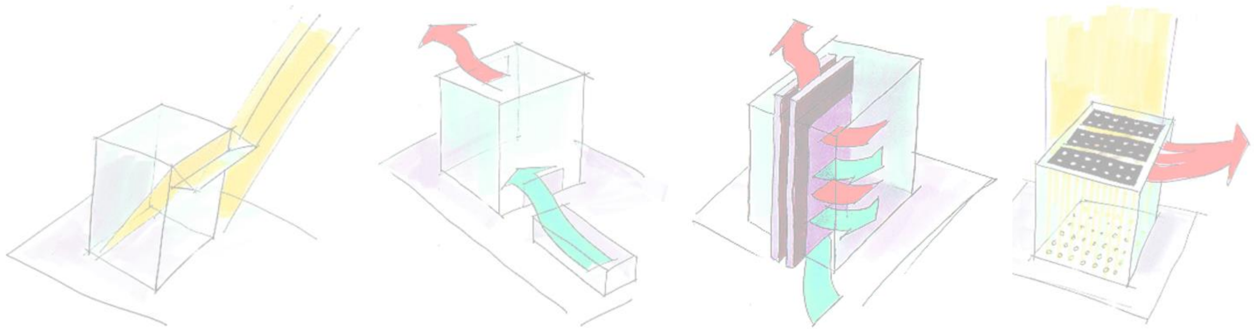
British Columbia Institute for Technology, NE01 Building, Vancouver BC

Energy Upgrade and Retrofit Study Report



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1. Executive Summary

The NE01 building on the British Columbia Institute for Technology (BCIT) campus has the potential to be transformed into a much more energy efficient and comfortable building. The results of the simulation show a reduction potential between 49 and 76%. The goals of this report and the work of Transsolar were to study the feasibility and make recommendations to achieve this objective. Based on this, Transsolar had the following five goals:

- Understand the NE01 building and assess its current state
- Analyze the climate situation to drive passive design strategies
- Engage students and faculty for feedback and idea generation through a workshop
- Investigate potential for comfort improvements in the space and energy reduction
- Develop an energy strategy to meet the ambitious Factor Four goals

In order to identify interventions to drive this transformation, a holistic understanding of the building's energy systems and consumption level was developed. By working closely with the Factor Four team and NE01 facilities managers to compile data from the building's operational life (ie. architectural and mechanical drawings, reports and audits, and real-time energy data) an initial understanding of the ventilation, heating, cooling, and lighting systems was developed. The report and study is based on this understanding.

NE01 is heated through an all air system, with centralized air handling units, and localized reheat coils. The energy is sourced from the district hot water supply (central boilers on BCIT campus) and local back-up boilers on site. NE01 is cooled in the same manner, but using on-site chillers as its energy source. Both the heating and cooling demands of the building are significantly higher than one would expect in the mild Vancouver climate. The ventilation system is sized for the dual purpose of providing fresh outdoor air and conditioning, and is currently operated with a daily on/off schedule which does not respond or vary based on occupancy. The ventilation system also pulls heat from the recirculation of building return air in the air handling units. These factors have led to bad air quality in NE01 and an unnecessary level of electricity consumption and heating. NE01's lighting levels and electricity consumption were broken down, and show significant reduction potential based on the lack of functional occupancy sensors and the unnecessary 24/7 operation of certain areas of the building. The average specific energy consumption of the building is estimated at 270 kWh/m^2, with heating identified as the biggest energy demand. However, these energy numbers reflect the reality that NE01 is not a comfortable building. If operated to meet the ASHRAE 62.1 and 55 standards for air quality and thermal comfort, the energy consumption is estimated at 345 kWh/m^2.

In all cases, these systems still have many unknowns due to the multiple renovations on the building's mechanical and electrical systems since the 1970's, which has led to variable equipment and conditions throughout the building. A detailed building audit should be carried out by students as part

of the NE01 living lab concept as an educational exercise, which will also facilitate the optimization of the building systems.

The Vancouver climate was analyzed, and compared to conditions on the BCIT campus to facilitate the identification of passive design strategies for NE01. Due to Vancouver's mild climate, a great potential exists to utilize natural ventilation to supply fresh air and facilitate a stronger connection to the outdoors along the North façade of the building, where the majority of classrooms are found. The user control afforded by operable windows for natural ventilation has also been shown to increase comfort and productivity of occupants.

To better understand NE01's current state and explore intervention possibilities, a design charette was led by Joshua Vanwyck, Project Lead at Transsolar, to engage BCIT students, faculty and facility managers. One main insight from this design charette was the poor air quality and thermal comfort in the building. The air in NE01 was described as stuffy and stale, causing headaches and other symptoms from prolonged exposure. The ventilation system operation was identified as the key source of this problem, with low levels of ventilation throughout the day, recirculation of "wasted" return air, and system shut-off while the building is still occupied. The thermal comfort is also a key issue due to the low insulation level in the façade and the limited ventilation operation hours mentioned above. These comfort issues and concepts can be further explored through a classroom level living lab where conditions are monitored and surveys are carried out to measure the impact of different interventions on comfort.

To develop a recommendation list for NE01, eleven different interventions were analyzed, which address building-wide and room-level comfort issues and high energy consumption levels:

1. Utilize Natural Ventilation: *Operable Windows on Façade*
2. Reduce Heating Requirements: *Increase Window Quality*
3. Reduce Heating Requirements: *Exhaust Heat Recovery*
4. Reduce Heating Requirments: *Instant Water Heaters for WC*
5. Improve Daylight Autonomy: *Light Redirection*
6. Reduce Lighting Electricity Consumption: *Lighting Controls*
7. Reduce Lighting Electricity Consumption: *Light bulb Retrofit*
8. Reduce Atrium Over-Heating: *Skylight Shading & Natural Ventilation*
9. Reduce HVAC Energy Requirements: *Separate Conditioning from Ventilation System*
10. Reduce Heat Loss through Façade: *Insulation Enhancement*
11. Improve Daylight Autonomy: *Increase Window Area on North Façade*

A one-zone thermal simulation was performed to model the current state of an NE01 classroom. A base case representing a comfortable version of NE01's current state was created in order to facilitate intervention comparison. Daylight factor simulations were also performed. Based on the individual intervention calculations and simulation results, the following recommendations were developed:

1. Building-Wide Ventilation: Split HVAC with Natural Ventilation
2. Façade Improvements
3. Integration of Heat Recovery in Ventilation System
4. Lighting Upgrades

These four recommendations are grouped interventions from the original list of 11 interventions. This strategy should be carried out sequentially, with the highest priority being placed on the first group of interventions due to their comfort benefits, energy reduction potential, and alignment with pending NE01 system upgrade requirements. Each set of interventions builds upon the last, and an overall incremental reduction in energy consumption is shown in Figure 1, which outlines the percent reduction possible from the comfortable base case, as well as NE01's current energy consumption.

	Heating [kWh/m2]	Cooling [kWh/m2]	HVAC Electricity [kWh/m2]	Plug Loads & Lighting [kWh/m2]	Total [kWh/m2]	Reduction from base [%]	Reduction from current [%]
Current	118	38	32	69	267	-23%	100%
Base	196	38	32	69	345	100%	129%
Split HVAC and Natural Ventilation	79	11	7	69	176	-49%	-34%
+ Façade Improvements	62	11	7	69	159	-54%	-40%
+ Heat Recovery	10	12	7	69	108	-69%	-59%
+ Lighting Upgrades	10	12	7	41	81	-76%	-70%

Figure 1 NE01 Energy Savings based on Integration of Recommended Strategies

1) Building-Wide Ventilation: Split HVAC with Natural Ventilation

The first step in reducing the energy demand and increasing the comfort level of NE01 is separating conditioning and ventilation, and installing all operable windows along the facades for natural ventilation and night flushing. A radiative conditioning system allows the ventilation system to be driven by air quality rather than heating requirements and fresh outdoor air can be supplied through natural ventilation to rooms along the façade for the majority of the year. The use of natural ventilation and night flushing also eliminates cooling needs for spaces with window access and provides users with more control over the thermal comfort and air quality of their space. Energy savings of 49% is achievable through this combined strategy.

2) Façade Improvements

To further reduce NE01's heating demand, the current façade should be enhanced by installing double glazed windows and adding internal insulation along the building facade. This will reduce heat loss through the façade, resolving thermal comfort issues (downdraft and sensation of being cold despite warm air) and reducing heating demand.

3) Integration of Heat Recovery in Ventilation System

To further reduce NE01's heating demand, heat recovery should be implemented. Although excess heat from the buildings exhaust air is already being used through air recirculation, employing heat exchange rather than air recirculation improves air quality immensely, and can reduce heating needs even more. Due to the variation in the ventilation system throughout the building, the system should be investigated unit by unit for the potential to integrate heat recovery. In the case that NE01's entire ventilation system is replaced, air handling units with high efficiency heat recovery should be selected.

4) Lighting Upgrades

Finally, the combination of LED lighting and lighting controls in various common spaces (bathrooms, cafeteria, corridors, and staircases) is recommended to reduce the electricity demand of NE01. By introducing LED lighting in these spaces, dimming is possible, and the lifespan of the light bulbs is not reduced. This is a cost effective solution to enhance the first three strategies. With both lighting controls and LED bulbs, a total energy savings of 76% from the base case, or 70% from the current state, is possible.

5) Additional Interventions

Natural ventilation and a shading system should be implemented in order to address comfort issues in the cafeteria atrium space.

In the case of a need to replace the hot water systems for bathrooms, electrical instantaneous hot water heaters should be used to reduce total electrical and gas needs while reducing time for hot water delivery.

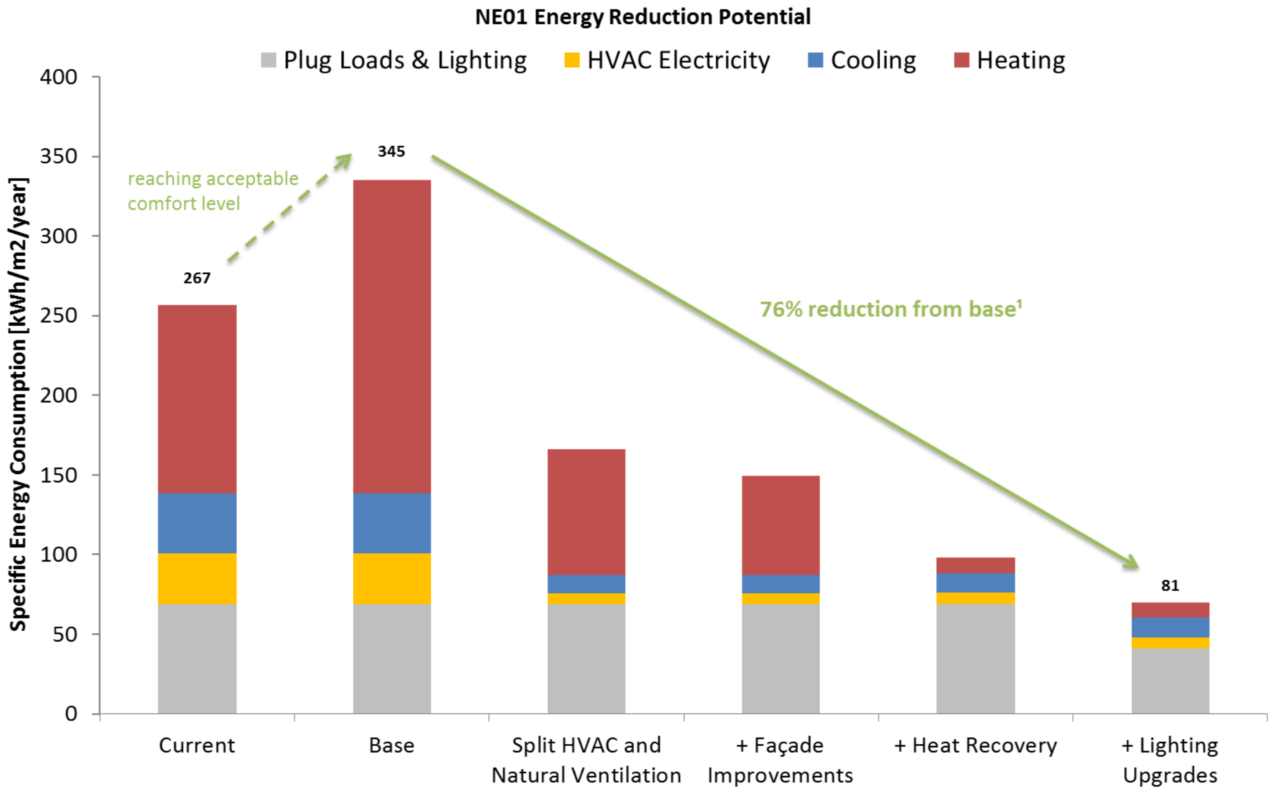

Figure 2 Overall Energy Reduction Potential from Comfortable Base Case[1]

[1] The base case used for comparison reflects NE01's energy consumption if it were operated at comfortable conditions.

2. Climate Analysis

The Vancouver climate is highly affected by the ocean, making it one of the most temperate and comfortable climates in Canada. This affords many opportunities to find creative and effective solutions to reduce heating and cooling loads in the project.

For the climate analysis and all simulations the weather data used was CWEC (Canadian Weather year for Energy Calculation) weather data from Vancouver International Airport (YVR), which represents data averaged over many years. Transsolar compared the temperature, wind direction, and wind speed with measured weather data from a weather station on the BCIT campus from 2009. This 2009 weather data from BCIT was also compared with 2009 data from CWEC to better understand the difference in conditions between BCIT and YVR.

The CWEC data originates, as seen below, approximately 14 kilometers from the project site and is considered to be reflective of conditions at the site with respect to solar radiation, and general thermal conditions. Because BCIT is located farther away from the ocean and in a more urban environment, we expect slightly higher day time temperatures.

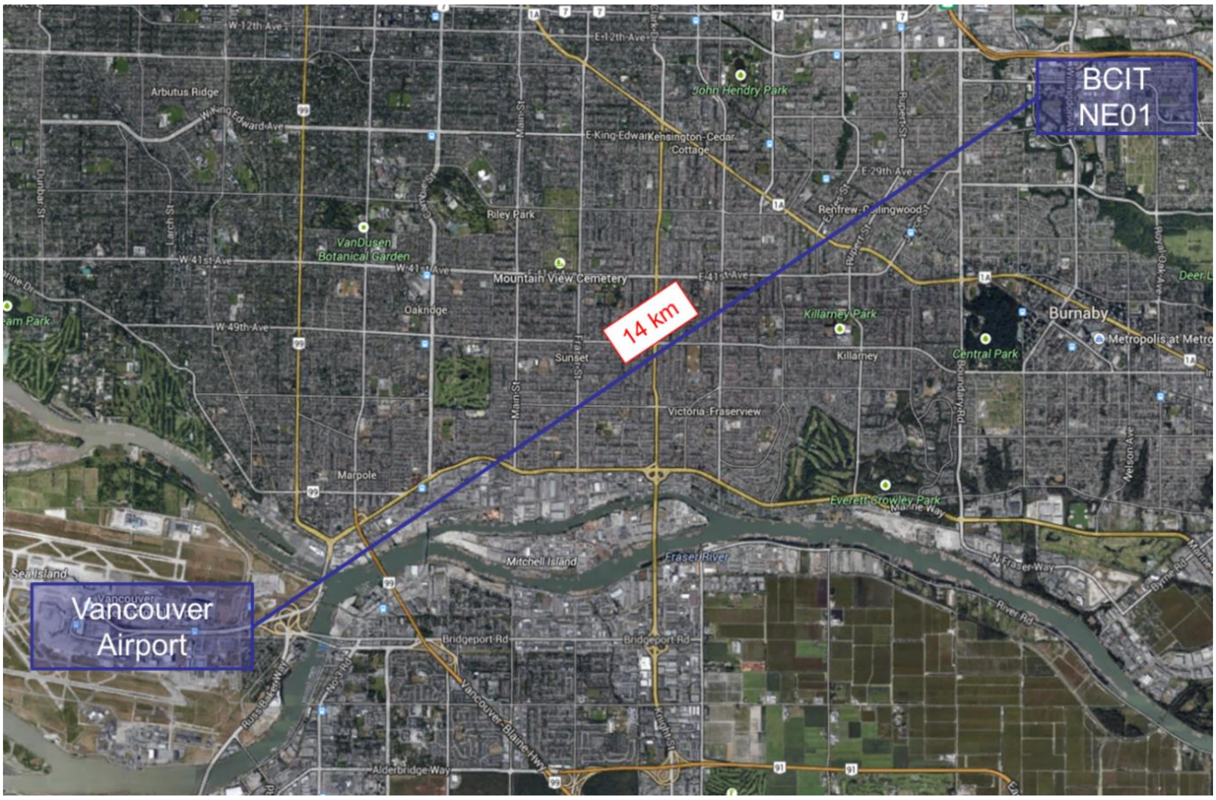

Figure 3: Location of Weather Data Source in relation to site

The temperature comparison, shown in Figure 4, shows the differences between the temperatures experienced on the BCIT campus (unknown placement) and the Vancouver International Airport. Based on the two 2009 data sets, this particular year seemed to have both extreme hot and cold temperatures compared to a normal year. However, the BCIT data still shows the occurrence of hotter and colder days on average, as compared to the 2009 weather data from YVR.

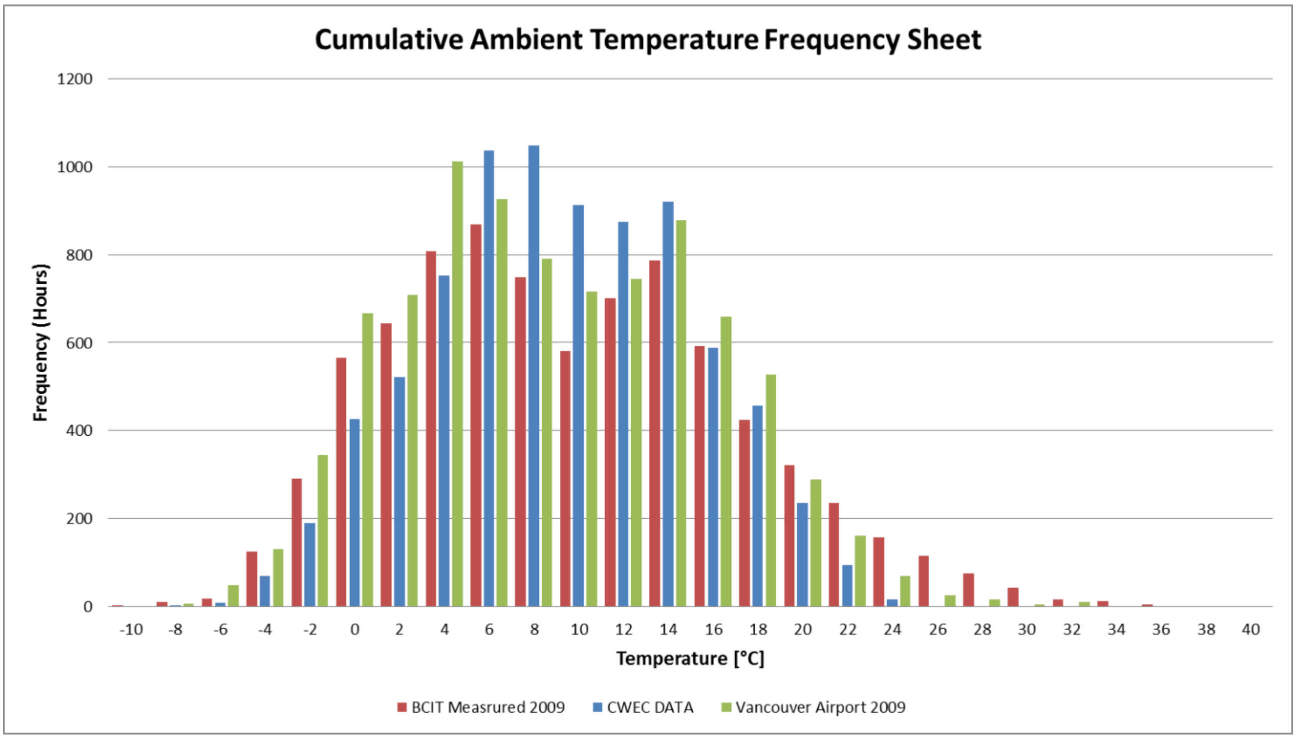

Figure 4 Comparison of BCIT and cwec Vancouver Airport Weather Data

Wind is more difficult to predict, as wind conditions are site dependent, but from the compared wind data from CWEC YVR and BCIT on-site data, a correlation between the high speed winds (above 3.5 m/s) can be observed, as the frequency of these winds from both the East and West directions is approximately 200 hours. This confirms an overall tendency for all strong winds to follow the east west axis. Slower winds will be more site dependent, but their impact is much lower, especially due to the mild climate of Vancouver.

