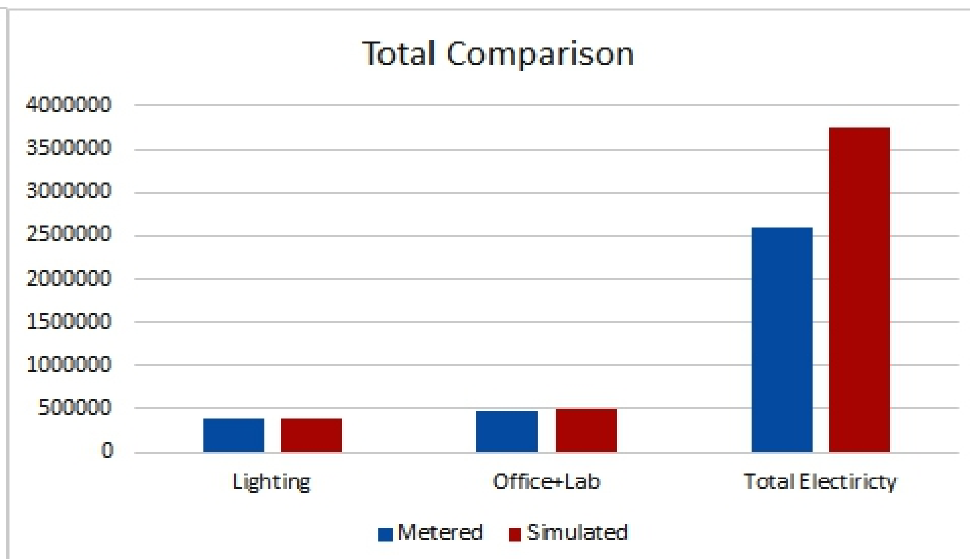
Also, it is assumed that, since the primary function of the building is to provide a laboratory facility, humidity levels are closely controlled to maintain the indoor environment of lab. In order to model this behavior of this building, humidification and de-humidification set points were explored. however, it was noted that controlling humidification and de-humidification setpoints increased the total electricity use and cooling energy.

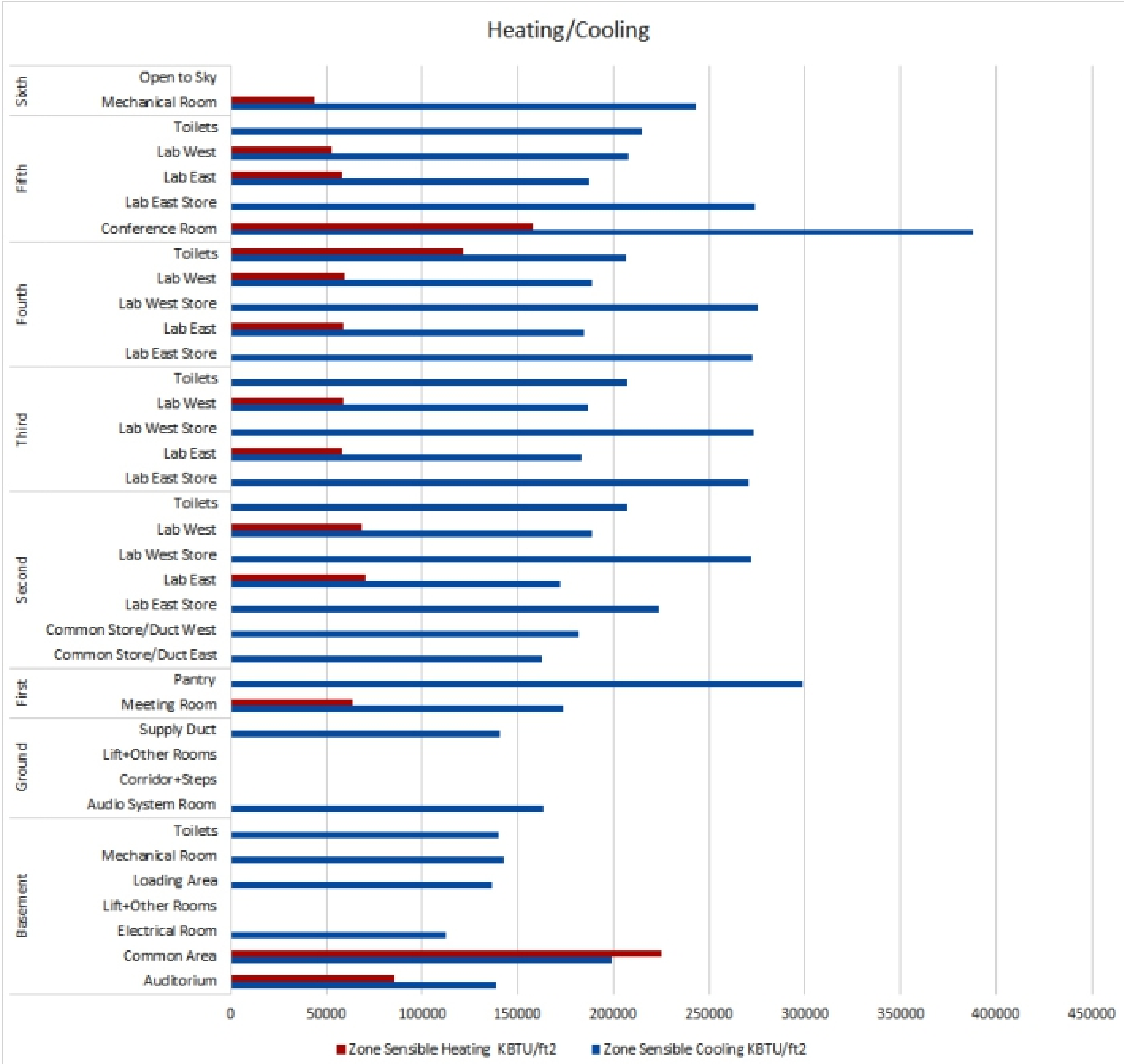
5. Final Calibrated Results & Analysis

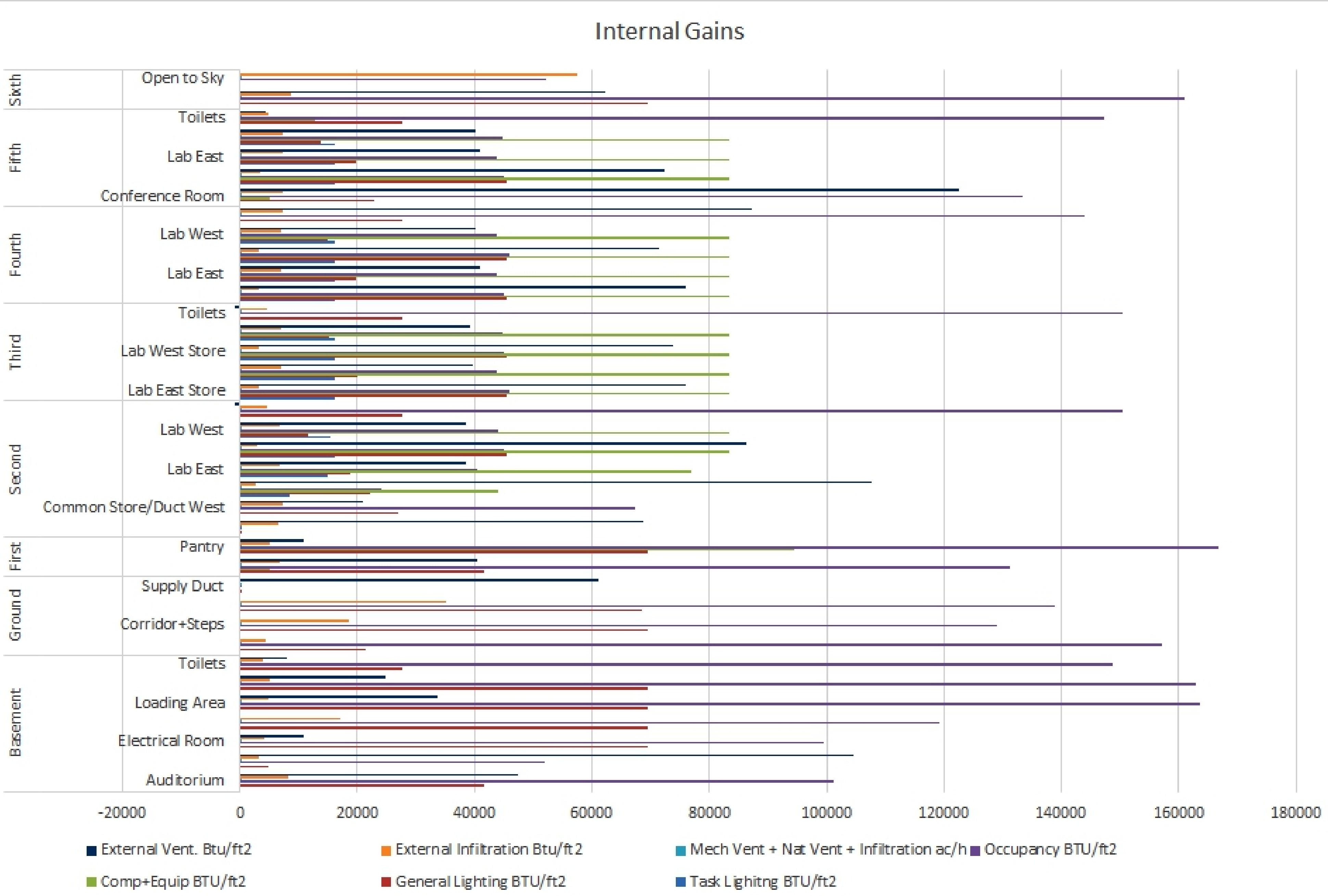




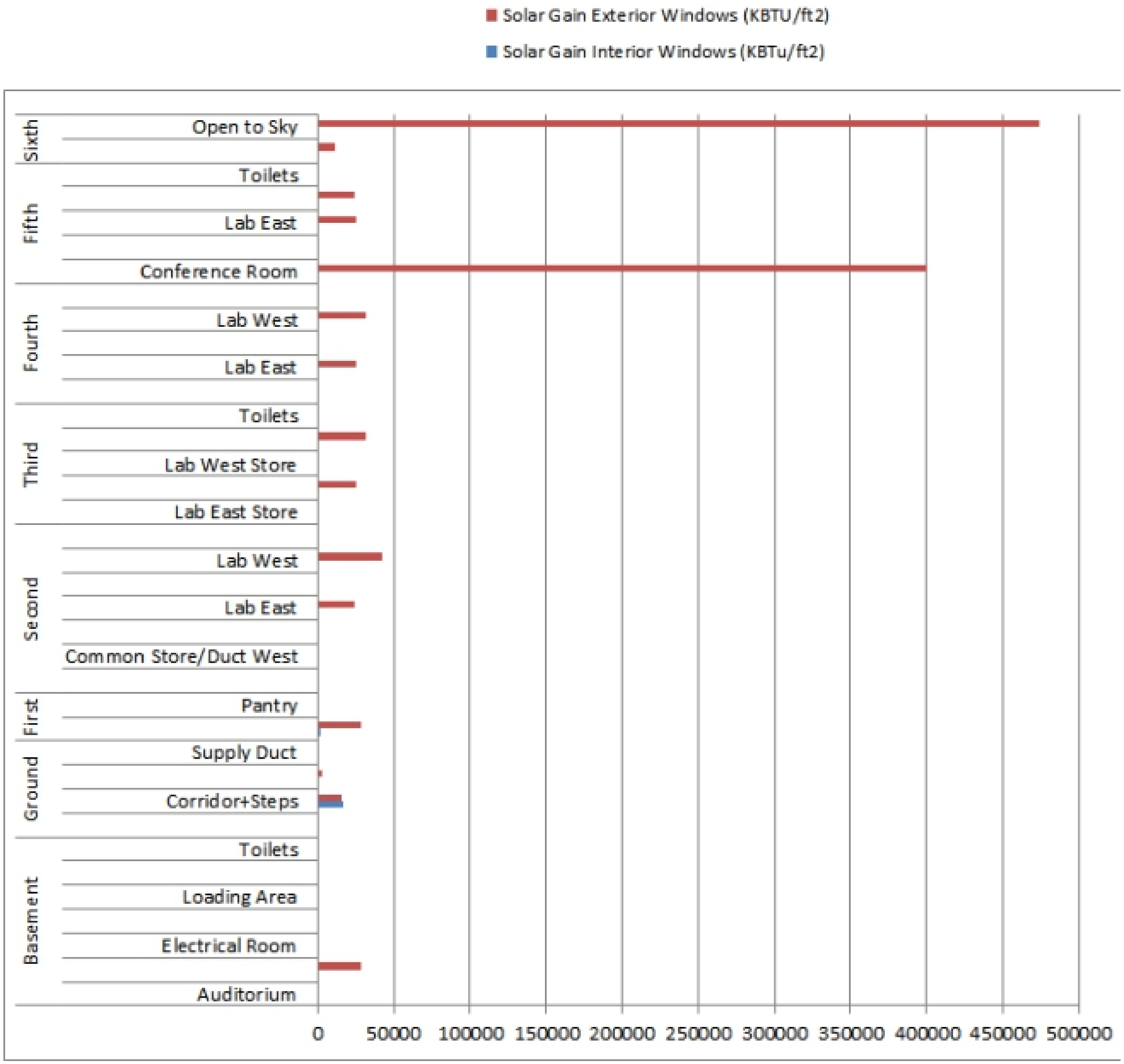





Heating/Cooling
Sixth
Open to Sky
Mechanical Room
Fifth
Toilets
Lab West
Lab East
Lab East Store
Conference Room
Fourth
Toilets
Lab West
Lab West Store
Lab East
Lab East Store
Third
Toilets
Lab West
Lab West Store
Lab East
Lab East Store
Second
Toilets
Lab West
Lab West Store
Lab East
Lab East Store
Common Store/Duct West
Common Store/Duct East
First
Pantry
Meeting Room
Ground
Supply Duct
Lift+Other Rooms
Corridor+Steps
Audio System Room
Basement
Toilets
Mechanical Room
Loading Area
Lift+Other Rooms
Electrical Room
Common Area
Auditorium
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
Zone Sensible Heating KBTU/ft2
Zone Sensible Cooling KBTU/ft2


Internal Gains
Sixth
Open to Sky
Fifth
Toilets
Lab East
Conference Room
Fourth
Lab West
Lab East
Third
Toilets
Lab West Store
Lab East Store
Second
Lab West
Lab East
Common Store/Duct West
First
Pantry
Ground
Supply Duct
Corridor+Steps
Basement
Toilets
Loading Area
Electrical Room
Auditorium
-20000
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
External Vent. Btu/ft2
External Infiltration Btu/ft2
Mech Vent + Nat Vent + Infiltration ac/h
Occupancy BTU/ft2
Comp+Equip BTU/ft2
General Lighting BTU/ft2
Task Lighitng BTU/ft2

This final calibrated model becomes the baseline model for design strategies and their testing, later in the project. The building was analyzed for its zone wise heating / cooling load and internal vs fabric gains. The zone wise breakdown allowed the opportunity to find out the zones with highest loads across the variables such as cooling, heating, and lighting.