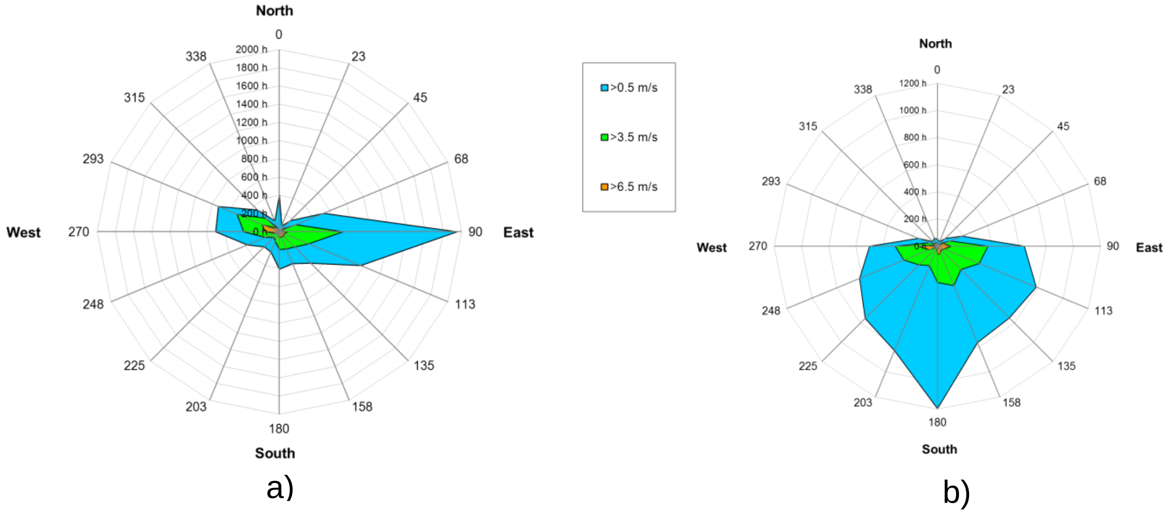

Figure 5 Comparison of CWEC YVR (a.) and BCIT (b.) Wind Rose

The current weather data does not take into account climate change and temperature increases over the next 25 years. The 2009 BCIT measured weather data is used to compare the interventions proposed on a more extreme year.

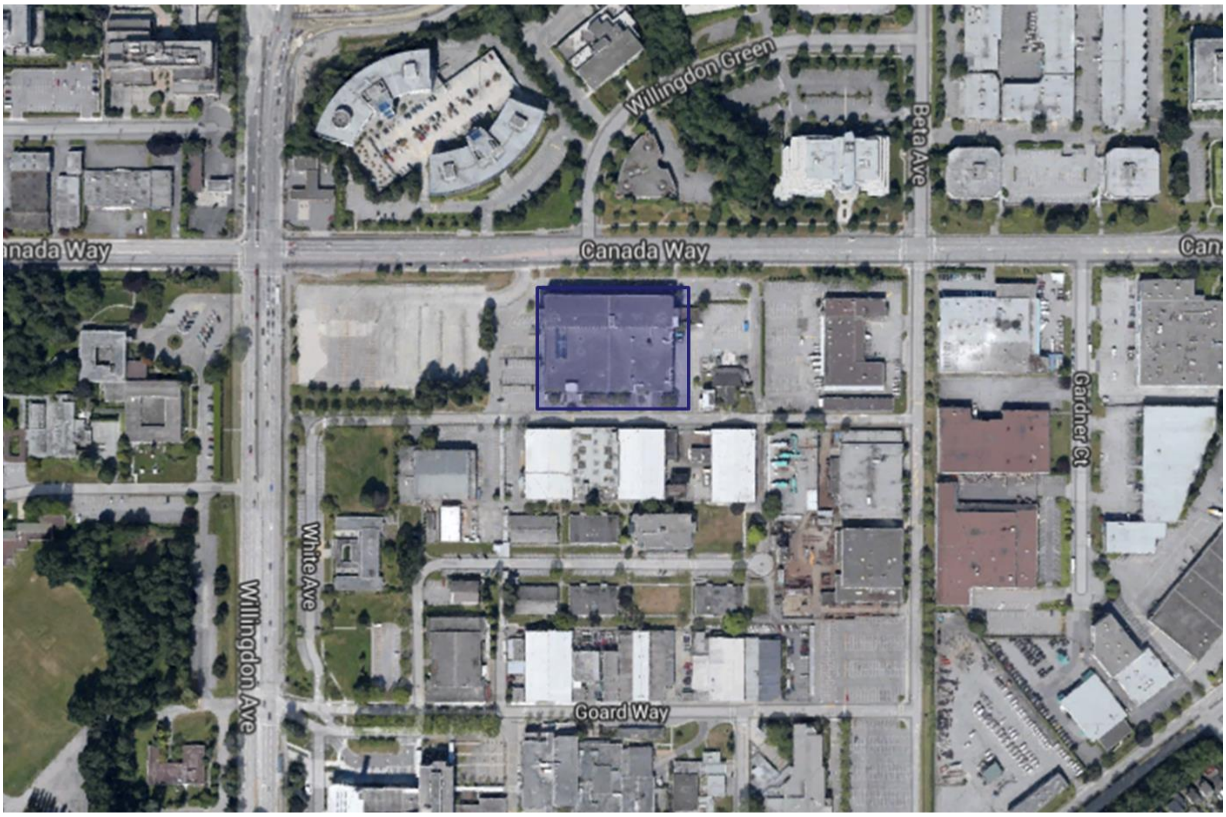

Figure 6: Site of NE01 Building on BCIT Campus

The following climate analysis examines the solar exposure, air temperatures and humidity levels throughout the year as well as the dominant wind directions during the different seasons.

The solar radiation on a horizontal surface in Vancouver over the entire year measures approximately 1300 kWh/m². This is a similar to solar exposure in Germany and could generate up to 200 kWh/m² useable electricity with the latest photovoltaic panels.

As seen in Figure 7 the majority of the solar radiation occurs from April to September, which correlates with the highest air temperatures. This suggests a need to maximize solar gains during the winter seasons when the temperatures are lowest and to reject or minimize solar gains in the summer season.

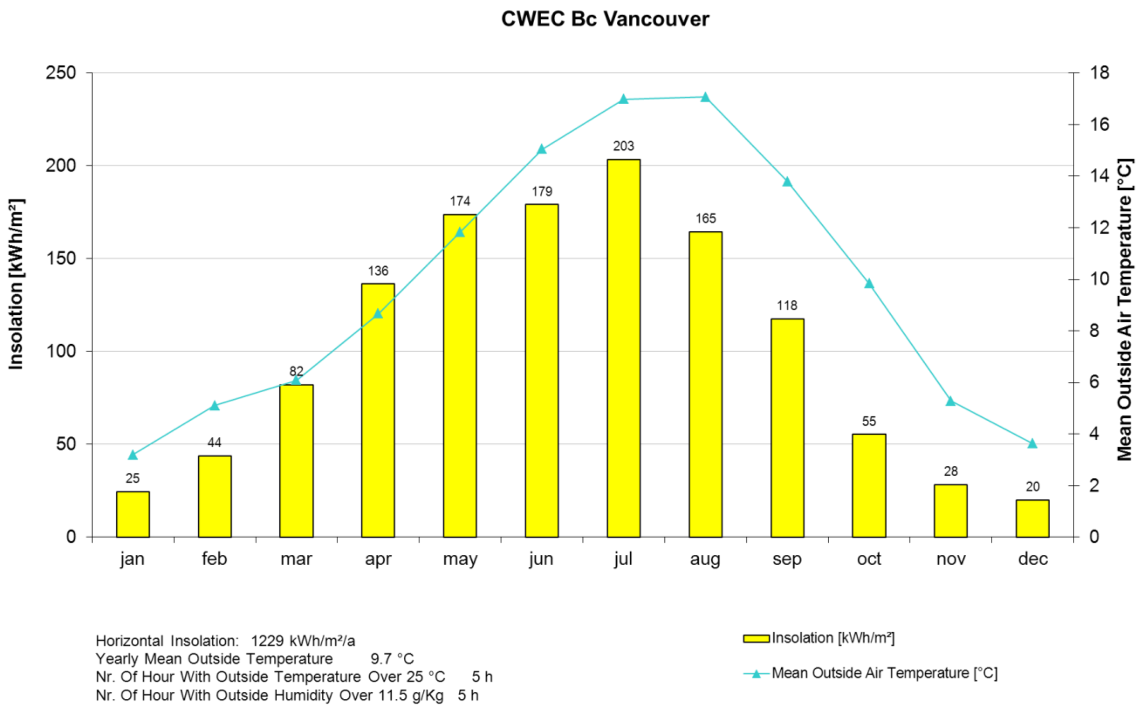

Figure 7: Solar Radiation with mean outside temperature

The only façade with significant glazing on the building is the North façade. From Figure 8 it is clear that solar radiation on the North Façade is minimal in comparison to the other façades, shown in Figure 9. Receiving primarily diffuse light throughout the year the north facing windows are a very small source of heat gain. The potential to increase the daylight autonomy in the rooms along the North Façade is explored through a natural daylight study presented later in the report.

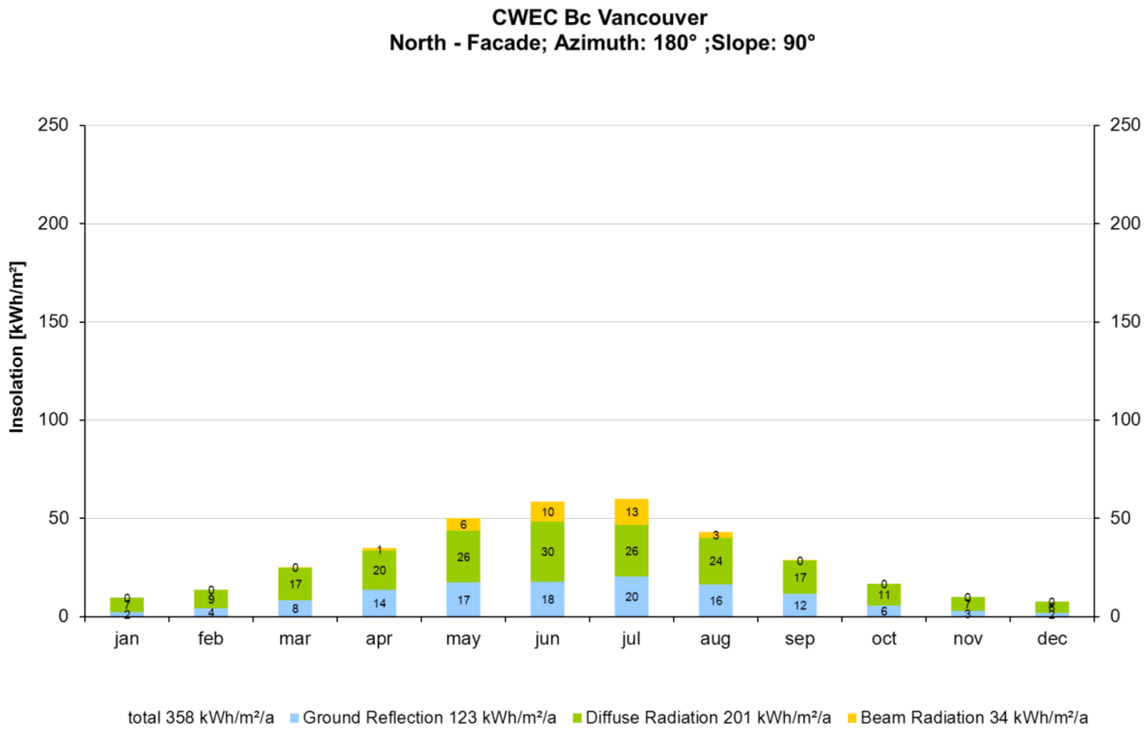

Figure 8: Solar Radiation on North Façade

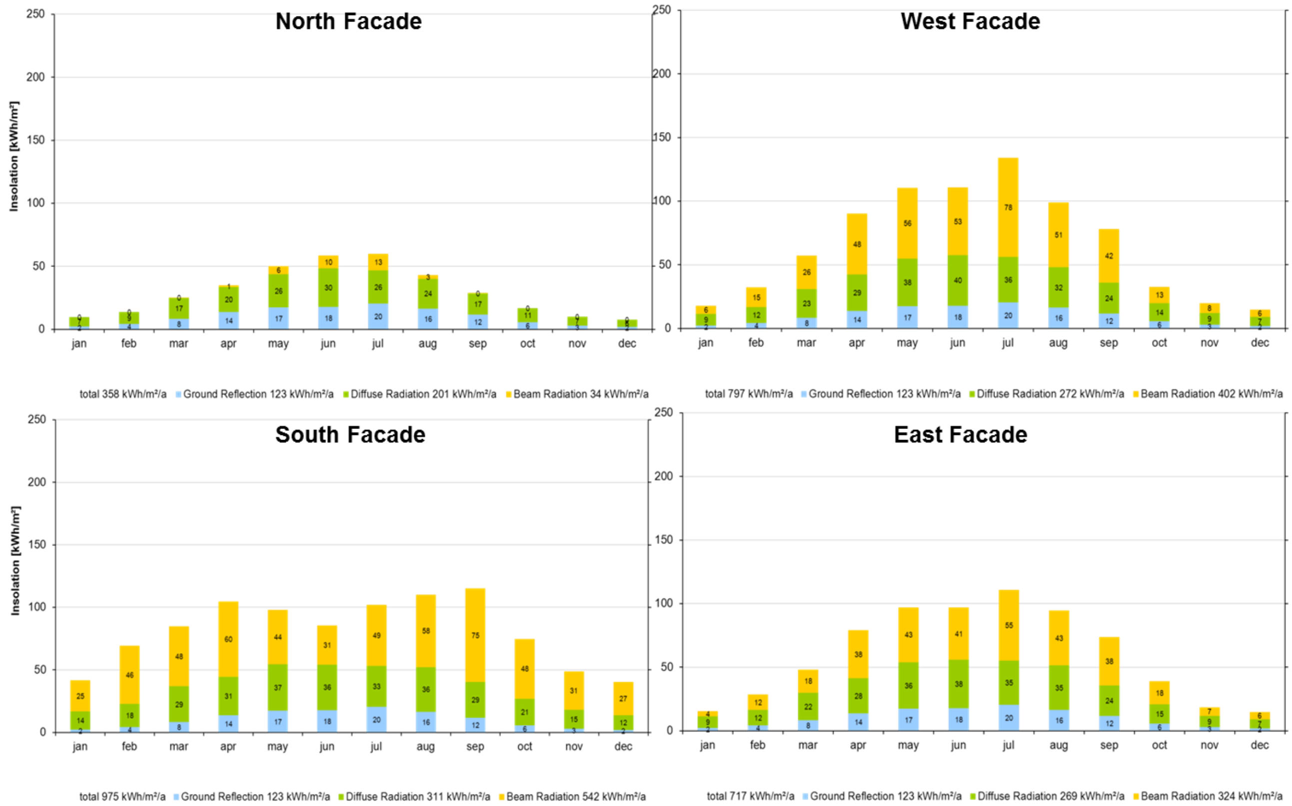

Figure 9: Comparison of Solar Radiation on Facades

When examining the solar exposure on the other building facades, the trend identified for the overall location is seen. The majority of the radiation occurs in the summer month and is direct radiation. During the winter months there is very little direct radiation, so most of the light will be diffuse.

A much higher potential for improving natural daylight exists along the West, East, and South facades, if the addition of windows is feasible. Direct sunlight on the horizontal roof surface is also high, which can lead to uncomfortable overheating in the atrium due to solar gains through the skylight. This heating potential is highest in summer, when it is not needed, therefore operable shading may be worth considering to block solar gains through the atrium skylight.

As mentioned the temperatures in Vancouver are relatively mild. As seen in Figure 10 there are regular day and night temperature swings even in the summer time when temperatures are highest. The annual frequency distribution of temperatures, in Figure 11, shows less than 4% of the total hours below 0°C. Approximately 60% of the hours lie between 10°C and 26°C during which natural ventilation without any preconditioning would be possible.

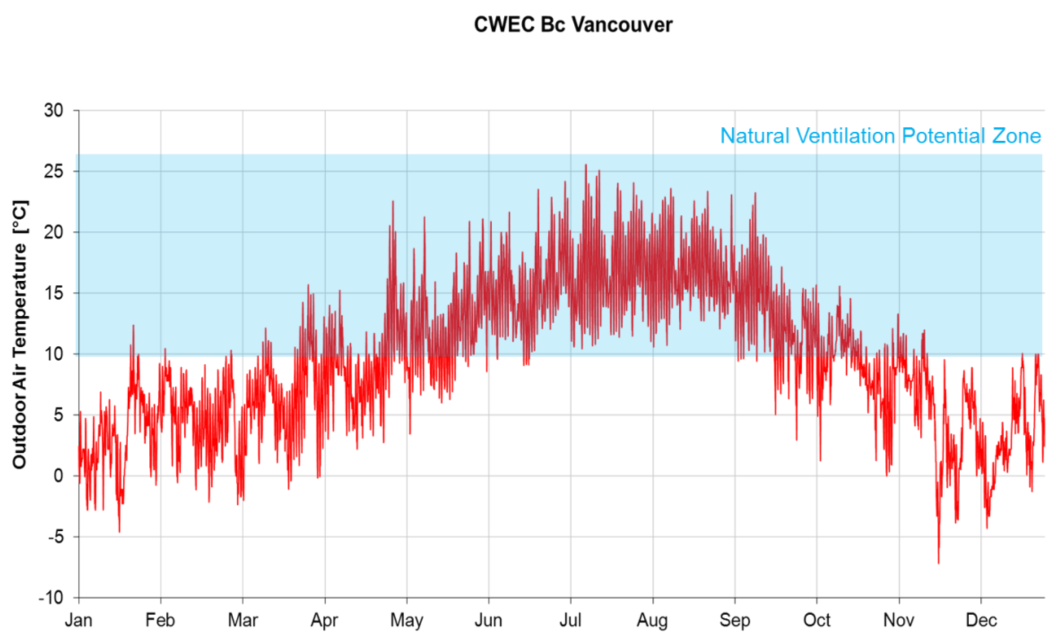

Figure 10: Annual Hourly Outdoor Air Temperatures

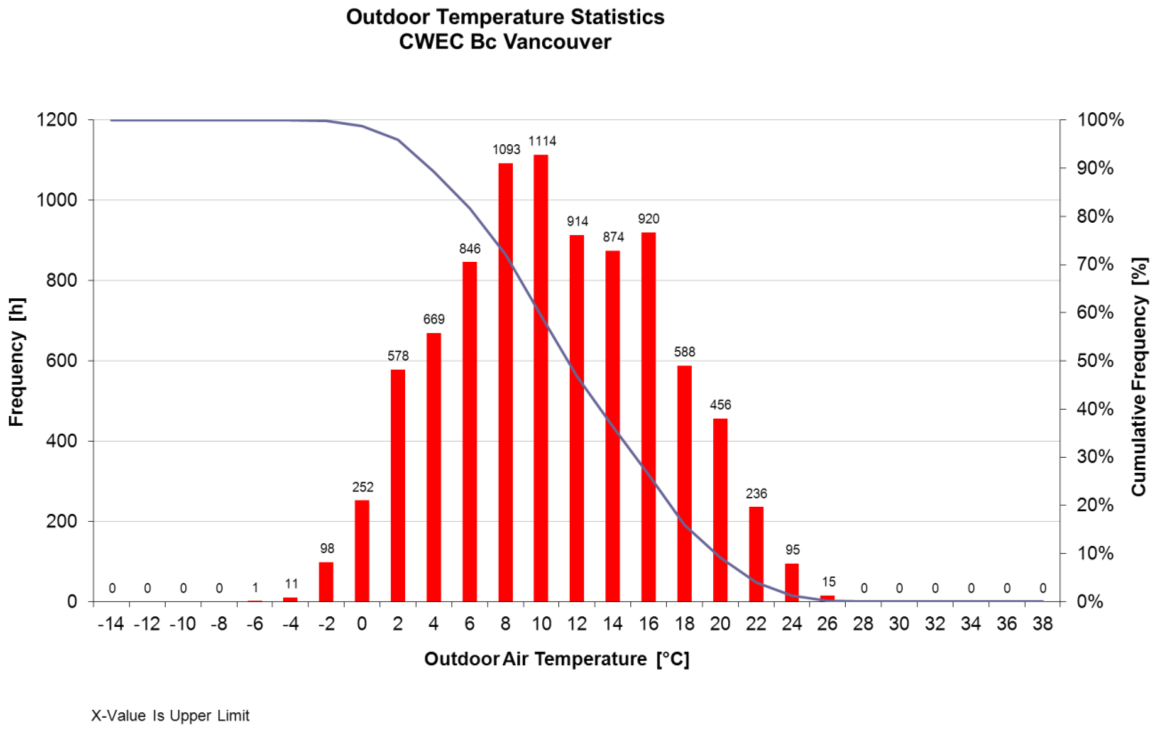

Figure 11: Annual Temperature Frequency Distribution

It is clear that when solar radiation is controlled then Vancouver is primarily a minor heating climate. This is ideal for a highly passive building where the internal gains from people and equipment as well as solar gains can contribute to the heating in winter.

One concern when radiant cooling or natural ventilation is used is the risk of condensation. Figure 12 shows clearly that although throughout the rainy and cold periods of the year the temperatures and humidity levels reach the dew point, this is rarely the case after temperatures exceed 15°C. Consequently when air is heated or brought into a warmer room, the moisture levels should not be sufficient to cause condensation on the slab.

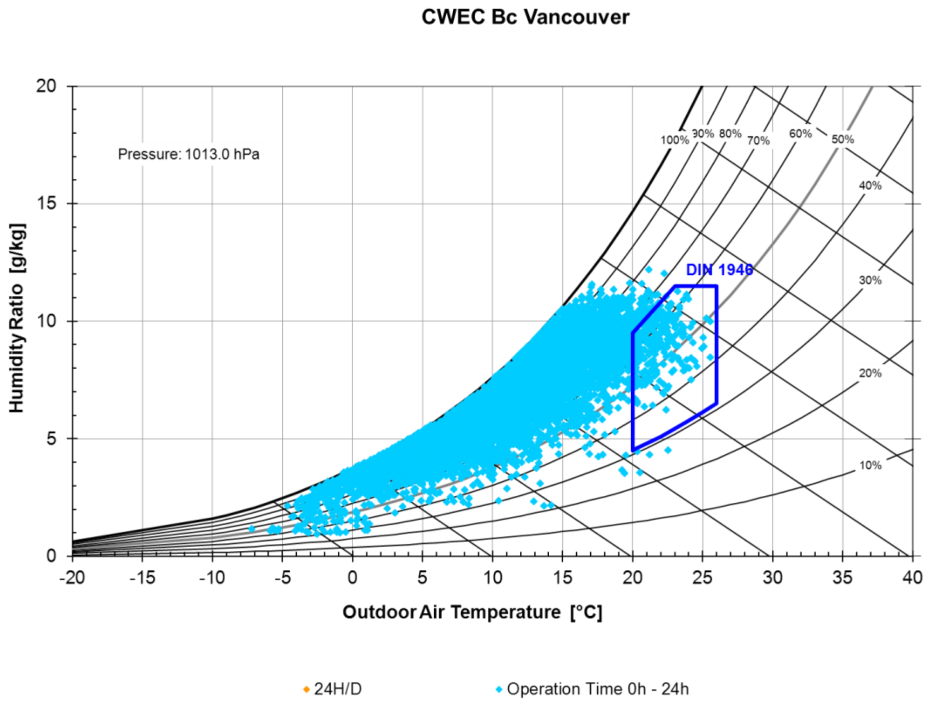

Figure 12: Annual Psychometric Chart

The wind situation in Vancouver is somewhat counter intuitive, as with a large body of what one would expect the majority of winds to come from the ocean. However the impact of Vancouver Island and Puget Sound seem to change the expected situation. Instead the majority of wind, none of which is particularly strong, comes from the East. Transsolar examined measured wind data from the Vancouver airport for the last five years and discovered some interesting patterns.

The first as mentioned and shown in Figure 13 highlights that most wind comes from the East throughout the year, with some wind coming from the West. The light blue coloured area indicates winds with speeds between 0.5 m/s and 3.5m/s which are relatively light and not sufficient to even start a wind turbine for example. It is clear that the majority of all winds are less than 3.5m/s. As noted above the low speed winds will likely vary around the site based on the buildings in the surroundings and the large open road to the south.

In order to understand wind direction during different seasons, hourly wind direction and velocity was examined when temperatures were below 6°C (Figure 14), above 10°C (Figure 15) and the hours during rainfall (Figure 16).

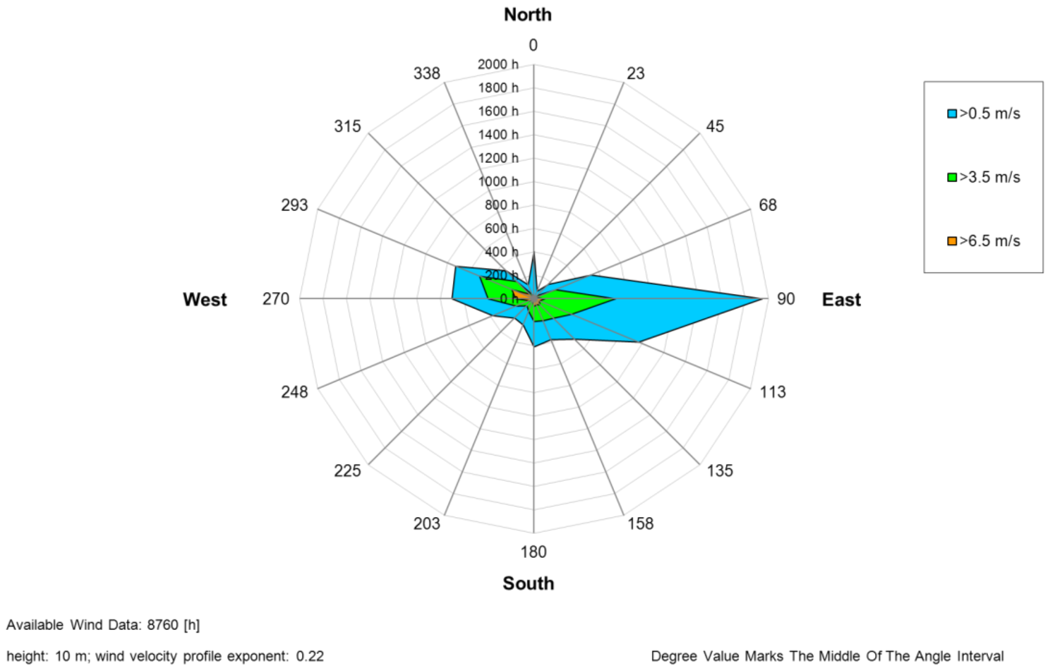

Figure 13: Annual Windrose for all Temperatures

For temperatures below 6°C (Figure 14) almost all of the wind comes from the East.

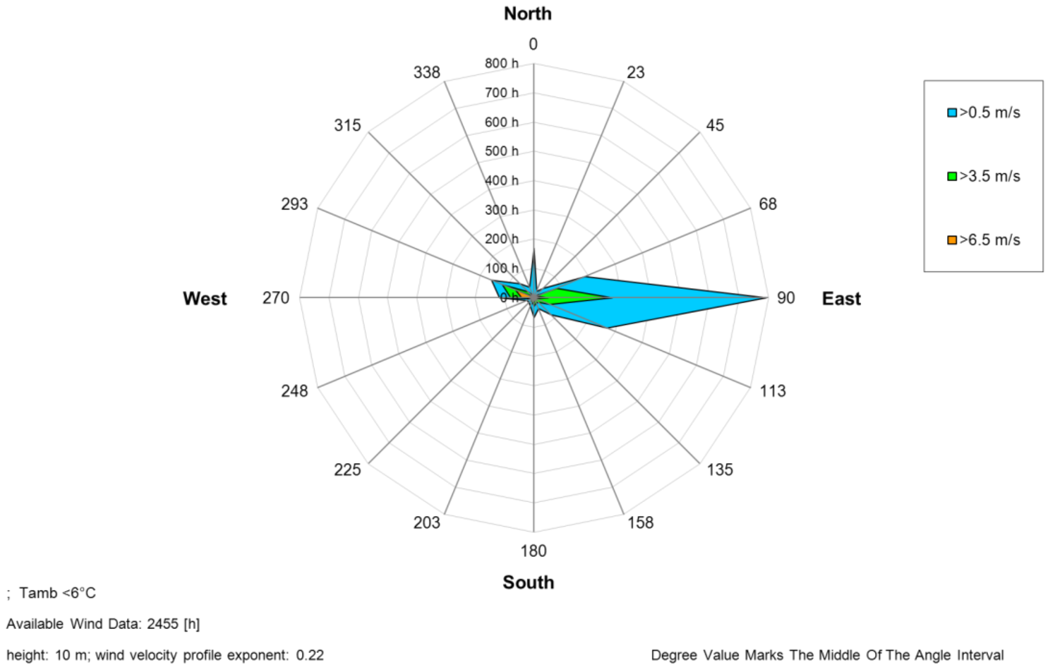

Figure 14: Cold Season: Windrose for temperatures below 6°C

At temperatures above 10°C (Figure 15) the wind hours maintain an East – West pattern.

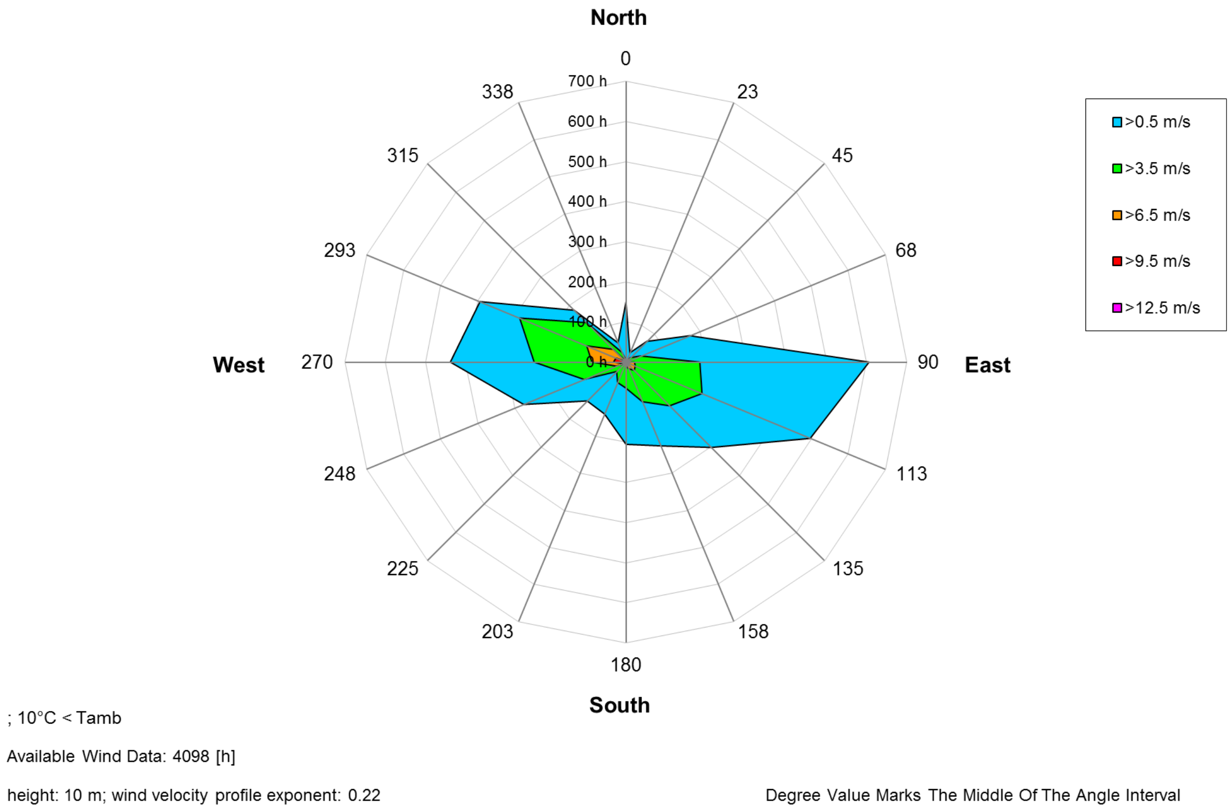

Figure 15: Shoulder Seasons and Summer: Windrose for temperatures above 10°C

In order to further support the exploration of intervention possibilities with respect to outdoor spaces, the wind profiles for the times when there was rain were also studied. When it rains the wind comes almost exclusively from the East. The design implications of this are such that an outdoor rooftop space needs to be protected primarily on the east side of the building.

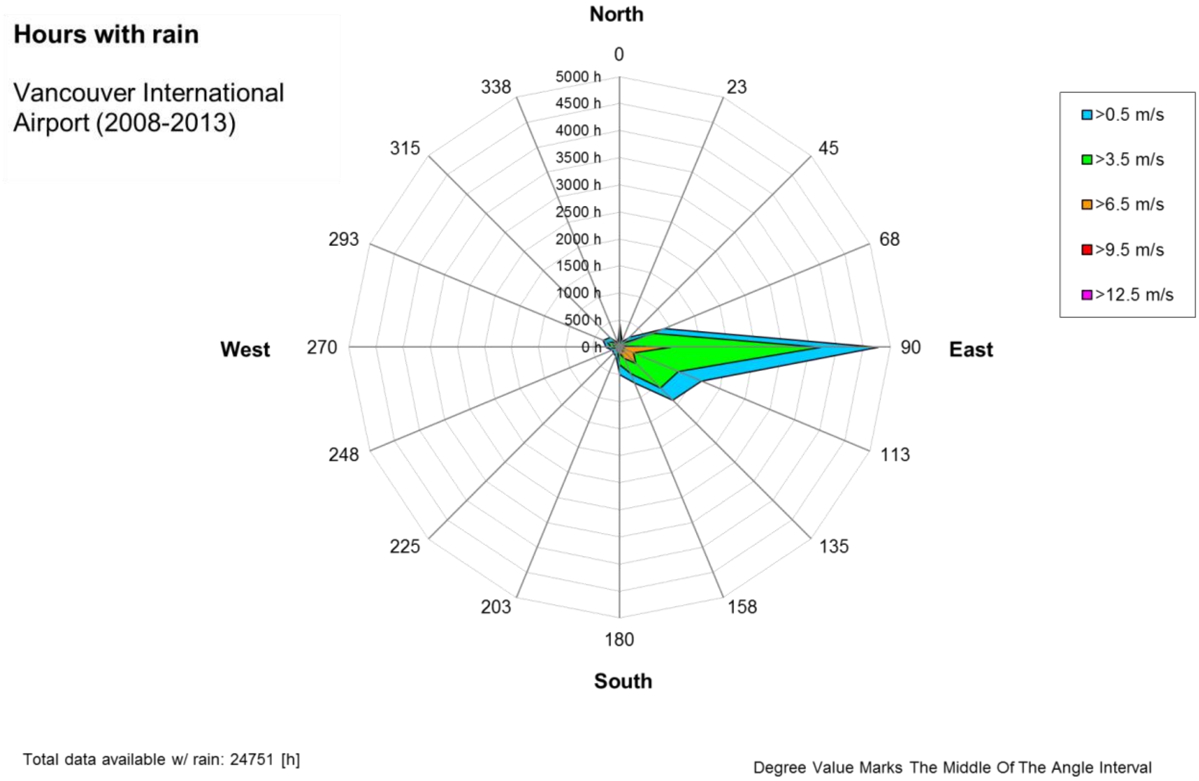

Figure 16: Windrose for all temperatures when it is raining

Overall the climate has few extremes and favours natural ventilation and some mild heating during the winter season. Currently, the impact of wind is minor due to the orientation and structure of the building, but should be considered if a new roof patio or south based entrance is developed as the winds from the east would then have a bigger impact.

Because the BCIT measured temperature data does not have all of the information required to perform a thermal simulation, the CWEC data from YVR was used. Although there are differences with respect to high ambient temperatures in the summer, the majority of the data is consistent between YVR and BCIT. A validation of using this data, based on the overall energy reduction potential, is presented in section 7.