Based on the final calibrated model results, it was deduced that common area (circulation area) has the maximum cooling as well a heating load.

Comparing fabric and internal gain, it was found out that in this building, the internal gains were dominant and contributed greatly towards the ultimate cooling load of the building.

Looking across the plot of internal gains, it could be inferred that, lighting and occupancy were the most dominant internal heat gain sources.

The core areas, which are the circulation area and the lab storage areas had high cooling and lighting load.

Therefore, based on this analysis, reducing the cooling and lighting load of core areas was accepted as design objective.

6. Design Proposal & Changes

Airflow

In addition to the heat source, airflow will help in faster air discharge. Also, will raise negative pressure at the outlet of atrium

Skylight + Heat Source

Heat source at the top of the atrium induces negative pressure and thus helps in convection.

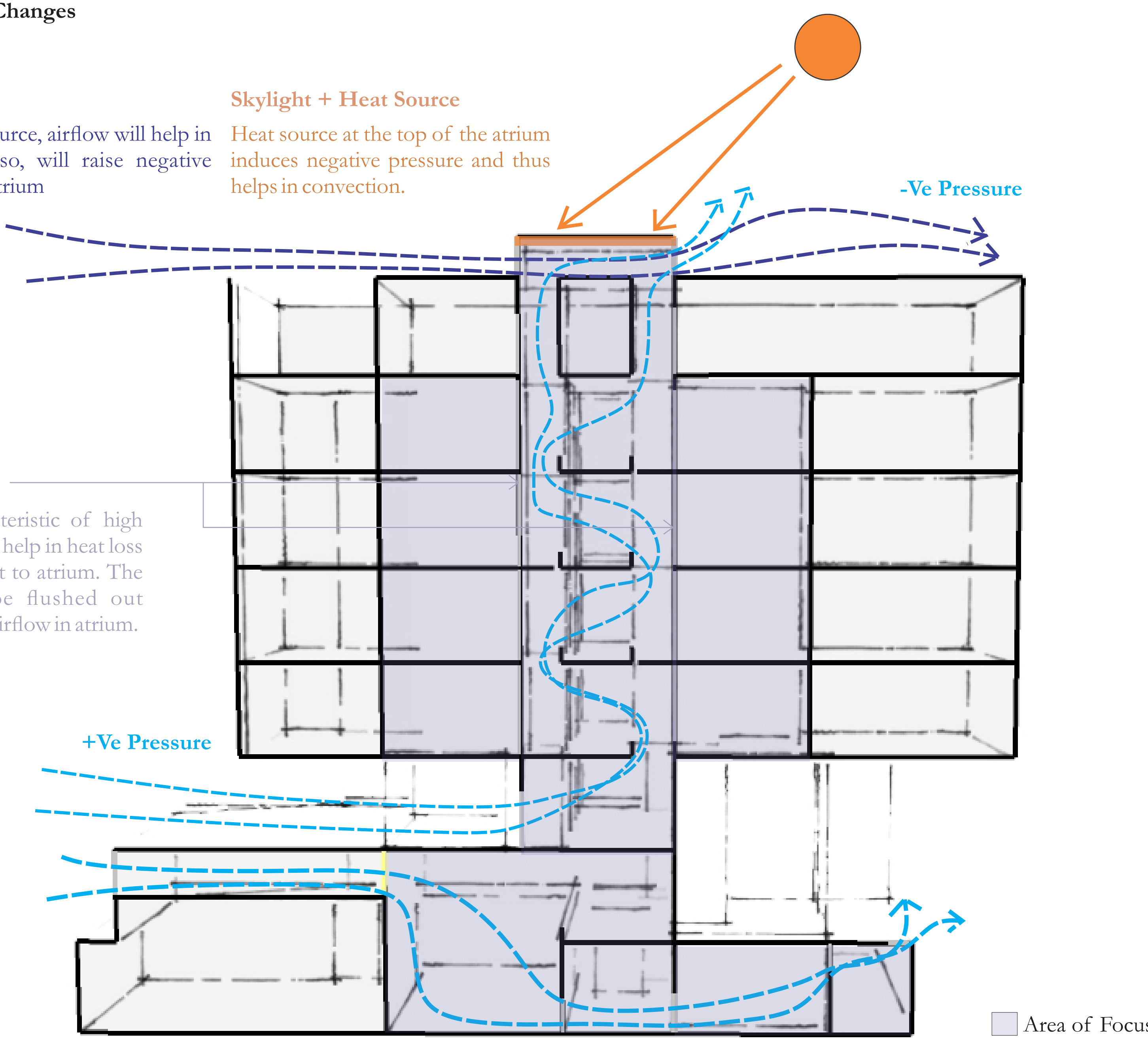
Glass in Atrium

Glass, due to its characteristic of high thermal conductivity, will help in heat loss from Lab rooms adjacent to atrium. The heat will eventually be flushed out through convection and airflow in atrium.

Air Inlet for Atrium

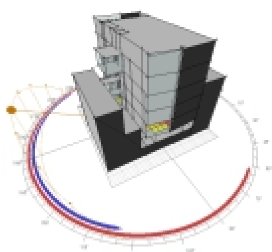
Air Inlet for Basement

Inlets located on the windward side to capture air during the outside air temperature is in comfort range.

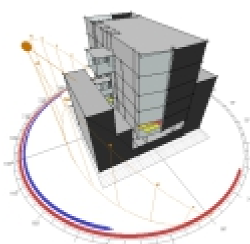


7. Testing new Design Strategies

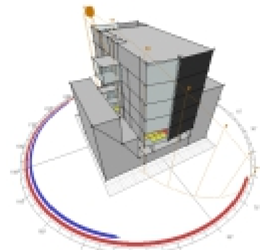
7A. Daylight Testing



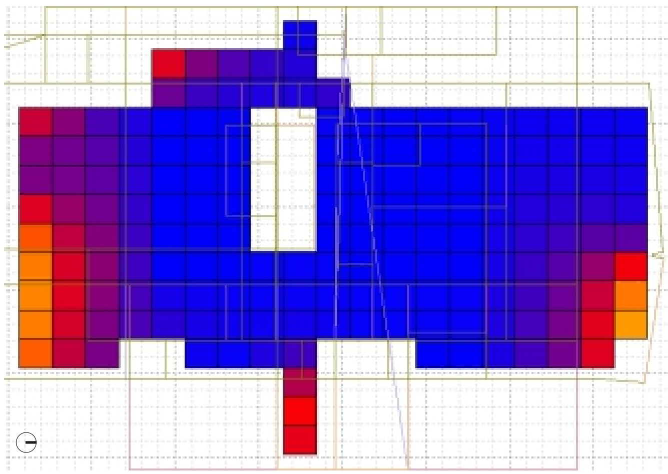
21st Dec_Overcast Sky

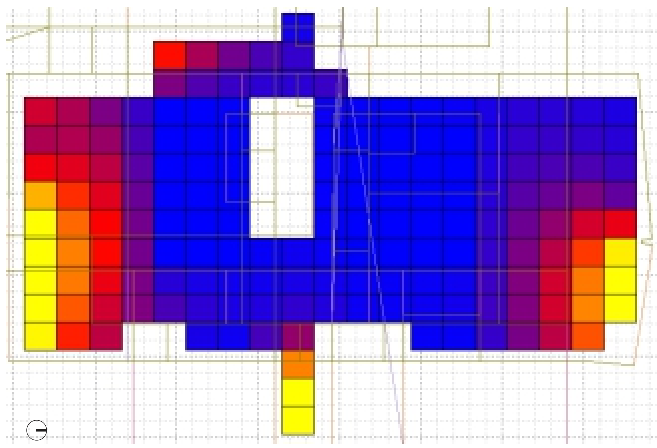


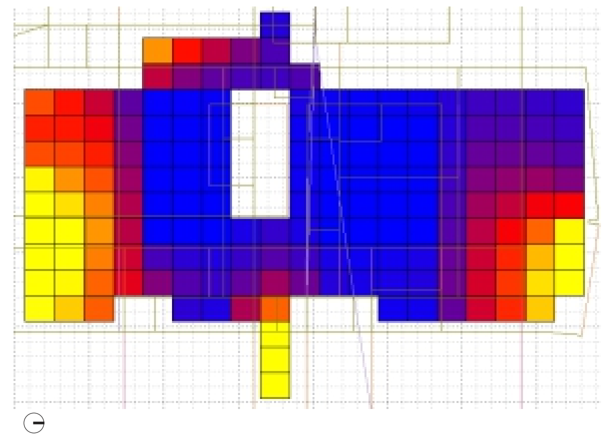
21st Dec_Overcast Sky



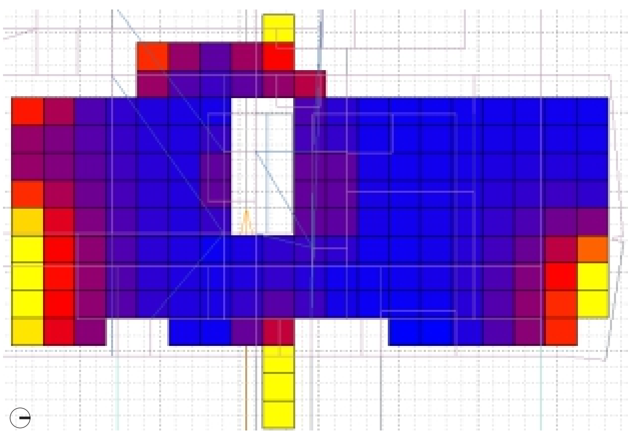
21st Dec_Overcast Sky

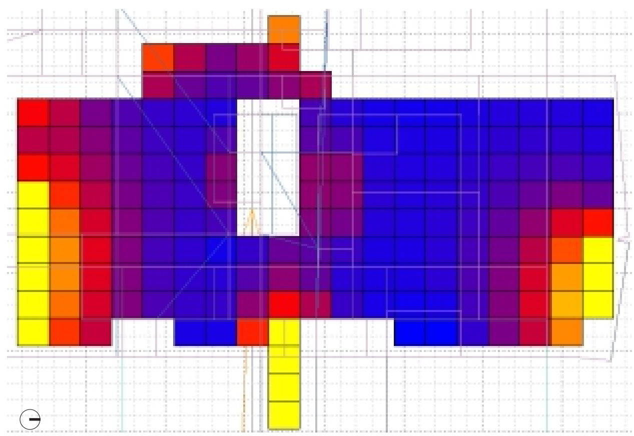


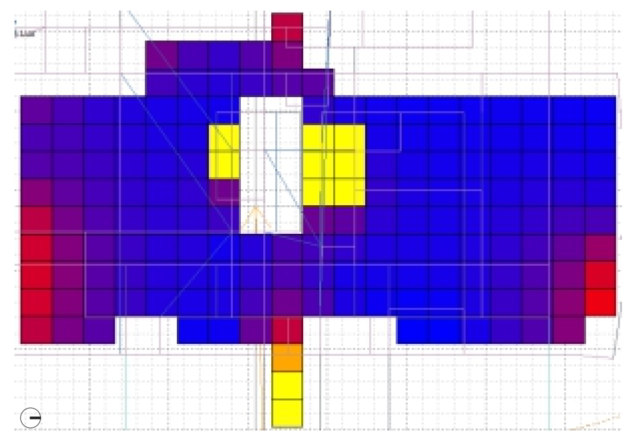




7A1. Baseline Results







7A2. After Design changes Results

7B. Ventilation Testing

7B1. Climate Analysis

In order to use natural ventilation, favorable wind direction, speed, and solar radiation were investigated. Analyzing the weather summary report, it could be inferred that during the summer months, the dry bulb temperature fall into comfort range. Also, during the summer months, Philadelphia receives the maximum incident solar radiation. Considering that, prevailing wind speed and direction was analyzed for summer months. In computational fluid dynamic model, prevailing wind was modeled from **south west** direction with **3.4 m/s** wind velocity.

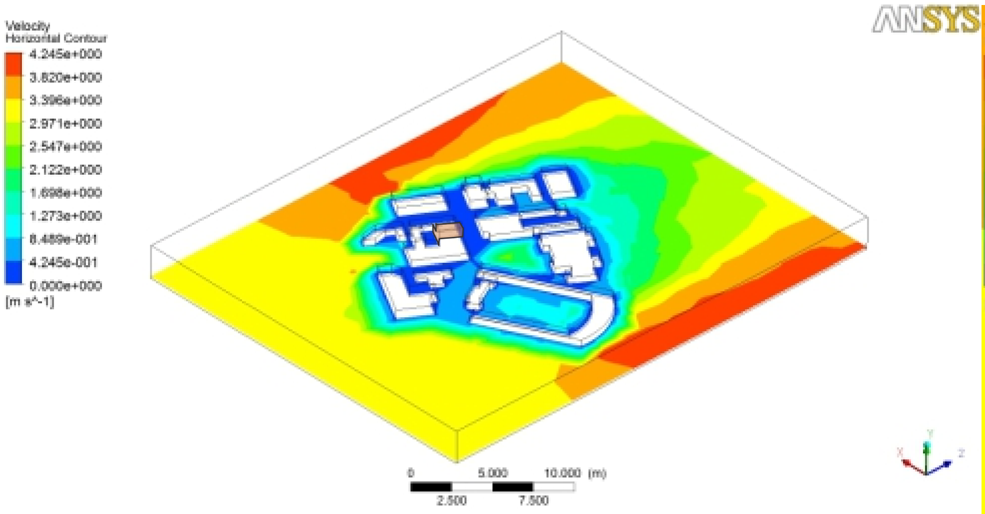
WEATHER DATA SUMMARY

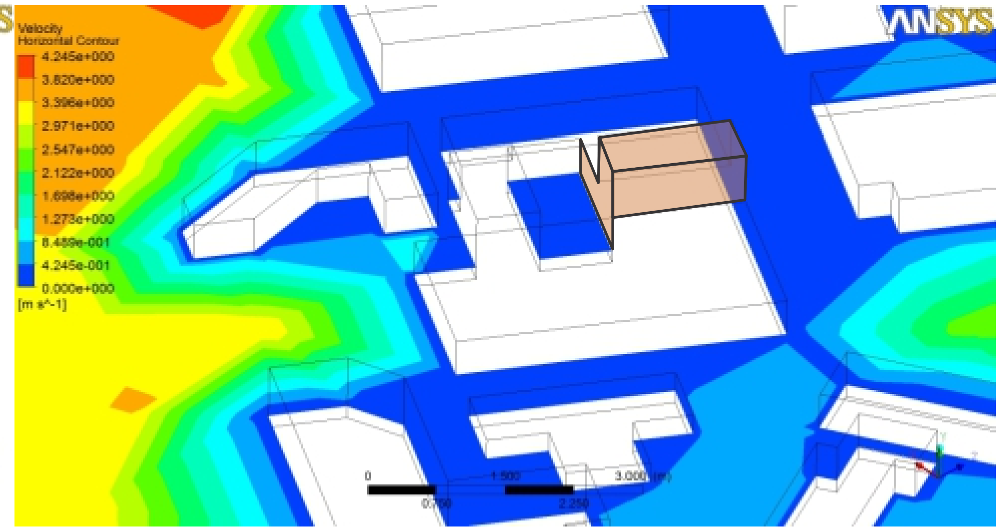
LOCATION: **Philadelphia International Ap, PA, USA**
Latitude/Longitude: 39.87° North, 75.23° West, **Time Zone from Greenwich** -5
Data Source: TMY3 724080 WMO Station Number, **Elevation** 2 m