3. NE01 Current State

3.1. Energy Breakdown

In order to identify interventions for the NE01 Upgrade, a holistic understanding of the building's energy systems and consumption levels was needed. By pulling details from equipment inventories (see Appendix 1), building audits, energy metering data, and personal experience of the occupants, Transsolar broke down the total energy consumption of the building by demand type, as seen in the figure below. Three main assumptions were made:

1. Electricity consumption was increased by 10% due to gaps identified in the recorded data
2. A 75% efficiency factor was assumed for the district heating and local natural gas boilers
3. Ventilation runs at full capacity in all spaces during occupancy hours (8:30 am – 9:30 pm)

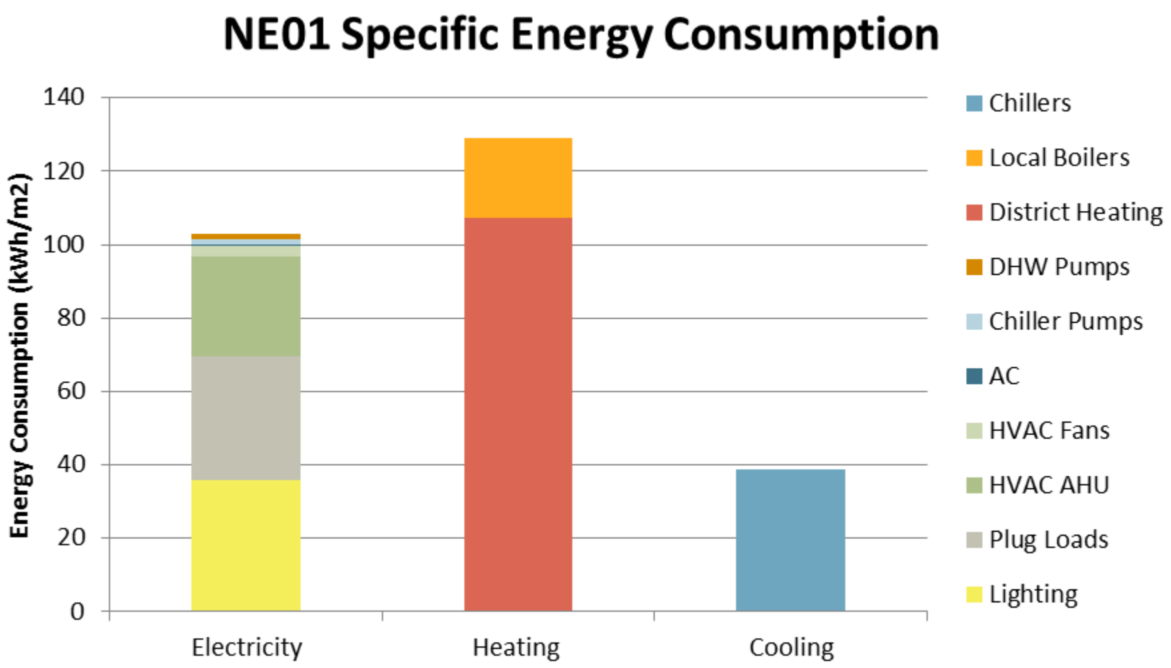

Figure 17: NE01 Energy Breakdown

Three major energy sinks for the building can be identified by looking at this data: high heating, cooling loads, and high electrical loads for HVAC. Given the mild temperatures experienced in Vancouver, the use of natural ventilation is possible to reduce these energy loads significantly. Based on the calculations made, the total energy consumption of NE01 is 270 kWh/m^2. This number represents average energy consumption, but does not reflect the variation in energy usage by program type (i.e. classrooms vs. corridors). In Figure 18, the energy consumption of NE01 is directly compared to energy consumption averages of other university campus buildings in British

Columbia, as well as other BCIT averages. Although NE01 appears to be in good standing, by taking into account the relatively low occupant and energy intensive lab space density compared to other university campus buildings, NE01's energy consumption has the potential to be reduced significantly. NE01's comfort levels are also very low, therefore a larger energy demand should be assumed to reach good occupant comfort.

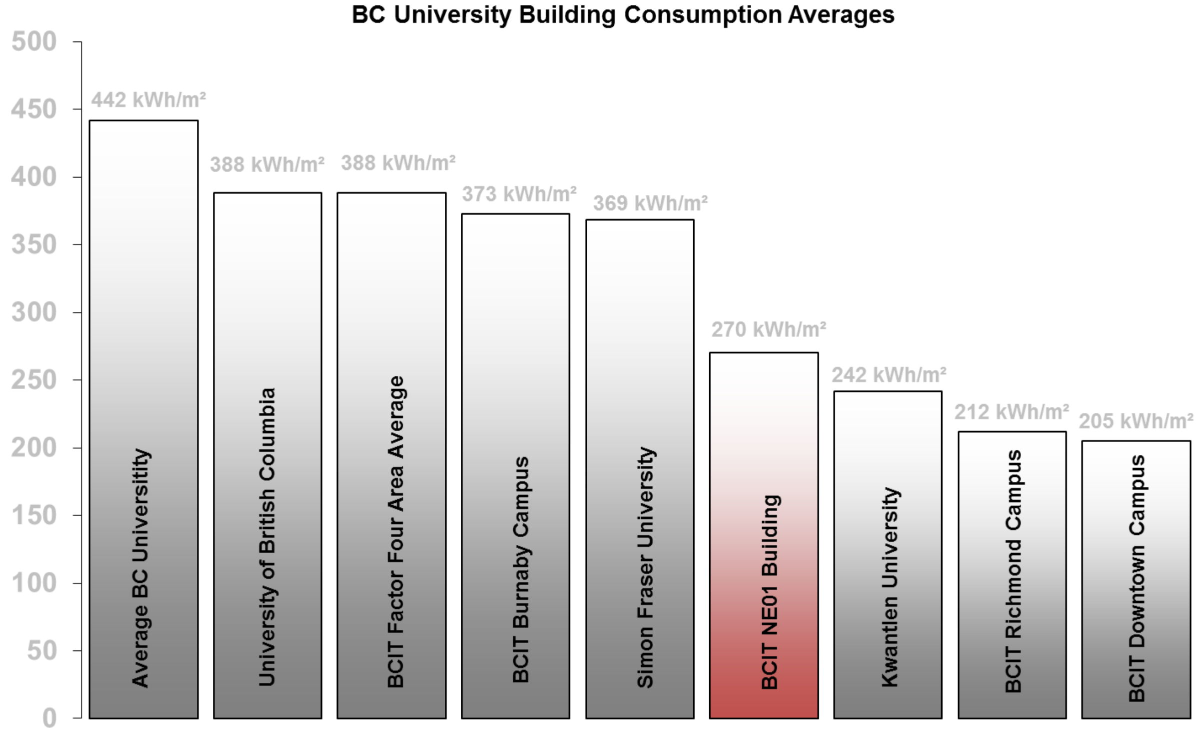

Figure 18: NE01 Building Consumption Compared to BC Campus Averages

3.1.1. Heating, Ventilation, and Air Conditioning (HVAC)

Due to renovations on the HVAC system since NE01 was built, the state of the system is not very clear. Based on equipment inventories and building reports Transsolar has developed a basic understanding of the HVAC system, a simplified version of which can be seen in Figure 19. It is important to note that this may not represent the system building-wide due to information that may be missing.

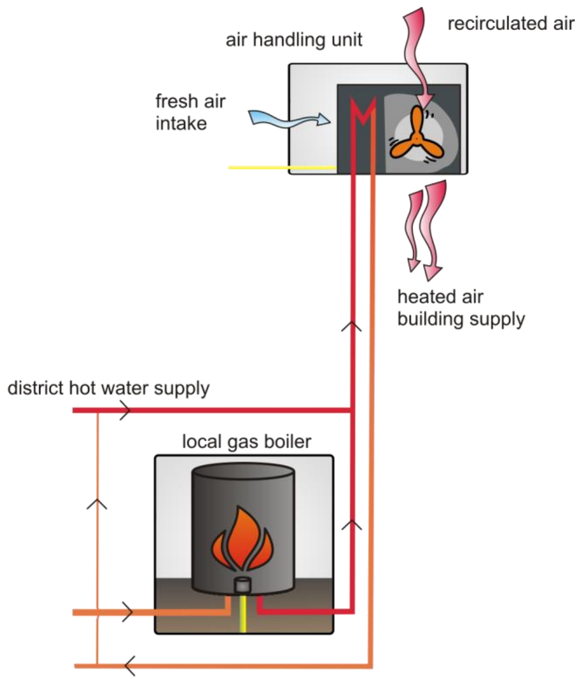

Figure 19: Simplified NE01 HVAC System Set-Up

The building has an all-air conditioning system, where the fresh air intake is heated to a base temperature in two central air handling units (with coils or heat exchangers), and then further heated at the local outlets by re-heat/cool coils. This heat is supplied by hot water from the district hot water system, as well as supplemental local natural gas boilers (see energy consumption details in Table 1). In the summer, the air is cooled using local chillers and several air conditioning units. The heated or cooled air is then circulated using supply and exhaust fans. The main supply air handling units appear to use recirculation of air to reduce total energy consumption. The setting and calibration of these units is unclear. It is possible that the performance of these recirculation units is contributing heavily to the poor air quality.

Table 1: Energy Consumption (gas/electricity) of NE01 Heating

Heating Source	Annual Energy Consumption (GJ)	Annual Energy Consumption (kWh)
District Heating (measured)	4923	1 367 609
Local Boilers (estimate)	1000	277 800
Local Boiler Pumps	-	15 707
Space Heaters	N/A	Included in Plug-Loads

3.1.2. Lighting

A student lighting audit was used to inform Transsolar’s calculations for total lighting electricity consumption. Based on the low lighting densities per square meter in comparison with Swiss recommended levels, shown in Figure 20, the wattage numbers in office spaces may not fully represent the current situation in NE01, but the lighting levels in the other spaces seems to be accurate. Sia is recognized for being very ambitious with their energy densities, so it is unusual to have numbers significantly below these. However, the data is difficult to verify without performing a review which may be considered as part of a living lab exercise

Area Type	Average Density [W/m2]	sia Standard Density [W/m2]	
Classrooms	11	10	
Offices	5	12	?
Workshops	12	n/a	
Drafting Rooms	13	10	
Computer Labs	13	n/a	
Corridors	5	5	
Washrooms	9	12	
Cafeteria	7	5	

Figure 20 NE01 Lighting Density by Space Type – compared to Swiss sia standard

3.2. **Operation Schedules**

In order to accurately estimate the different components of NE01’s energy consumption, the building systems hours of operation were needed. The schedules were approximated based on the measured hourly electrical consumption data, shown in Figure 21, lighting logger data, and occupant/facility manager experience.

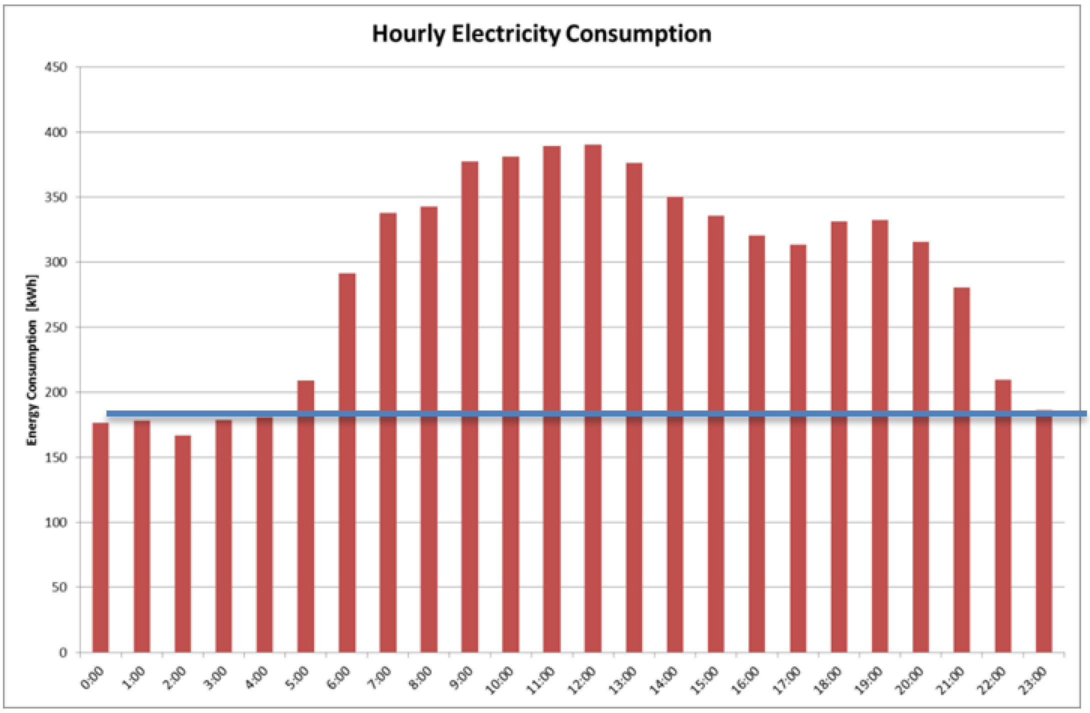

Figure 21: Metered Hourly Electricity Consumption (Weekday)

The schedules for equipment and lighting operation shown below were used to create the energy breakdown presented in the previous report section.

The heating/cooling/ventilation system operation hours (Figure 22) were estimated based on Transsolar's experience and input from the NE01 facility managers, and are based on the following assumptions:

- HVAC runs from 8:30 am – 9:30 pm, and is not occupant dependent
- Cooling is only required for roughly 6-7 hours per day over 4 months (mainly for core spaces)
- Heating hours "back-calculated" using metered data for hot water supply

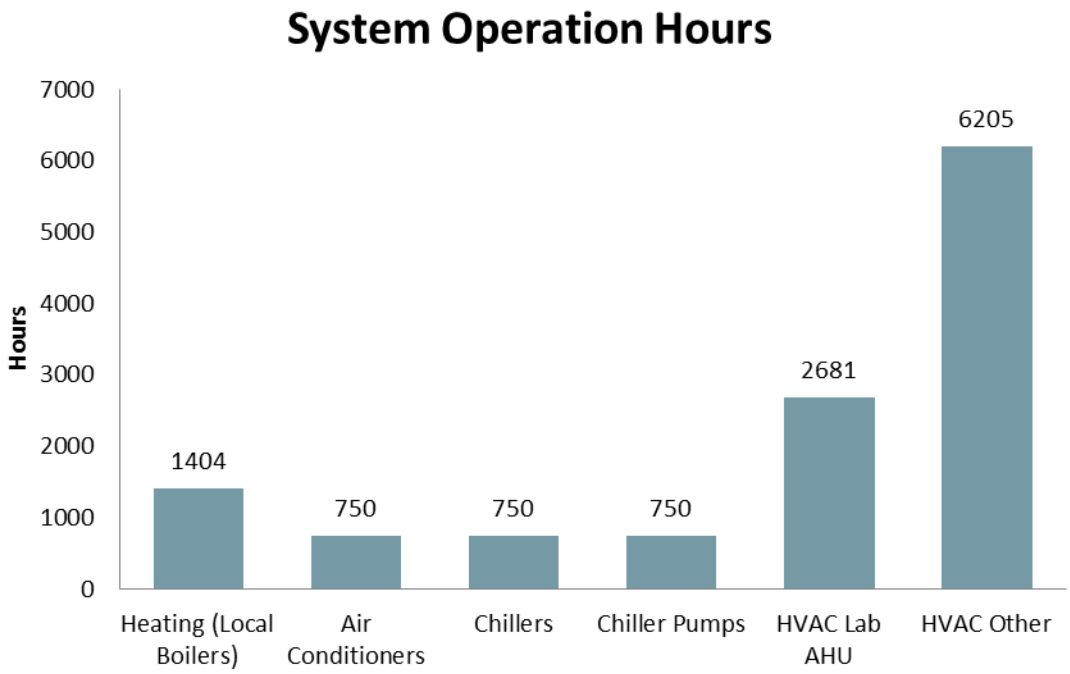

Figure 22: System Operation Hours by Year

The lighting “schedules” are represented by hours of operation per year by program type (Figure 23). A rough breakdown of lighting usage by number of hours per day and days per year was also created for clarity, shown in Figure 24. The lighting logger data was used, when available, but may not be fully representative of the annual space use as the data was measured over a two week period. Note that a typical year has 8760 hours.

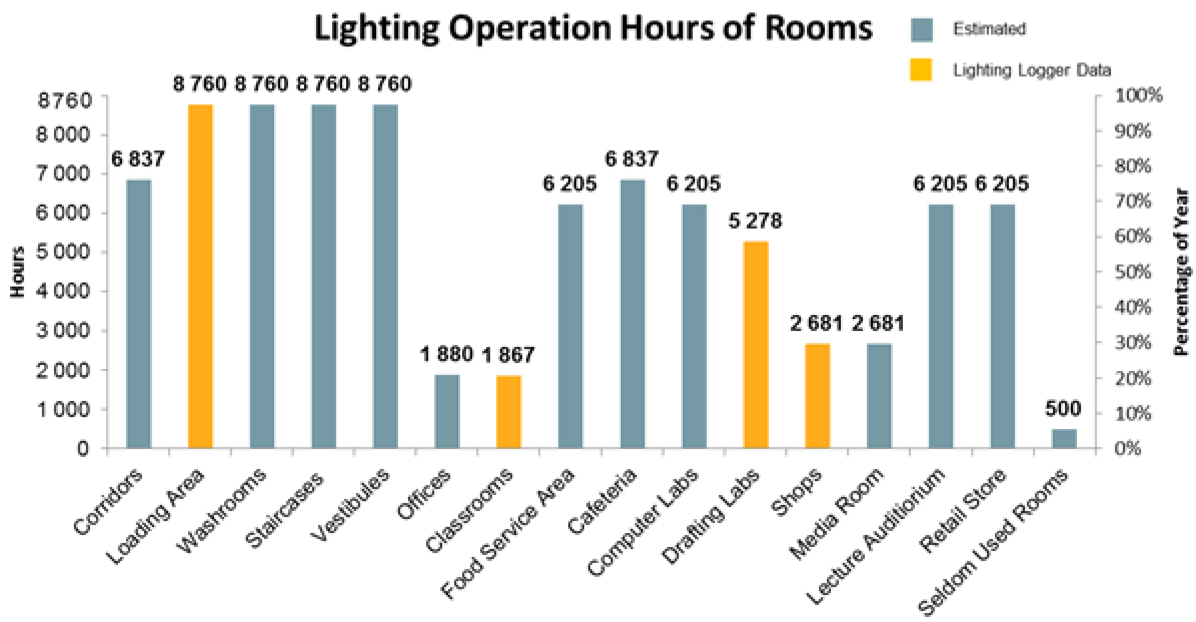

Figure 23: Lighting Hours of Operation by Year

Area Type	Hours/Day	Days/Year
Offices	8	235
Washrooms	24	365
Staircases	24	365
Corridors	17	343
Cafeteria	17	343
Drafting Rooms	15	343
Classrooms	8	343
Unused classrooms	2	246
Shops	8	343
Food Services	17	343
Computer Labs	16	343

Figure 24: Lighting Hours of Operation by Hours/Days

3.3. Room-Level Current State

3.3.1. Energy Calculations

NE01's specific energy densities throughout the building were further studied to gain a better understanding of the energy consumption by space type. Rooms within the core will have different heating and cooling demands than rooms along the façade, or with access to windows. In addition, different program types, such as classrooms, offices, and workshops, will require different levels of energy based on the activities carried out, the occupancy density, and occupancy schedules. To estimate these differences, and understand the energy consumption of a classroom on the façade of the building (which represents the highest heating demand of the building), the average specific energy demand of the building (cooling, heating, electricity) was adjusted using weighted factors based on use and needs.

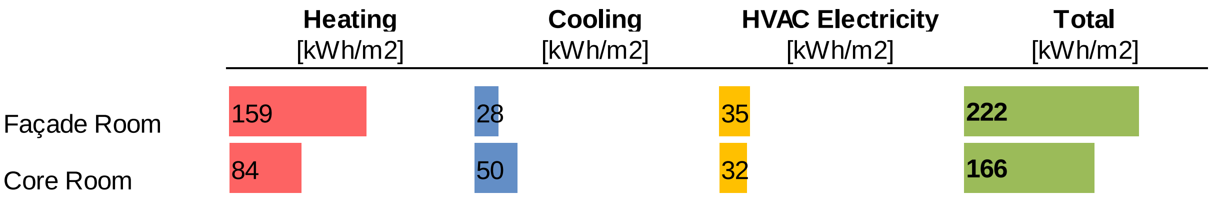

Figure 25 Adjusted Demand for Facade and Core Spaces

3.3.2. Classroom Level Energy Simulation Base Case

A one zone thermal simulation was performed to gain a better understanding of the building conditions, and to predict the impact of interventions on classroom level comfort and energy consumption.

A classroom on the North façade (Classroom 209) was used to set the zone geometry and general boundary conditions for the classroom simulation. A large part of the work conducted involved ensuring that the specifications and boundary conditions represented a closely the current reality. The following boundary conditions are an aggregation of the input from the workshop, drawings, information from staff and facilities, as well as Transsolar's extensive experience with buildings.