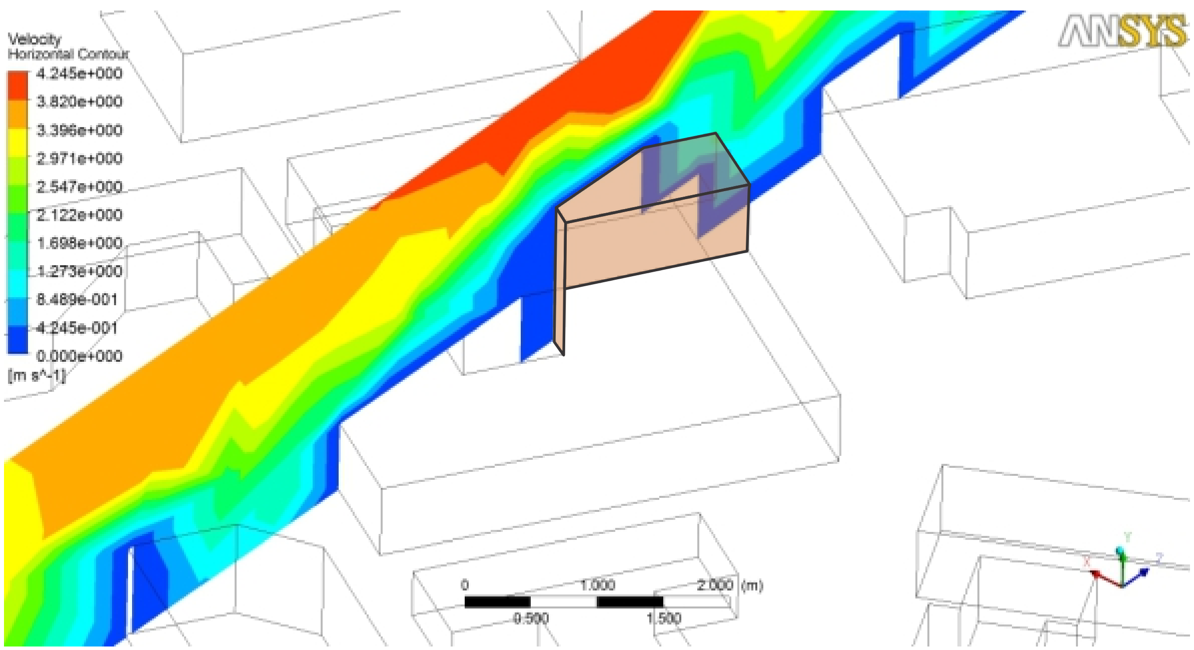
MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	265	304	380	424	443	475	435	489	408	344	271	232	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	378	378	378	371	340	360	303	398	381	389	334	335	Wh/sq.m
Diffuse Radiation (Avg Hourly)	115	118	158	174	201	209	215	209	164	142	127	107	Wh/sq.m
Global Horiz Radiation (Max Hourly)	505	710	859	924	954	978	928	911	845	722	545	458	Wh/sq.m
Direct Normal Radiation (Max Hourly)	930	930	905	953	847	882	845	923	857	936	923	916	Wh/sq.m
Diffuse Radiation (Max Hourly)	274	361	404	462	454	495	477	453	481	336	286	240	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	2016	2730	3819	4779	5655	6252	5714	5626	4365	3269	2224	1766	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	3085	3491	3922	4324	4385	4791	4026	4681	4169	3847	2889	2732	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	902	1082	1622	1994	2603	2775	2851	2447	1788	1382	1073	834	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	28428	32579	40783	45756	47720	51374	47162	52500	43948	36805	28812	24763	lux
Direct Normal Illumination (Avg Hourly)	35579	36552	37099	37068	33923	36242	30675	40216	38123	37894	31738	31019	lux
Dry Bulb Temperature (Avg Monthly)	-1	0	7	12	18	22	25	23	20	12	7	3	degrees C
Dew Point Temperature (Avg Monthly)	-7	-6	0	3	10	15	18	17	14	5	2	-4	degrees C
Relative Humidity (Avg Monthly)	68	59	60	56	63	70	68	69	70	67	71	60	percent
Wind Direction (Monthly Mode)	310	300	300	310	70	240	240	230	0	240	280	300	degrees
Wind Speed (Avg Monthly)	5	3	4	4	3	3	3	4	3	4	4	4	m/s
Ground Temperature (Avg Monthly of 3 Depths)	4	3	4	5	11	15	19	21	20	17	13	8	degrees C

7B. Ventilation Testing

7B2. External Wind Analysis





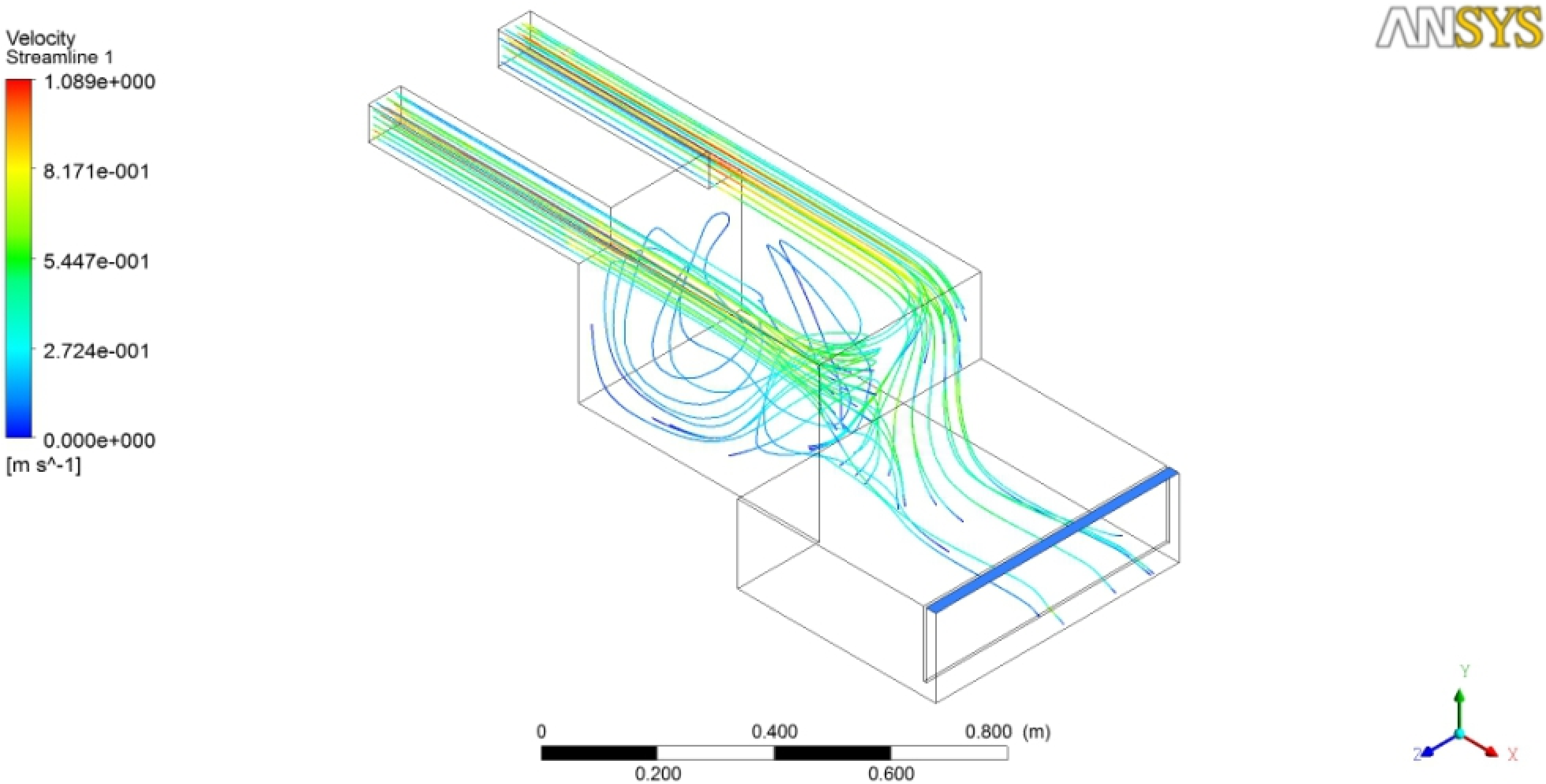


In case of Skirkanich Hall, since the courtyard in west side is the only wind access, wind velocity on west face of skirkanich hall was used for internal CFD simulation. Wind Velocity on West Face is no more than 4m/s. This wind velocity was used as the boundary condition for internal wind analysis of atrium and basement in later stages.

7B. Ventilation Testing

7B3. Internal Wind Analysis

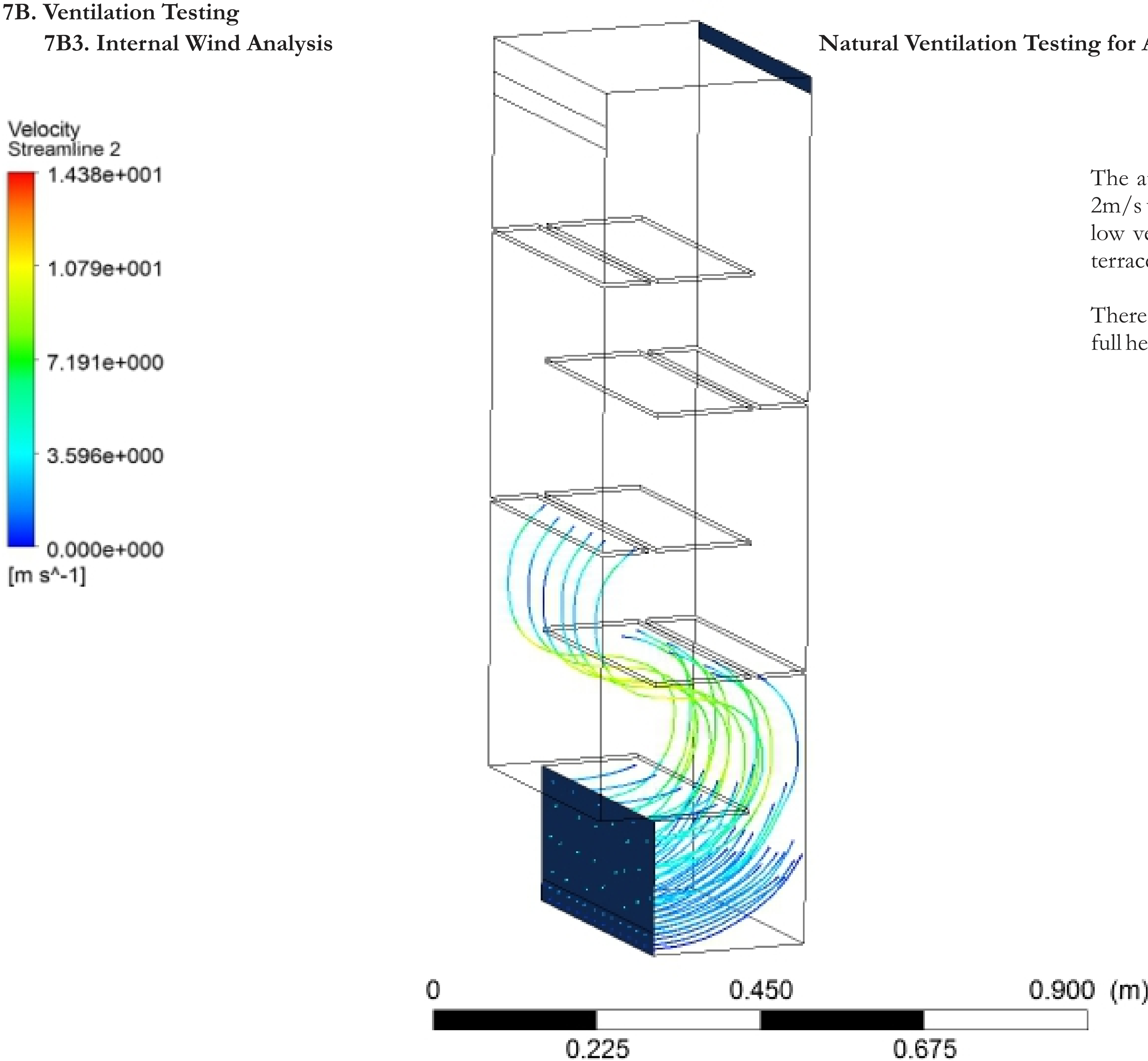
Natural Ventilation Testing for Basement



2 m/s was the input at both the velocity inlets. The Outlet opens up on the east side of the building. and generates negative pressure and helps in cross ventilation in the basement mechanical room.