The boundary conditions are outlined in the three tables below.

Table 2: Classroom 209 General Description

Site	**Orientation**	**North**
Weather	Weather Data Source	cwec_vancouver
Building Geometry	Floor to Ceiling Height	4.3 m
	Floor Area	7m x 10m
	Window Area	(.6 x 3 m) x 2
Occupancy	Maximum Occupancy	24 persons

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Table 3: Classroom 209 Material Specifications

Structure Type	Material	U-Value	Thickness
External Wall	Pre-cast concrete 3 cm wool insulation Drywall	1.610 W/m^{2}K	.164 m
Internal Wall	Concrete block	2.321 W/m^{2}K	.113 m
Floor	Pre-cast concrete	3.053 W/m^{2}K	.178 m
Ceiling	Pre-case concrete	3.053 W/m^{2}K	.178 m
Window	Single glazing	5.68 W/m^{2}K [SHGC = .855]	N/A
	Aluminum Frame	4.16 W/m^{2}K	N/A

Table 4: Classroom 209 Loads

Load Type	Description	Load Specification
Occupancy	Occupancy Density	3 m^2/person
	Sensible Load due to metabolic rate	75 W
	Latent load due to metabolic rate	75 W
	Occupancy Schedule	See Figure 26
Lighting	Minimum Lighting Levels	300 lux
	Lighting Control	Occupancy Schedule
	Average Lighting Power Density	13 W/m^2
	Convective Part	40%
Laptops	Power	50 W
	Laptop Control	Occupancy Schedule [1/2 people]
Ventilation	Air Supply Flow Rate	1266 m^3/hour
	Ventilation Schedule	8:30 am – 9:30 pm
Economizer	Mix Set Temperature	15°C
	Minimum Outdoor Air Supply	2 ACH (774 m^3/hour)
Infiltration	Constant Infiltration Rate	.2 ACH
Heating	Heating Type	all air ideal heating
	Daytime Set Point Temperature	21°C Air Temp.
	Nighttime Set Point Temperature	15°C Air Temp.
Cooling	Daytime Set Point Temperature	24°C Air Temp.

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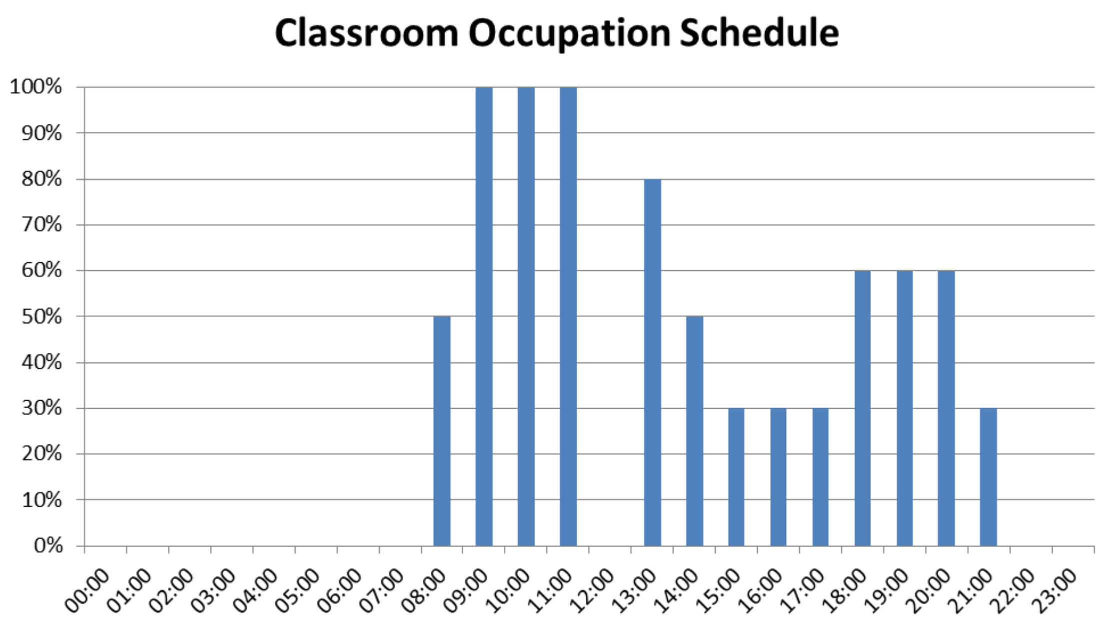

Figure 26: Approximated Classroom Occupation Schedule

The first simulated case represents the state of a regular classroom on the North Façade of NE01. The energy density of the classroom for both heating and HVAC electricity demand matches the adjusted specific energy consumption of a space on the facade. The cooling, however, does not align with the calculated values. In the simulation using BCIT measured weather data, a cooling load similar to the predicted is seen. However 2009 was an unusually hot year and doesn't reflect the norm. There are many unknown factors surrounding the cooling within NE01, including set point temperatures, as well as the total cooling hours and cooling demand of the building. In addition, it is possible that cooling demand is driven due to excess pre-heating of supply air, over-cooling of the building spaces, which is difficult to approximate without additional information. The focus of the thermal simulation is mainly heating and HVAC electricity load reduction, as they represent the two largest loads

	Heating [kWh/m2]	**Cooling** [kWh/m2]	**HVAC Electricity** [kWh/m2]	**Total** [kWh/m2]
Calculated Values	159	28	35	**222**
Simulated Values Current State	164	2	32	**198**

Figure 27 Energy Demand Comparison of Calculated and Simulated Current State

In the final calculated energy reduction, the cooling levels simulated using the 2009 BCIT data, and the subsequent reduction due to the recommended interventions, is applied to the façade classroom simulation results.

The simulated comfort levels also align with the current comfort expressed by occupants in NE01. Occupants in a space experience comfort not only through the air temperature of the room being within an acceptable range, but through the influence of the surface temperatures that the person is exposed to and the speed of air flow in the space. The surface temperatures of windows, walls, ceiling and floor contribute to the radiant temperature experienced by the occupant. This combination of air and radiant temperature form the operative temperature, which is the temperature that the user will experience. This applies as long as the speed of air movement is less than 1m/s. Meeting DIN EN 15251, the German thermal comfort standard, which closely maps ASHRAE 55, means keeping maximum indoor operative temperatures between 24°C and 28°C based on outdoor temperatures. Minimum indoor operative temperatures should similarly be between 20°C and 24°C. As shown in Figure 28, a large portion of occupied hours fall outside of the DIN comfort zone. The use of personal space heaters in NE01 throughout the winter confirms these results.

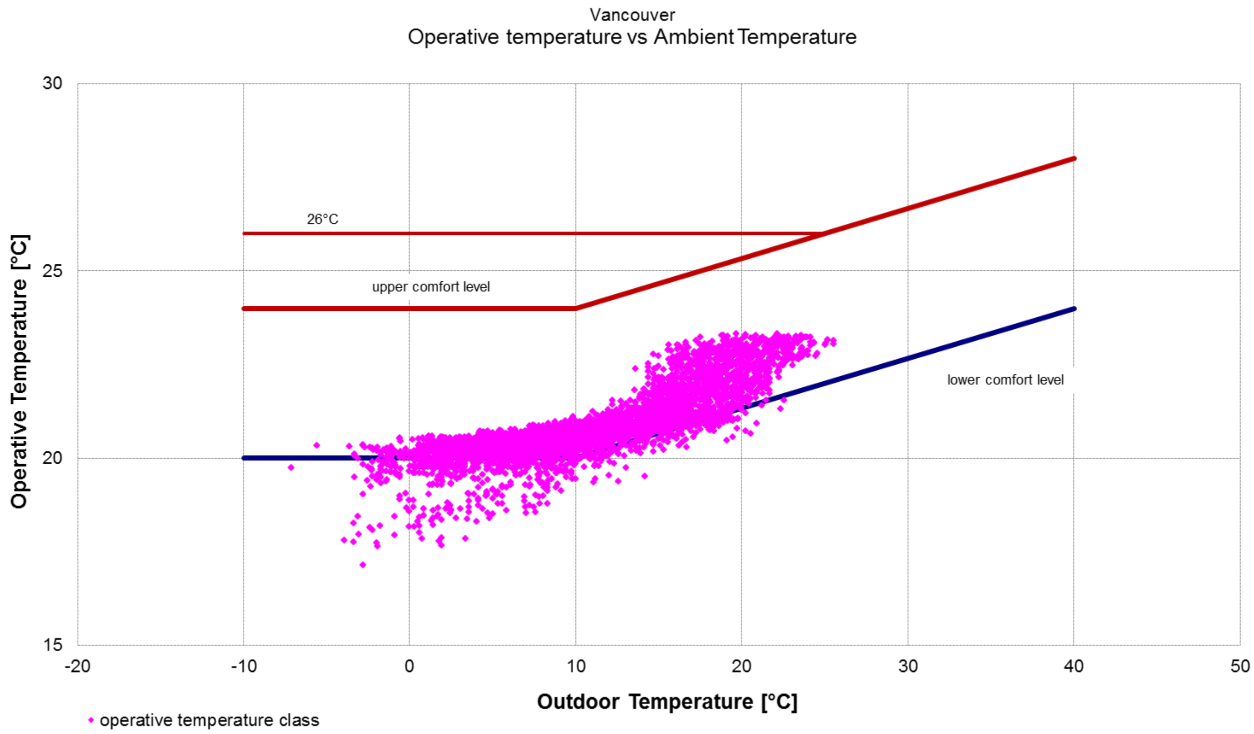

Figure 28 Thermal Comfort Visualization of Current Classroom Conditions

There is also poor air quality (expressed by user) which is assumed to be a results off the high recirculation rate of return air in the air handling units. The state of the air ducts, moisture, cleaning of the ducts and such is not known and could be an investigation for the living lab.

In order to compare interventions, Transsolar has created a new “base case,” which better represents the energy consumption of NE01 if operated to a good comfort standard. This “base case” has the same boundary conditions outlined for the “current state case,” but with no recirculation of exhaust air (ventilated with 100% outdoor air), an extended operation schedule, and an adjusted set point temperature for heating based on operative rather than air temperature.

Table 5 Base Case Classroom Simulation Boundary Conditions

Load Type	Description	Current Case	Base Case
Ventilation	Air Supply Flow Rate	1266 m^3/hour	1266 m^3/hour
	Ventilation Schedule	8:30 am –9:30 pm	8:00 am –10:30 pm
Economizer	Mix Set Temperature	13°C	N/A
	Minimum Outdoor Air Supply	2 ACH	100% Outdoor Air
Heating	Daytime Set Point Temperature	21°C Air Temp.	21°C Operative Temp.
	Nighttime Set Point Temperature	15°C Air Temp.	15°C Operative Temp.

By changing this set point control, the radiative cooling from the external wall is taken into consideration. Figure 29 shows the improved thermal comfort in the space and the increase energy consumption due to the elimination of recirculation air.

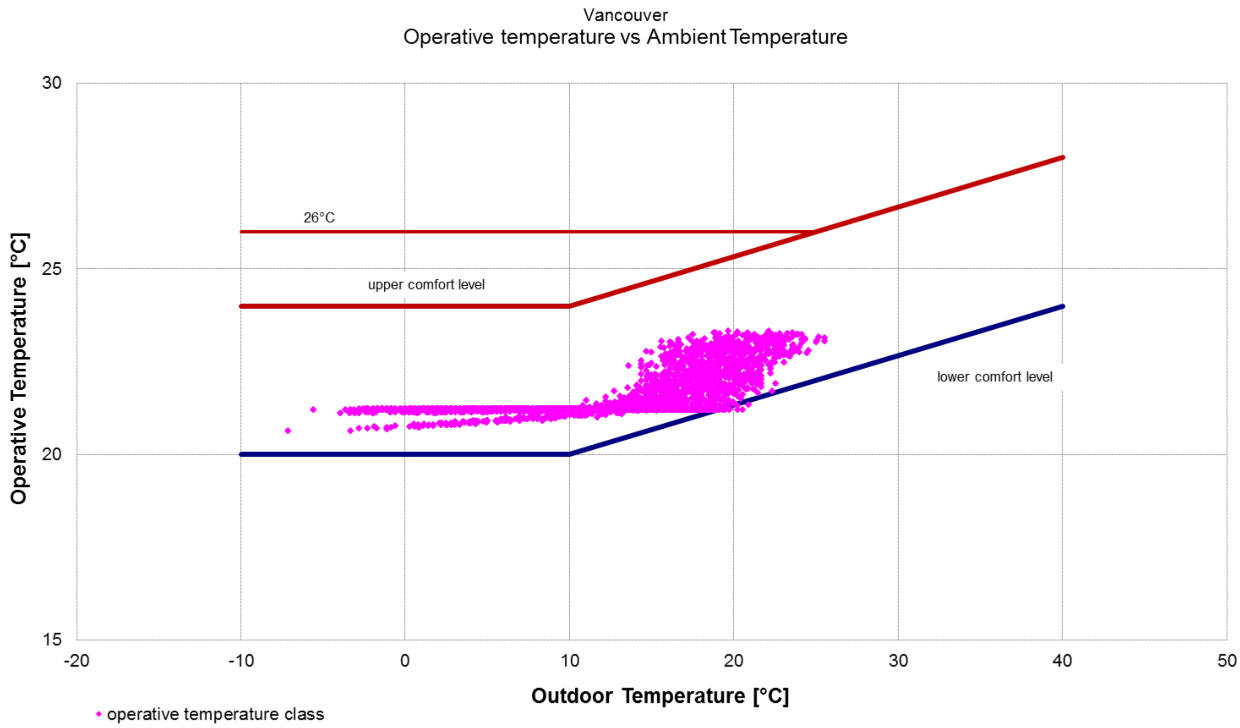

Figure 29 Thermal Comfort Visualization of Comfortable Base Classroom Conditions

This case represents the energy demand needed for the building to operate in a way that creates a reasonable level of comfort, meeting ASHRAE 62.1 and 55 standards for air quality and thermal comfort, with the existing system and building construction. If operated this way, the façade room-level energy consumption increases by 106kWh/m^2 from the current case, as shown in the figure below. On a building level, this energy consumption is estimated at 345kWh/m^2.

	Heating [kWh/m2]	**Cooling** [kWh/m2]	**HVAC Electricity** [kWh/m2]	**Total** [kWh/m2]
Current State	164	2	32	**198**
Base Case	271	2	32	**304**

Figure 30 Energy Demand Comparison of Façade-Room Simulated Current State and Base Case

The energy consumption values shown above are used to compare the potential reductions in heating, cooling, and electricity demand of the proposed interventions. All intervention results that were measured through a thermal simulation are presented on a room-level in the intervention section (4). These results are extrapolated on a building scale to get total energy reduction figures in the final recommendation section (7).

3.4. Design Charette Takeaways

A design charette was led by Joshua Vanwyck, Project Lead at Transsolar, at BCIT on Wednesday March 12th to engage with students, faculty and facility managers to gain a better understanding of the building systems, occupant comfort issues, and to explore potential intervention ideas. There was discussion surrounding the frequent low occupancy density in certain parts of the building, as well as the lack of user control with respect to ventilation, temperature, and lighting. New insights with respect to air quality, thermal comfort, and visual comfort were uncovered (full notes in Appendix C):

Air Quality

- Poor air quality (reference to 1st floor corridor)
- Ventilation turned off at 8pm
- Generally stale air
- Complaints of headaches after being in building too long

Thermal Comfort

- Overheating in cafeteria atrium (during sunny periods)
- Cold in winter near façade (single-paned windows)
- Need for extra heaters
- Overheating in some areas and overly cool in other areas.

Visual Comfort

- Low lighting levels and flickering (fluorescent bulbs)
- Glare from windows
- Poor connection to the outside

The discussion and takeaways from the design charette have informed Transsolar's proposed intervention ideas and recommendations, discussed later in this report.

4. Intervention Possibilities

In this section, possible interventions for NE01 are explored. An explanation of the intervention and its purpose is given, and the potential reduction (cooling, heating, and electricity) of each intervention is shown. The interventions are split into two main categories: baseline and large-scale interventions. The baseline interventions are less complex interventions which can be carried out incrementally if desired. The large-scale interventions involve renovations to the building structure of systems, and must be carried out building-wide. The intervention section serves the purpose of outlining possible actions that BCIT can take in order to improve the quality of the NE01 building, but are not recommendations in themselves. This is due to the fact that some interventions are meant to be implemented in tandem, due to important synergies. For example, while implementing natural ventilation in NE01 with the existing all-air ventilation system does raise comfort levels to a certain extent, it is much better suited in combination with a separated ventilation and conditioning system.

4.1. Baseline Interventions

4.1.1. Utilize Natural Ventilation: Operable Windows on Façade

The mild Vancouver climate could be utilized to provide natural ventilation to all façade facing areas and potentially those connected to the atriums for up to 48% of the year through the addition of sufficient operable windows, as shown below.

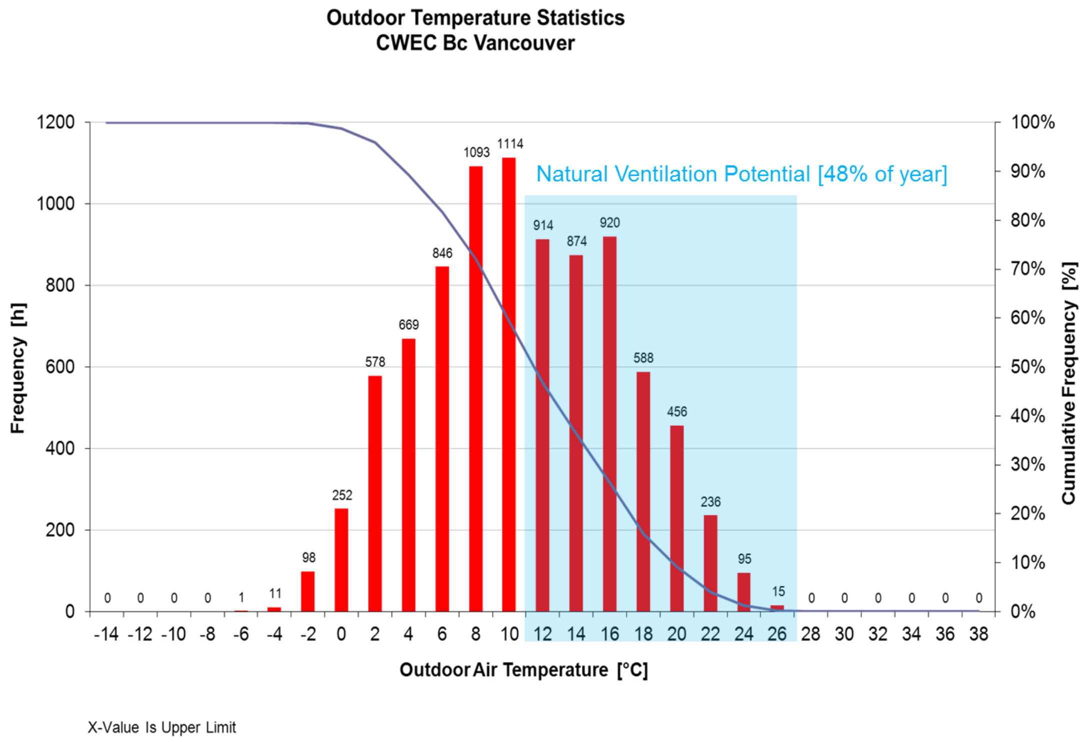

Figure 31: Natural Ventilation Potential based on Outdoor Air Temperature

On top of improved air quality, energy consumption can also be reduced by turning off the mechanical ventilation or running fans based on CO2 levels.