7B. Ventilation Testing

7B3. Internal Wind Analysis



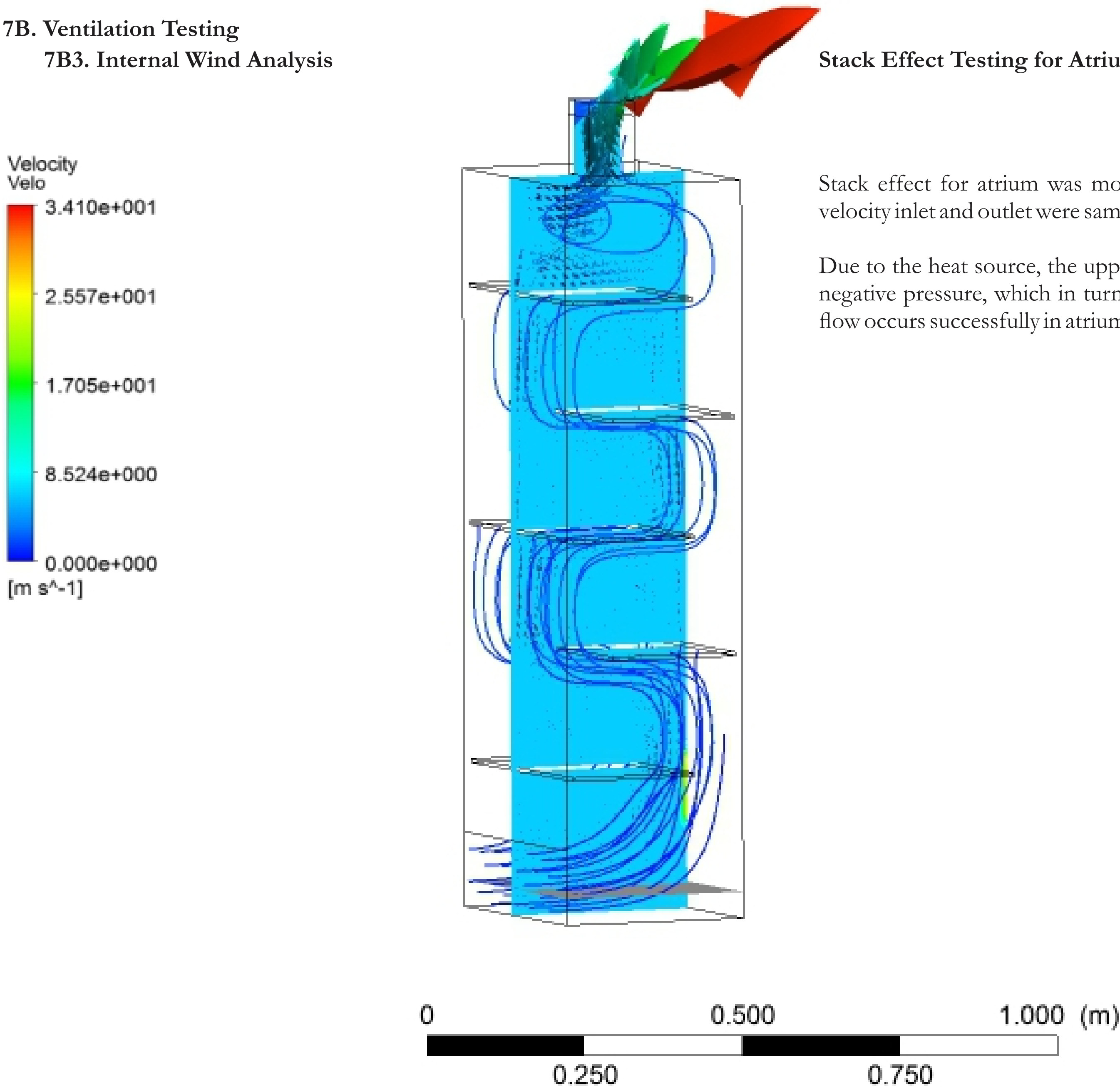
Natural Ventilation Testing for Atrium

The atrium was modeled for natural ventilation first and 2m/s was used at velocity inlet. However, due to extremely low velocity input, the air fails to reach the outlet at the terrace level.

Therefore, stack effect experiment was conducted to have full height convection of airflow in atrium.

7B. Ventilation Testing

7B3. Internal Wind Analysis



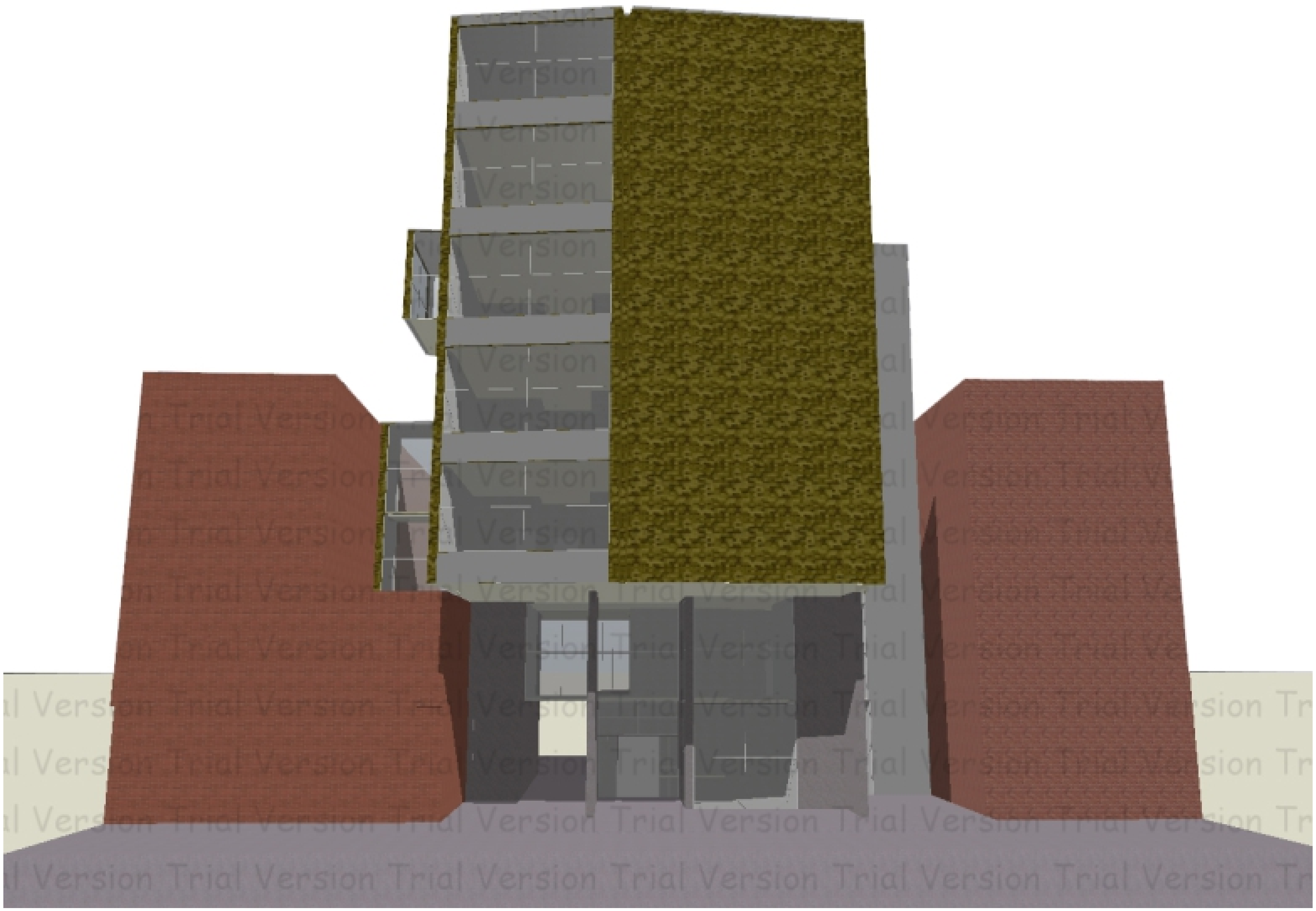
Stack Effect Testing for Atrium

Stack effect for atrium was modeled with a aluminium heat source on the top. The velocity inlet and outlet were same as they were in natural ventilation study.

Due to the heat source, the upper part of the stack heats up tremendously and creates negative pressure, which in turn helps in pulling air from below. And thus convection flow occurs successfully in atrium.