Two room-based thermal simulations were performed to measure the impact of natural ventilation on the energy consumption and comfort of a classroom space along the facade. The first variation was based on daytime natural ventilation only. The second variation added nighttime flushing of the space, taking advantage of Vancouver's cool summer nights and the thermal mass potential of the exposed concrete in the room to pre-cool the room. The use of natural ventilation is based on user control. The simulation controls for natural ventilation (windows opened), shown in Table 6, are based on experience with the behavior of occupants in manually operated naturally ventilated buildings. Providing information in spaces with operable windows, such as which ventilation mode is on (mechanical vs. natural) or CO2 sensors, encourages users to control the comfort in their space more effectively. Having students test use of operable windows and average CO2 levels in rooms with windows could be an interesting topic for the Living Lab.

Table 6 Natural Ventilation Simulation Boundary Conditions

Variation	Load Type	Description	Load Specification
Base	**Mechanical Ventilation**	Mechanical Ventilation Turn-off	None (schedule based)
	Natural Ventilation		None
	Cooling	Mechanical Set Point Temperature	24°C

	Night Flushing		None
Natural Ventilation	**Mechanical Ventilation**	Mechanical Ventilation Turn-off	between 14°C < Tamb < 26°C
	Natural Ventilation	Daytime Schedule	8:30 am – 9:30 pm [occupation based]
		Windows Opened Manually [Fresh Air Supply]	14°C < Tamb < 20°C For 6 minutes every hour
		Windows Opened Manually [Fresh Air Supply]	20°C< Tamb < 26°C always open
		Window Opened Manually [Cooling]	TopRoom > 23°C & Tamb > 15°C
	Cooling	Mechanical Set Point Temperature	None
+Night Flushing	**Night Flushing**	Nighttime Schedule	9:30 pm – 8:30 am
		Windows Opened Manually [Cooling]	TAirRoom > 23°C
		Windows Opened Manually	Tamb > 14°C

*Tamb = outdoor air temperature

Based on the assumption that mechanical ventilation is turned off when natural ventilation is possible, a reduction in heating, and electricity demands of 9% is possible on one-room level, as shown in

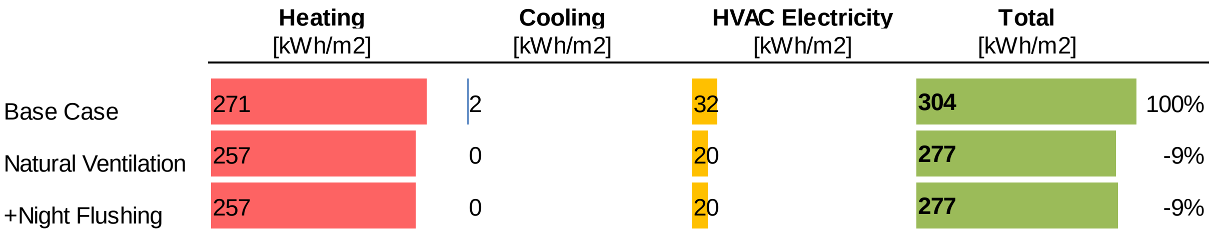

Figure 32. Cooling is not need as windows can be opened when overheating is experienced.

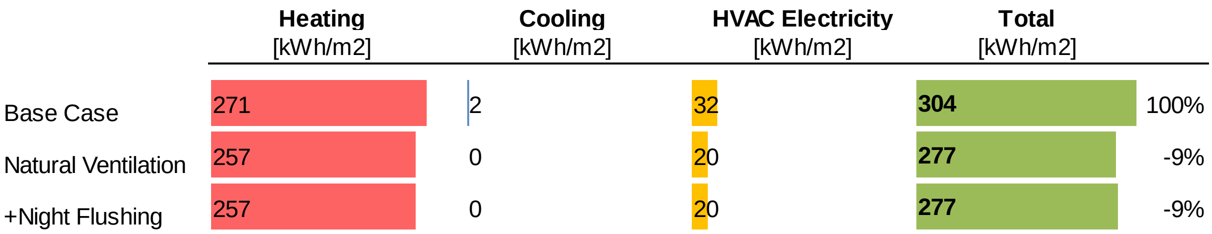

Figure 32: Potential Energy Reduction using Natural Ventilation along façade

The potential energy reduction due to natural ventilation on a building level was calculated based on existing window area available on the façade. This means that the consumption of the building spaces without access to windows was unchanged.

The addition of night flushing does not increase the heating or electricity demand of the building, but will improve comfort in the summer (or reduce cooling demand) due to the cooling of the building's thermal mass at nighttime. It is important to note that user behavior is very important in implementing night flushing, as users must actively open windows before leaving the building. Electrical window controls are also possible, but this leads to high installation costs and a more complex system.

4.1.2. Reduce Heating Requirements: Increase Window Quality

Increased comfort and reduced heating requirements along the façade is possible with an upgrade in window quality, from the current single glazing to double glazed windows with lower thermal conductivity (u-value) and solar gain (g-value) coefficients. New window fixtures will reduce the radiative and conductive cooling from the window surface in the winter and shoulder seasons. Two thermal simulation variations were performed, using the boundary conditions below, to show the potential impact of double and triple glazed windows. Relatively high u-values of the frame were assumed given current availability in Canada.

Table 7 Double and Triple Glazing Simulation Boundary Conditions

Variation	Structure Type	Material	U-Value
Base	Window	Single Glazed Window	5.68 W/m^{2}K [SHGC = .855]
	Window Frame	Aluminum	4.16 W/m^{2}K
Double	Window	Double Glazed Window	1.27 W/m^{2}K [SHGC = .591]
	Window Frame	Aluminum	3.5 W/m^{2}K
Triple	Window	Triple Glazed Window	0.59 W/m^{2}K [SHGC = .451]
	Window Frame	Aluminum	3.5 W/m^{2}K

	Heating [kWh/m2]	**Cooling** [kWh/m2]	**HVAC Electricity** [kWh/m2]	**Total** [kWh/m2]	
Base Case	271	2	32	**304**	100%
Double Glazing	253	2	32	**286**	-6%
Triple Glazing	251	2	32	**285**	-6%

This intervention fits naturally with the utilization of natural ventilation, as window replacements are necessary for both interventions. As seen above, the improvement between double glazing and triple glazing is minor.

4.1.3. Reduce Heating Requirements: Exhaust Heat Recovery

The implementation of a heat recovery system in NE01 has the potential to reduce heating requirements significantly, while keeping a high level of air quality. Heat recovery utilizes exhaust heat from the building without mixing the exhaust air back into the air supply. The need for replacing the current HVAC system before the end of the building's useful life has also been indicated, presenting an opportunity to integrate this intervention into that renovation.

The following two heat recovery systems should be investigated based on their potential for implementation and energy reduction:

1) Direct heat recovery by placing the intake and exhaust in parallel to facilitate heat exchange
2) Indirect heat recovery using a run around loop to transfer heat from the exhaust to the intake

The impact of installing a 70% efficiency heat recovery unit has been calculated through the classroom thermal simulation, the results of which can be seen below.

Table 8 Heat Recovery Simulation Boundary Conditions

Variation	Load Type	Description	Load Specification
Base	Heat Recovery	N/A	none
Heat Recovery	Heat Recovery	Set Point Temperature (for Bypass)	18°C
		Efficiency	70%

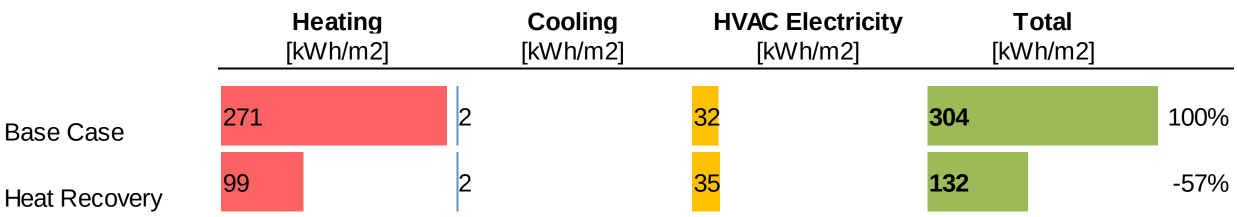

Figure 33: Potential Total Energy Reduction Based on 70% Heat Recovery

4.1.4. Instant Water Heaters for WC Hot Water Supply

Some of the documents suggested the need to replace the hot water piping for sanitary systems. Transsolar would recommend the elimination of hot water piping to bathrooms and simply provide instantaneous hot water heating in each bathroom.

In order to avoid situations with legionella, normally hot water systems should at least once a day or week raise the temperature of the entire system to 60°C, this then must also be recirculated throughout the building leading to significant losses. Studies of instantaneous hot water heaters, which take cold water just before the sink and heat it using electricity have shown energy reductions of up to 85% on domestic hot water demand for offices and schools.

It will be essential to confirm that the electrical systems have sufficient capacity to provide the heat required, but normally this is not an issue.

Some example manufactures include:

- Stiebel Eltron (http://www.stiebel-eltron-usa.com/dhc.html)
- CLAGE (http://www.clage.com/en/product-range/mini-instantaneous-water-heaters/produktlist.php)

4.1.5. Improve Daylight Autonomy: Light Redirection

Improving access to daylight along the façade would greatly improve the visual comfort of occupants. Increasing the reflectivity of the fins along the façade of NE01 (white reflective paint) was explored as a possible simple intervention. In order to significantly reduce artificial lighting demand, a daylight factor of greater than 3% is considered ideal. A 3% daylight factor corresponds to 300 lux of light on a desk surface on a cloudy day with a uniform sky producing 10,000 lux. This is considered sufficient for most detailed desk activities.

The below results demonstrate the effects of increasing the fin reflectivity. Due to the limited window surface area, the average daylight factor in the space is not greatly affected by this change.

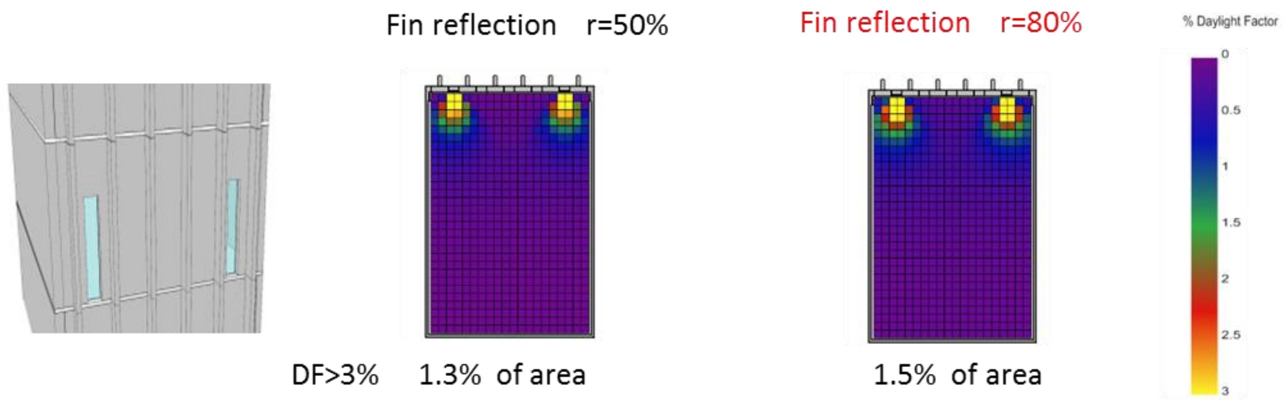

Figure 34: Daylight Factor Study Results – base case with lightened fins

On the other hand, if this intervention is paired with an increase in window number and area then more significant impacts can be achieved. Although, structurally this option is in question, it is clear that by opening more windows in the space a significantly improved natural lighting situation can be achieved.

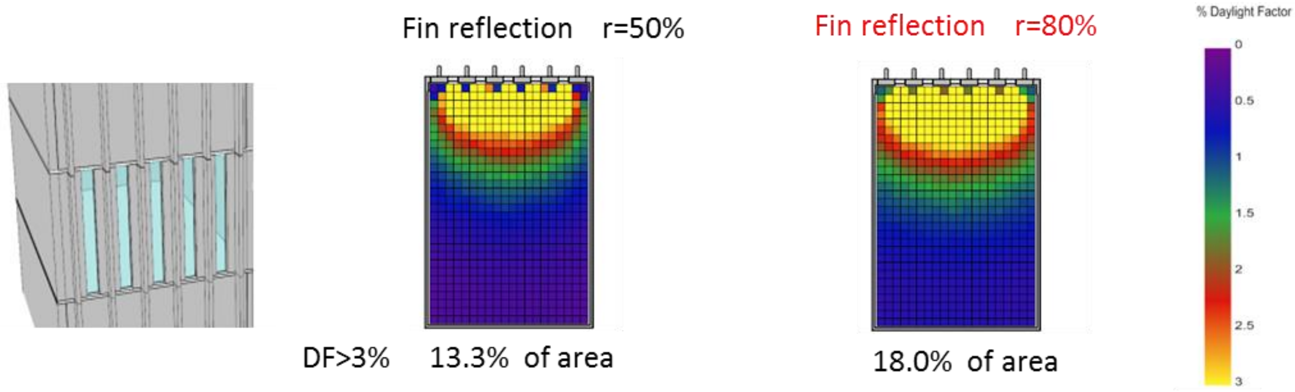

Figure 35: Daylight Factor Study Results - 5 extended windows with lightened fins

4.1.6. Reduce Lighting Electricity Consumption: Lighting Controls

The use of lighting controls is limited in NE01, and many existing sensors are not functional or not properly controlled. By installing lighting controls, and identifying the proper control settings for different space / program types, excess lighting can be minimized. Three different sensor types are recommended for different spaces.

1. Vacancy sensors will only turn off lights in a space, requiring the user to turn lights on when entering a room. These sensors are suitable for classrooms or offices.
2. Occupancy sensors function in the opposite way (lights turn on due to movement) and are better to use in common spaces, such as corridors and staircases. They should also be used in workshops to enable supervision of students when they enter the space. They typically also turn off on their own after a period of time unless occupancy is detected.
3. The third sensor type is sensitive not to occupation, but to daylight. These sensors can be used in spaces with window access, such as the atrium or external facing staircases, and reduce the need for artificial lighting when natural daylight is sufficient.

The potential reduction in electricity consumption has been calculated for individual interventions in the corridors, bathrooms, workshops, offices, and classrooms based on feedback from the design charette and experience with lighting controls. The proposed controls are shown in Table 9, with corresponding energy reduction numbers (compared to current electricity consumption of the space) in the figures below. The current operation hours of the classrooms is questionable, as this lighting logger data was measured based on a two week period, which may not be representative of the true lighting use for the whole year (exam period, vacation, etc.). This has resulted in an increase in electricity demand for the classroom spaces, with the proposed operation hours based on the occupancy schedule of the building.

Table 9: Lighting Operation and Controls

Space Type	Current Operation Schedule	Current Operating Hours	Proposed Controls	Control Type	Proposed Equivalent Operating Hours
Classrooms	Based on lighting logger data	1,867	Lighting off after 10-15 minutes of no occupation	Vacancy	2,160
Offices	5 hours/day 5 days/week 47 weeks/year	1,880	Lights off when no occupation	Vacancy	940
Workshops	Based on lighting logger data	2,681	10% lighting after 20-30 minutes of no occupation [on full 5 hours/day; dimmed 2 hours/day for 6 days/week]	Occupancy	1,540
Corridors	24/7 365 days/year	8,760	10-25% lighting after 10-15 mins of no occupation	Occupancy	2,570
Washrooms	24/7 365 days/year	8,760	lighting off after 10-15 minutes of no occupation	Occupancy	2,160
Cafeteria	14.5 -18 hours/day 7 days/week 50 weeks/year [33% dimmed otherwise]	5,341	Off during daylit hours or 10% after 10-15 minutes of no occupation Off at night	Occupancy Light	800
Staircases	24/7 365 days/year	8,760	10% dimmed when daylit (external staircases) or unoccupied	Occupancy Light	3,070
Vestibules, Loading	24/7	8,760	10% dimmed after 10-15 minutes of no occupation	Occupancy	2,320

Area	365 days/year		Off at night		

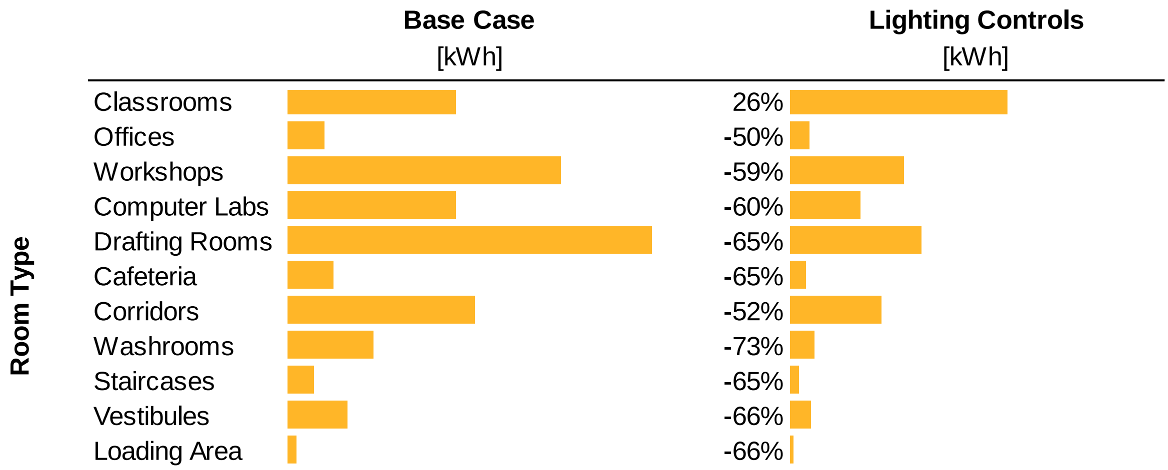

Figure 36: Electricity Reduction Potential with Lighting Controls by Space Type

The cumulative impact of these interventions on the building’s total electricity consumption (including spaces not calculated here) for lighting is shown below. Note that this assumes ideal dimming with no efficiency loss when dimming. This typically is only possible with incandescent or LED lights. Fluorescents typically are unable to dim effectively below 30% and even at that level often flicker and are not pleasing to see.

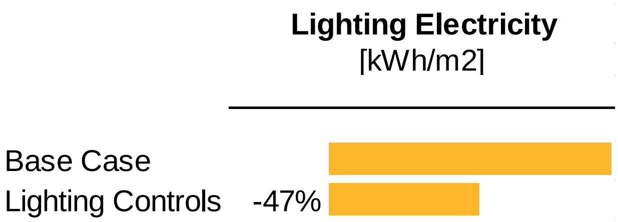

Figure 37 Lighting Controls Potenital Electricity Reduction

4.1.7. Reduce Lighting Electricity Consumption: Light bulb Retrofit

A simple strategy to reduce electricity consumption of lighting is to upgrade the quality of light bulbs used in the building. The current T8 32W bulbs have the potential to be replaced by T8 25W bulbs or LED lights (8-15W). An example of a retrofit from T8 35W to T8 25W bulbs was completed at Bradford District High School and resulted in energy savings of 84,000 kWh savings (a 19% Energy Reduction). The retrofit had a payback period of 5.2 years. The potential energy savings from T8 25W or LED retrofits for the NE01 building are shown below.

To approximate the potential reductions for both retrofit possibilities, all light bulbs with a 15W rating or higher in the building were assumed to be replaced (1:1) with new light bulbs (either 25W or 15W).

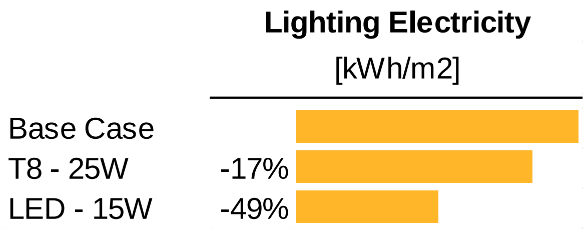

Figure 38: Light Retrofit Potential Electricity Reduction

The benefits of using LED lighting are very high in common spaces, where a dimming function or the use of lighting controls is desired. While switching lights on and off reduces the lifespan of fluorescent light bulbs significantly, LED light bulbs are not affected at all.

Measurement of existing lighting levels in the building and desired lighting levels could be conducted to determine which intervention and power density would work best. LEDs can be an expensive investment but have high payback potential in areas requiring dimming and long usage.

4.1.8. Reduce Atrium Over-Heating: Skylight Shading & Natural Ventilation

During the Design Charette and building tour, over-heating in the atrium space was identified as a comfort issue. Even in winter conditions, the atrium can overheat due to high solar gains through the skylight and West-facing windows. This problem can be greatly reduced and potentially eliminated by installing a fixed or controllable external shading device on the skylight, and installing operable windows along the cafeteria façade and skylight to evacuate the heat, as shown in . This would reduce solar gains and allow for natural ventilation, reducing overheating in the space.

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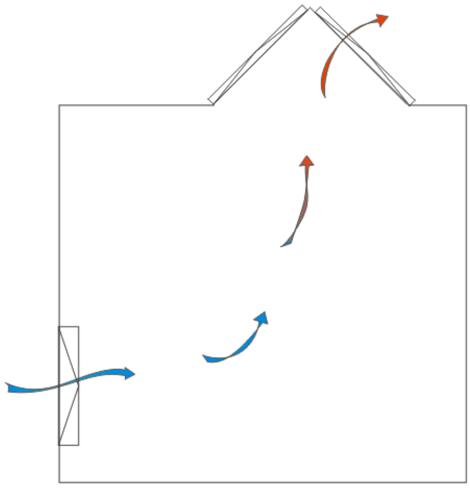


Figure 39 Natural Ventilation Effect in Atrium Space

There are many shading products available for this use. Figure 40 shows a Svensson product, which is a low cost fabric that allows some daylight to penetrate the shading structure. Another example of simple, moveable shading is shown in Figure 41.

Figure 40 Skylight Shading Example: Svensson fabric shading

Figure 41 Skylight Shading Example: Loyola Centre for Sustainable Urban Living; Transsolar Project

4.2. **Large-Scale Intervention**

4.2.1. Reduce HVAC Energy Requirements: Separate Conditioning from Ventilation System

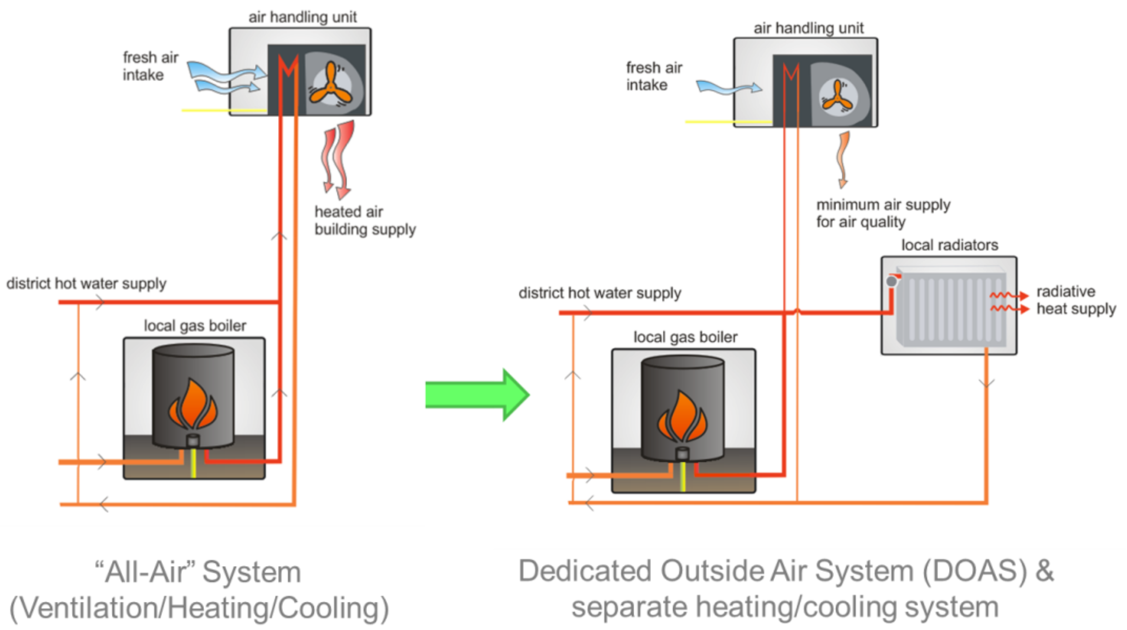


Figure 42: Proposed HVAC System Schematic

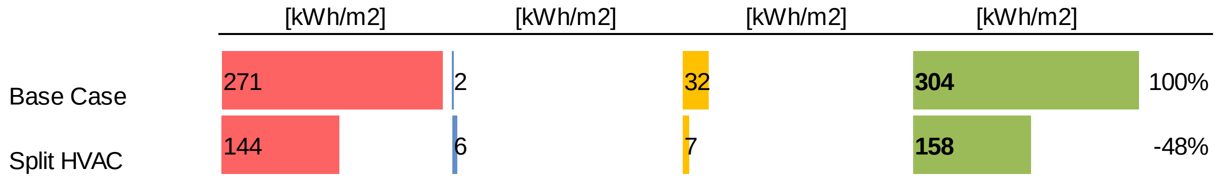
By separating the heating/cooling systems from the ventilation system, a large reduction in electricity consumption and more efficient heating/cooling can be achieved. Radiators installed along the façade of the building can be connected to the existing hot water supply used for reheat coils to provide radiative and convective heating to all of the building spaces. This allows the reduction of ventilation rates throughout the building. The current ventilation capacity for a classroom is approximately 50 m^3/person (based on 24 people per 72 m^2 classroom), while the hygienic ventilation requirement specified by ASHRAE 62 is only 25 m^3/person (or 15 cfm/person).

The impact of separating conditioning from the ventilation was explored through the classroom-level thermal simulation.

Table 10 Separated Conditioning and Ventilation Simulation Boundary Conditions

Variation	Load Type	Description	Load Specification
Base	Ventilation	Air Supply Flow Rate	1266 m^3/hour
	Heating	Heating Type	All air heating
Split Conditioning/ Ventilation	Ventilation	Air Supply Flow Rate	633 m^3/hour
	Heating	Heating Type	Convective Radiator

The decrease in ventilation rates, and thus required air heating, results in a reduction in heating and electricity of 48%.



Local radiative heating also enables the occupants to better control individual spaces leading to improved comfort in the spaces with reduced energy demand. Reduce Heat Loss through

4.2.2. Façade: Insulation Enhancement

The current building façade of NE01 consists of pre-cast concrete, and possibly a thin layer of unknown insulation material. The heat loss through these walls is high, resulting in a higher heating demand than needed in Vancouver's climate. A layer of insulation can be added to the interior or exterior of the facade to reduce these heat losses, as shown in Figure 43. The addition of interior insulation, such as calcium silicate, gas-concrete or even EPS may be a more simple option and that could be carried out by BCIT/Factor Four students. It may not be quite as effective in reducing heating demands as exterior insulation, but may be cheaper, and could be integrated into the NE01 living lab concept.

The addition of external insulation is preferred from a thermal perspective, but was not studied through a thermal simulation due to the concern that it would lead to possible structural requirements to upgrade the façade to building code.

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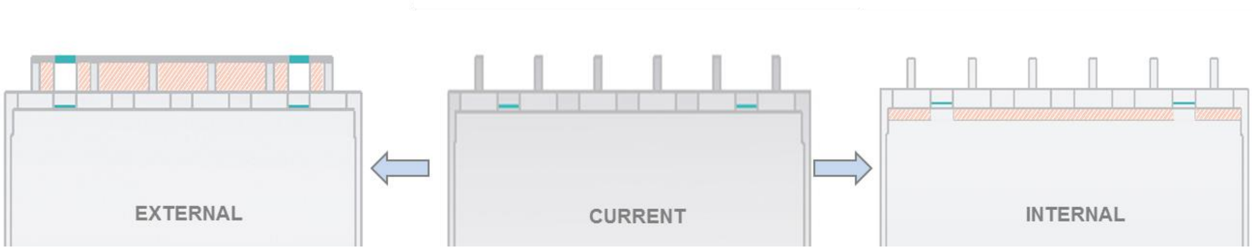
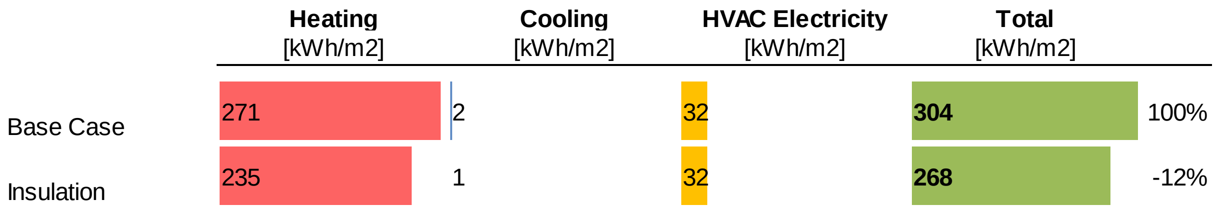


Figure 43: External or Internal Insulation Addition

A room-level thermal simulation for the addition of internal insulation was performed to determine the potential energy reduction of this strategy.

Table 11 Extra Insulation Simulation Boundary Conditions

Variation	Structure Type	Material	U-Value	Thickness
Base	External Wall	Pre-cast concrete Wool insulation Drywall	1.610 W/m^{2}K	.164 m
Extra Insulation	External Wall	Pre-cast concrete Wool insulation Gas Beton [10 cm] Drywall	0.652 W/m^{2}K	.264 m



4.2.3. Improve Daylight Autonomy: Increase Window Area on North Façade

In order to study the potential for daylighting, a daylight factor study was performed for a typical room on the North-façade. Given that Vancouver experiences significant periods of cloudiness the daylight factor model is considered to be appropriate. Figure 44 shows the 6 variations modeled.

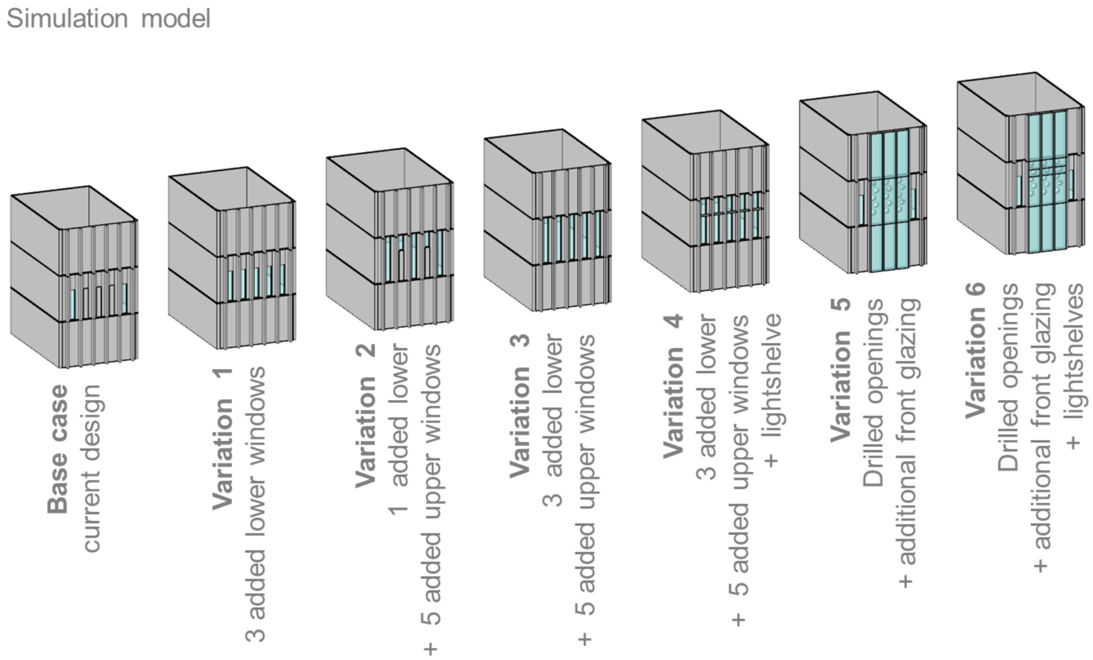


Figure 44: Daylight Study Simulation Model Variations

The results are as expected, and show that an increase in window area on the façade (size and number) has a significant impact on the amount of diffuse light entering the space. Based on Variation 3, shown in Figure 46, with the addition of 3 windows and an extension of all window height to ~4m, a 10-fold increase in floor area receiving acceptable daylight levels can be achieved. Variation 5 is based on the creation of a quasi-double façade with small drilled holes in the original concrete façade surface. This alternate approach was studied because it may not affect the structural integrity of the façade. Along with improving the daylight potential in the space slightly, the quasi-double façade could potentially be used as a chimney to drive natural ventilation.

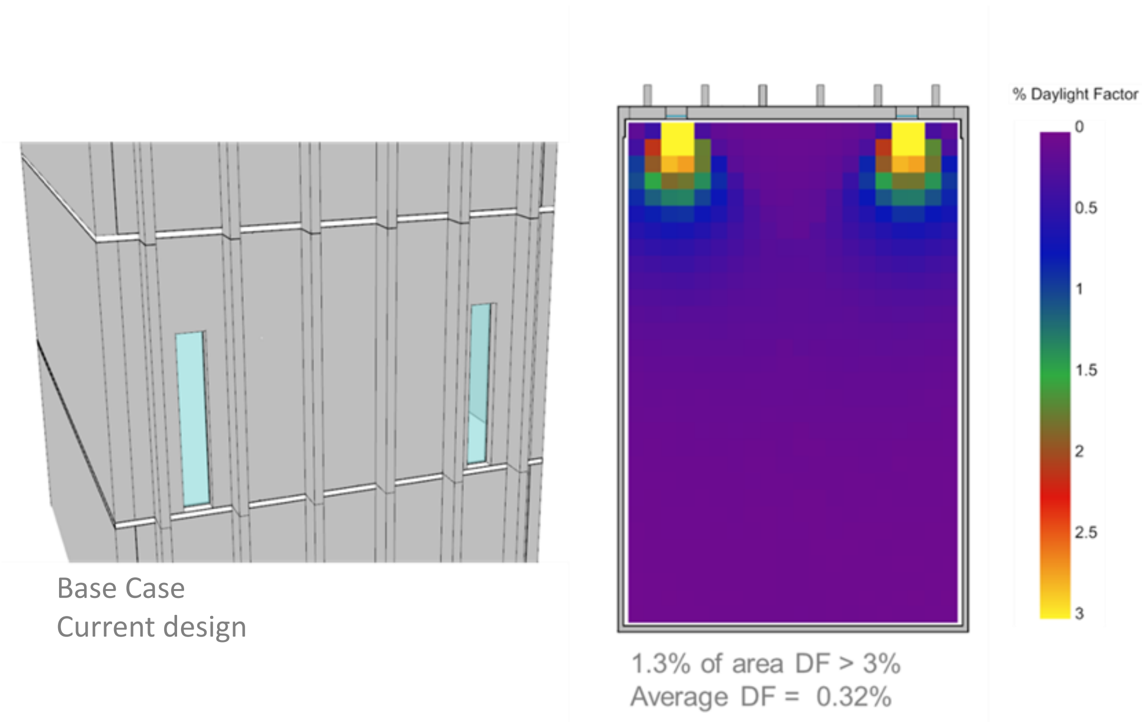


Figure 45: Daylight Study Results - base case

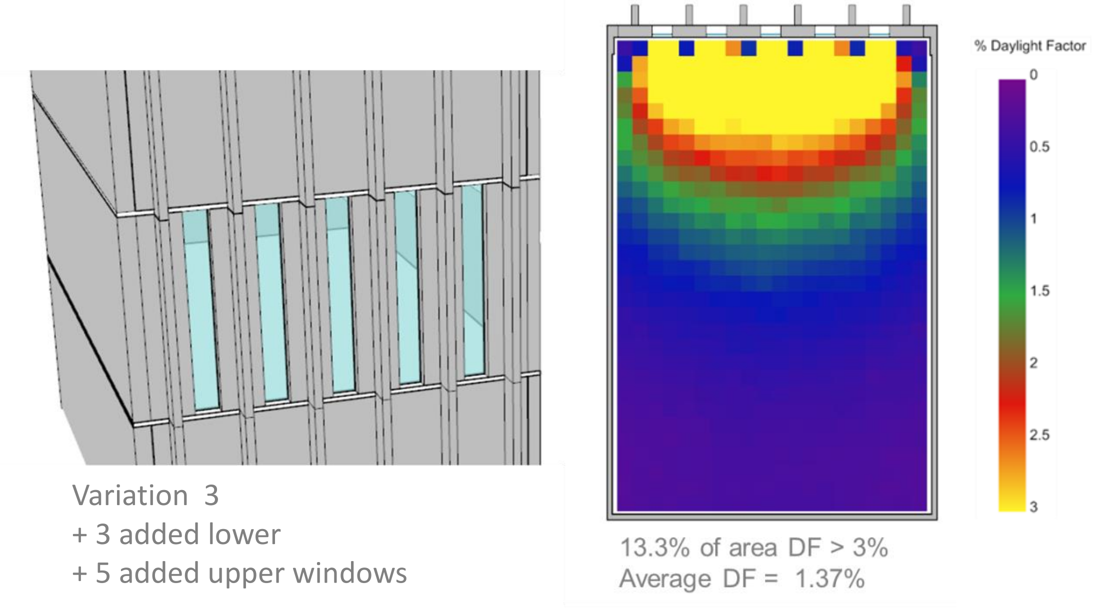


Figure 46: Daylight Study Results - variation 3

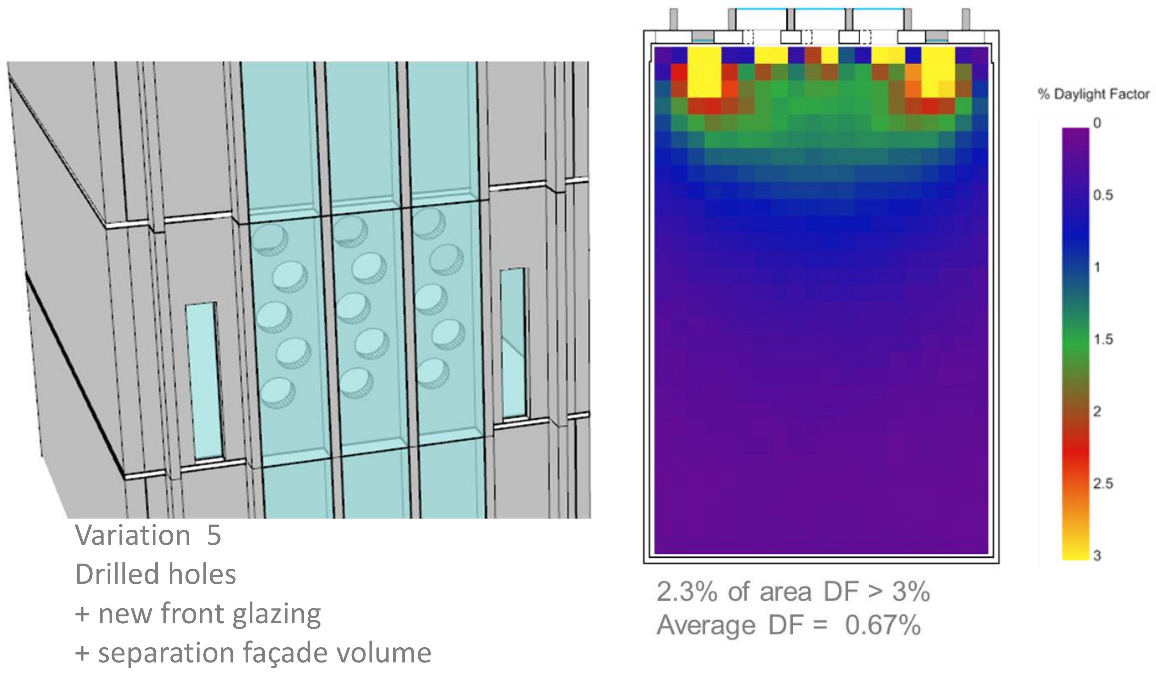


Figure 47: Daylight Study Results - variation 5

4.3. Additional Intervention Ideas

From the charette there were many ideas that surfaced. Although not all of them were studied in depth a few additional points are considered reasonable and worth discussion should the interest arise.