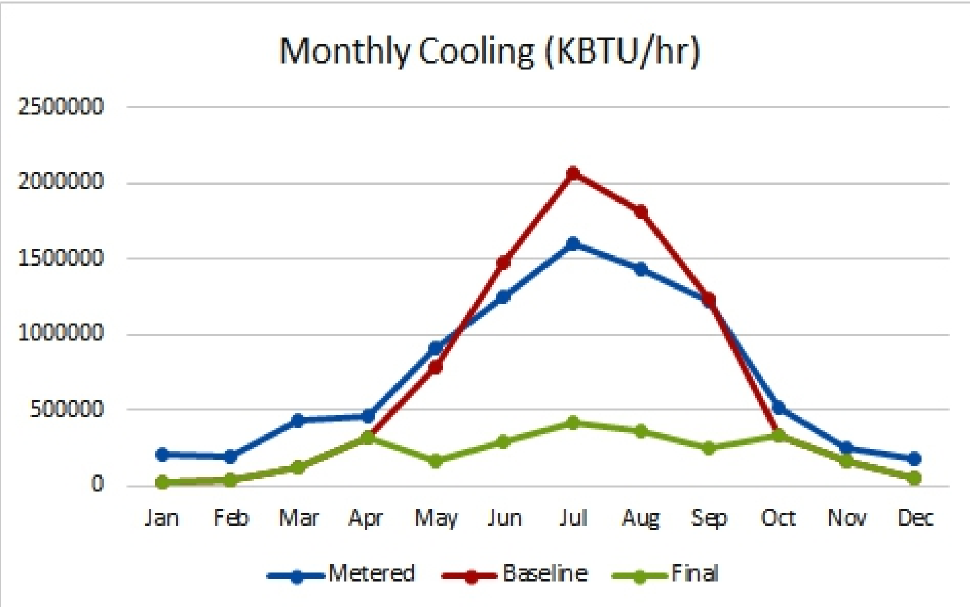
7C. Energy Model Testing

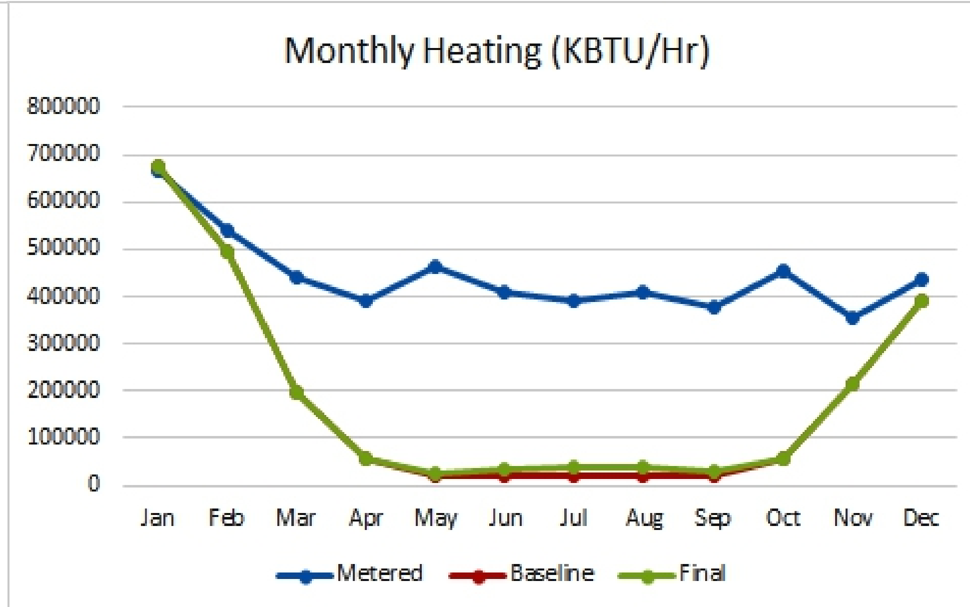
Final Energy Model

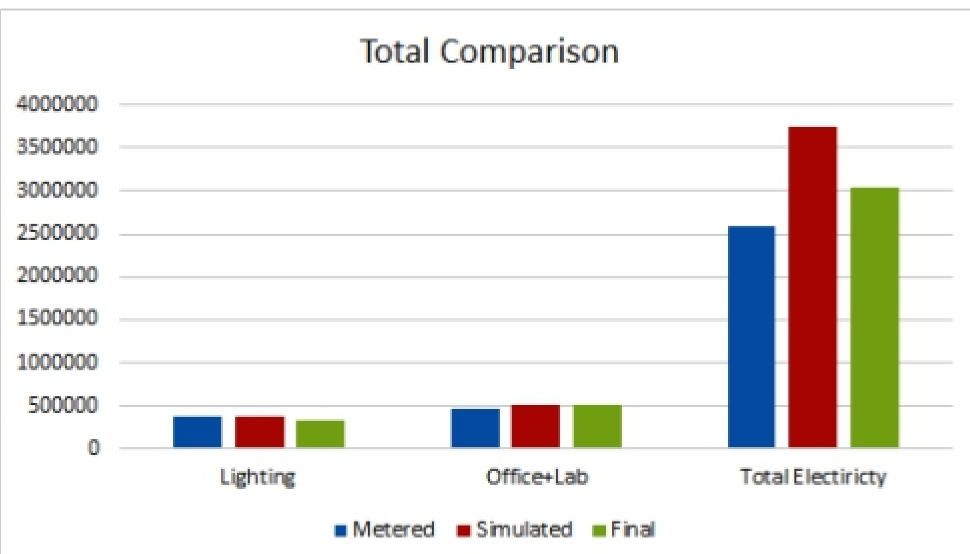


7C. Energy Model Testing

7C1. Final Results







Based on CFD and Daylight studies, changes were made in energy model and simulation results were recorded for their improvement against baseline results.

For summer months, Mechanical Ventilation and Cooling was kept on for 30% of the summer period, considering that ventilation of atrium with stack effect and ventilation of basement with natural airflow will provide necessary comfort condition during the rest of the 70% period.

Lighting schedules were changed for the lab rooms located adjacent to the atrium considering the results of daylight studies.

8. Conclusion & Observations

Zoning in energy model was done based on program allocation and function of spaces. Vertically connected spaces such as atrium, stairs, and lift blocks were modeled using holes in the slab. From the drawings and specifications, the information on materials and wall construction was extracted and were modeled in energy model in the exact same fashion. Activities and mechanical systems were assigned zone wise and default system templates were used initially.

After having the initial results, it was realized that the schedules for lighting and HVAC needed to be 24 hr schedule. Apart form the schedules, Wall construction U-Value, Glazing U-Value, occupant density, lighting density, VAV turndown ratin, Ach ratio, Heating setpoint and cooling setpoint were modified at various stages of calibration.

It was noted that, Ach and set point temperatures had prominent effect on simulation results and thus they need to be entered precisely and carefully.

By looking at zone wise breakdown, it was found out that the core areas had maximum cooling and lighting load. And thus it was accepted as design objective to address the high cooling and lighting load in core areas.

The only access for prevailing wind to enter the building was on the west side of building. However, since the courtyard on the west side of the building is surrounded by other university buildings, it was critical to receive sufficient wind velocity at the west face of the building. And therefore, stack effect was used to model and test the convection flow in the atrium space. If an intake fan is modeled in place of velocity inlet, the wind velocity of convention flows in the atrium can be improved. If the temperature of atrium is dropped to a considerable level, and a substantial difference in temperature is developed between atrium and lab storage space, storage space could loose heat to the atrium through conduction. And so lab storage space can be cooled passively.

Incorporating passive strategies in energy model requires systematic data entry and calibration, which increases the time required for simulating and calibrating a model.

Energy model software's inability to model the convection flows is a serious limitation and therefore, energy modeler is required to make many assumptions while modifying the model according to CFD tested geometry.

The lack of integration and coupling between different tools involved in building performance measurement process and remediation process increases the time required for successful full building energy simulation, which in itself can be a huge limitation for its regular use in the industry if not done with a clear and informed analysis strategy.