1) *Natural Conditioning of additional building using the Cafeteria atrium and staircases*

Transsolar has extensive experience using atriums to help drive natural ventilation into academic and office spaces. Any of the classrooms or spaces connected or near the atrium have the potential to use natural ventilation in the same way proposed for the north façade classrooms. Additionally a few of the external facing staircases could also function in this way. This would require automated opening at the top of the atrium and staircases, operable windows or ducting from the occupied space to the stairway or classroom. Opening to the hallways and opening of the doors connecting to the atrium would further extend the range of influence of the atrium.

One important issue to address would be fire safety. It is assumed that many of the external stairs act as fire escapes and should be disconnected from an air perspective from the rest of the building. Additionally many of the doors in the hallway may be fire protection doors. Some simple controls can often be used to address these issues.

2) *Natural daylight and ventilation through the creation of a new atrium in the center of the building*

Although potentially seen as quite radical, an interesting way to get natural ventilation and daylight into the rest of the building would be to literally cut a hole in the middle of the building and take out one of the classrooms to provide a new atrium which other classrooms and spaces could look onto. This would have the benefit of improving air quality, daylight, and comfort in the deepest part of the building.

A key issue to address would be the question of seismic stability in performing such a modification to the building. For this reason the intervention was not heavily investigated. Otherwise the method has been done for other renovations and seen positive results.

3) *Greening of the roof*

A clear message from staff and students in the design charette was the desire for more connection to the outside world. NE01 has one of the best views on campus. It may be worth considering creating a roof top patio with minimal planting to provide an improved sense of comfort and use of the building.

4.4. Thermal Simulation Weather Data Validation

To validate the thermal simulation results using the CWEC Vancouver weather data, a comparison of the percentage reduction of heating and cooling demand due to recommendation 1, 2, and 3, shown in Figure 48, was made for both weather data sets. Although the level of cooling using the BCIT weather data is significantly higher, the overall percentage reduction due to the recommended interventions is very similar.

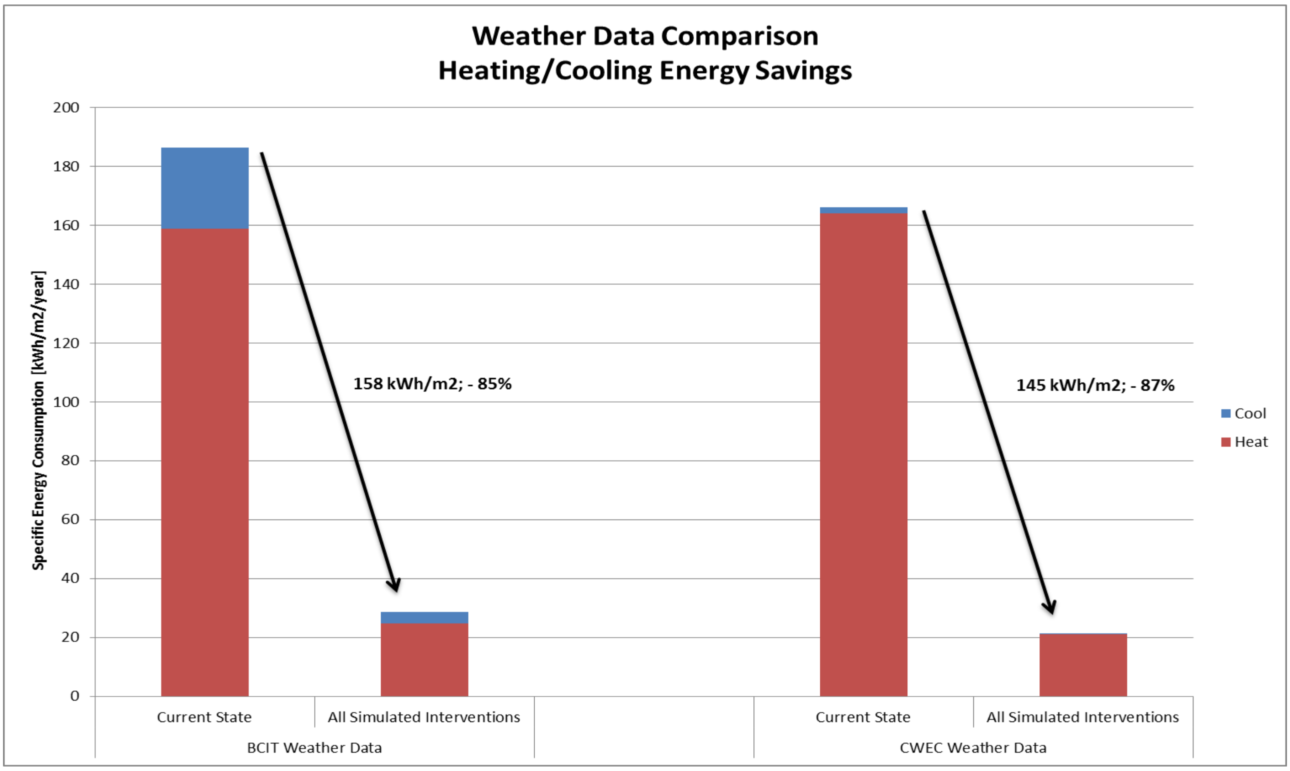


Figure 48 Energy Reduction Comparison for Thermal Simulation Weather Data

5. Living Lab Potential of NE01

The Factor Four initiative looks to engage students, faculty, and staff in its efforts to reduce the energy consumption in the Factor Four area by 75% without compromising service levels. NE01 is a great opportunity to put this in practice, by using the building as a living lab. Based on Transsolar's experience with applied research projects, and in office initiatives, and examples from other university campus living labs, at least three focuses are possible: room-level energy system optimization, comfort studies, and building wide energy reduction optimization.

5.1. Room-Level System Testing and Optimization

To create a true “living lab” out of the NE01 building, select classrooms could be used continuously for research projects or studies surrounding energy consumption of different building systems (mechanical vs. natural ventilation, gravity wall efficiency, etc.) as well as the resulting comfort impacts on a space. Students can utilize low-cost, easy to use devices and comfort surveys (discussed in next section) to monitor the classroom conditions. The Netatmo Weather Station (http://www.netatmo.com/) or Cubesensors (https://cubesensors.com/), shown in Figure 49 are devices currently available that measure local room conditions related to different aspects of comfort such as air quality (CO2 levels), humidity, temperature, pressure, and acoustic comfort.

Figure 49: Weather Station App Connected Gadgets

These measurement devices output real-time data, which can be viewed online via a computer or cell phone application. Historical data can also be accessed. Examples of the Netatmo Weather Station outputs are shown in Figure 50.

Figure 50: Netatmo Weather Station Measurements

5.2. Comfort Surveys

There is exciting potential to use the concept of a living lab to measure comfort levels in different NE01 spaces. With the engagement of students and faculty in the building, the impact of the NE01 upgrade on comfort could be measured through before and after surveys. Ongoing comfort surveys could also be used to optimize the comfort in the building, and lead to interesting student led research projects or studies exploring the concept of comfort in spaces. The quick and easy survey that the Transsolar Inc. office in New York City, NY, created to measure thermal comfort levels in their office is shown in the figure below. They have also plotted their survey results in various ways to identify comfort trends in their office and gain insights related to the broader concept of thermal comfort.

Research on the connection between comfort, room conditions and productivity is growing in interest but to date very little has been done. BCIT could position itself to do true before and after comparisons of the impact of sustainability and comfort improvements.

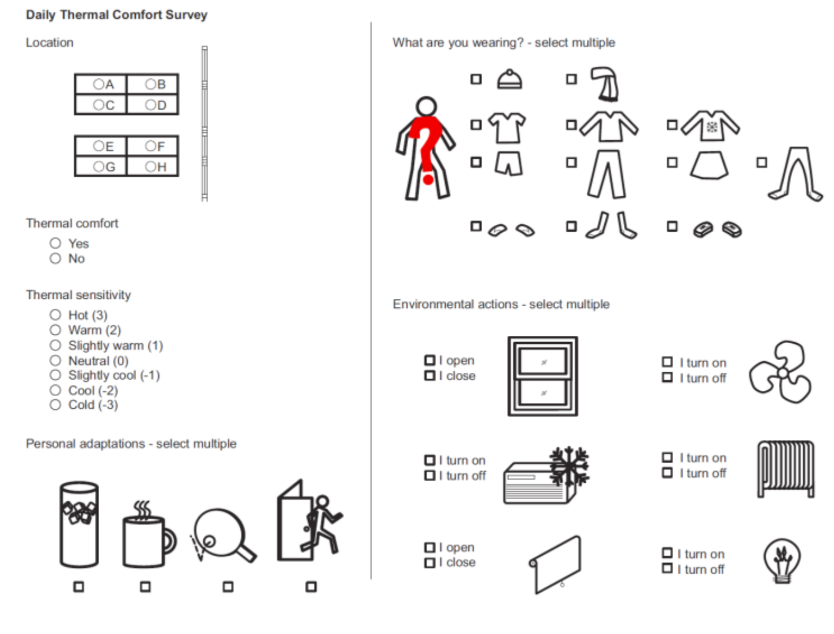


Figure 51: Thermal Comfort Survey - New York Transsolar Office

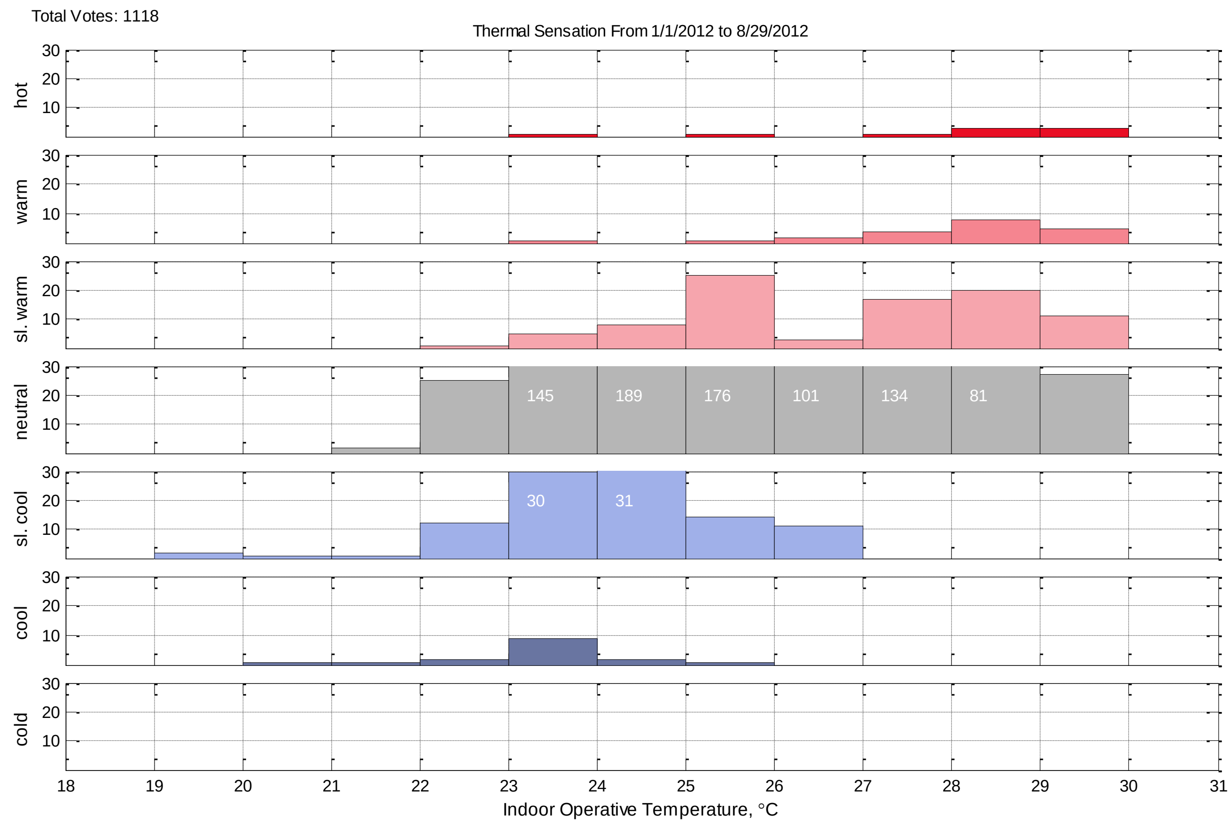


Figure 52: Thermal Comfort Survey Results - New York Transsolar Office

5.3. Building Level Audit

Students can learn about building systems by performing a thorough audit of NE01's systems, including their capacity, lay-out and controls. Once the building systems are understood more concretely, students can perform studies and tests to measure the effect of different interventions. This can facilitate the further optimization of NE01. For example, a clearer picture of the current ventilation and AHU unit controls could lead to the optimization of comfort levels and energy use on a unit by unit basis.

In order to help facilitate this activity, Transsolar has given Factor Four their excel-based energy calculations of the whole building consumption, with organized equipment inventory and operation schedule assumptions.

Once a proper building level audit has been completed then proper commissioning of the building would also be possible.

6. Intervention Evaluation

6.1. Criteria Definition

Transsolar evaluated the proposed interventions based on their energy reduction and comfort improvement potential. In order to make recommendations based on these results Transsolar has evaluated the individual interventions according to the following criteria:

- **Energy Reduction Potential** [Energy Reduction in kWh/m^2 and %]

Meeting Factor Four's 75% energy target is the main goal of this study and potential building renovation. The combination of recommended interventions should come as close to this goal as possible.

- **Cost** [Low/Medium/High]

The affordability was estimated by Transsolar based on experience on a 3 point scale. The use of energy reduction numbers, provided through this study, could be translated into costs savings by Factor Four, based on the local purchasing and energy sourcing conditions. It is assumed that BCIT's facilities and services have specific costing and procurement practices to do a proper costing of the proposed interventions.

Based on NE01's remaining predicted lifespan of 10-15 years, interventions should have a maximum payback period of 10 years.

- **Comfort** [--/-/0/+/++]

Thermal and visual comfort, as well as air quality, was identified as key issues for NE01. The impact of interventions on these comfort levels is measured on a 5 point scale, based on the thermal simulation results.

- **Complexity/Effort** [Low/Medium/High]

Complex interventions will require substantial planning and renovation time, which is not favoured for the NE01 upgrade. The alteration of any structural components of the building is also limited. Large structural renovations will be required to meet the current building code. A complex intervention is also more likely to be costly, which will be reflected in the cost criteria.

6.2. **Evaluation**

Table 12: Evaluation Matrix –Façade Effected Interventions

Intervention	Energy Savings	Cost	Comfort	Complexity/Effort	Recommended
Operable Windows on Façade	Small	Medium	+	Low	1
Improve Window Quality	Small	Medium	+	Low	2
Exhaust Heat Recovery	Significant	Medium	0	High	3
Light Redirection	None	Low	0/+	Low	5
Lighting Controls	Moderate	Low	0	Low	4
Light bulb Retrofit	Moderate	Low	0/+	Low	4
Separate Conditioning from Ventilation System	Significant	High	+	Medium	1
Insulation Enhancement	Moderate	Medium	+	Medium	2
Increase Window Area on North Façade	Negative	High	+	High	5

Table 13 Evaluation Matrix - Core Effected Interventions

Intervention	Energy Reduction	Cost	Comfort	Complexity/Effort	Recommended
Exhaust Heat Recovery	Significant	Medium	0	High	2

Lighting Controls	Moderate	Low	0	Low	3
Light bulb Retrofit	Moderate	Low	0/+	Low	3
Separate Conditioning from Ventilation System	Significant	High	+	Medium	1
Instant Water Heaters	Significant	Low	0	Low	1

Table 14 Atrium Specific Interventions

Intervention	**Energy Reduction**	**Cost**	**Comfort**	**Complexity/Effort**	**Recommended**
Operable Windows on Façade	Moderate	Medium	+	Low	1
Internal Skylight Shading	Moderate	Low	+	Low	1

7. Recommendations

Transsolar has developed a recommendation list based on the individual intervention evaluation, as well as the synergistic nature of the explored interventions. In order to maximize the energy reduction and comfort improvement for NE01 the interventions should be implemented in strategic combinations, which are outlined below. Each set of interventions builds upon the last, and an overall incremental reduction in energy consumption is shown in Figure 53, outlining the potential percent energy reduction from the comfortable base case and NE01's current consumption. The results are based on a series of thermal simulations for both façade classrooms and internal core spaces. Boundary conditions for core spaces were assumed to be the same as for the classrooms.

	Heating [kWh/m2]	Cooling [kWh/m2]	HVAC Electricity [kWh/m2]	Plug Loads & Lighting [kWh/m2]	Total [kWh/m2]	Reduction from base [%]	Reduction from current [%]
Current	118	38	32	69	267	-23%	100%
Base	196	38	32	69	345	100%	129%
Split HVAC and Natural Ventilation	79	11	7	69	176	-49%	-34%
+ Façade Improvements	62	11	7	69	159	-54%	-40%
+ Heat Recovery	10	12	7	69	108	-69%	-59%
+ Lighting Upgrades	10	12	7	41	81	-76%	-70%

Figure 53 Building Wide Energy Reduction Potential for Combined Intervention

1) Building-Wide Ventilation: Split HVAC with Natural Ventilation

The first step in reducing the energy demand and increasing the comfort level of NE01 is implementing two interventions that deal with the buildings ventilation system: separating conditioning and ventilation, and installing all operable windows along the facades (natural ventilation, night flushing). By using radiators throughout the building the ventilation system can be driven by air quality rather than heating requirements and fresh outdoor air can be supplied through natural ventilation to rooms along the facade. This strategy has the potential to reduce the electricity consumption (air handling units, supply, and exhaust fans) by 78 % and heating requirement (less outdoor air needs to be heated) by 60% The use of natural ventilation and night flushing eliminates the need for cooling to the spaces with window access, reducing the total cooling demand by 71%, for an overall energy reduction of 49%. Both radiators and operable windows provide users with more control over the thermal comfort and air quality of their space. This user control has been linked to an increase in productivity, as people are more pleased with the room conditions. As seen in the figure below the largest impact on productivity in the many studies came from individually controlled ventilation systems (in other words operable windows).

It is important to note that to properly ventilate the classrooms, windows that open fully (as though opening a door) would be required. This would require some sort of grate or protection barrier to meet code requirements, but massively increases ventilation potential without needing to add additional windows.

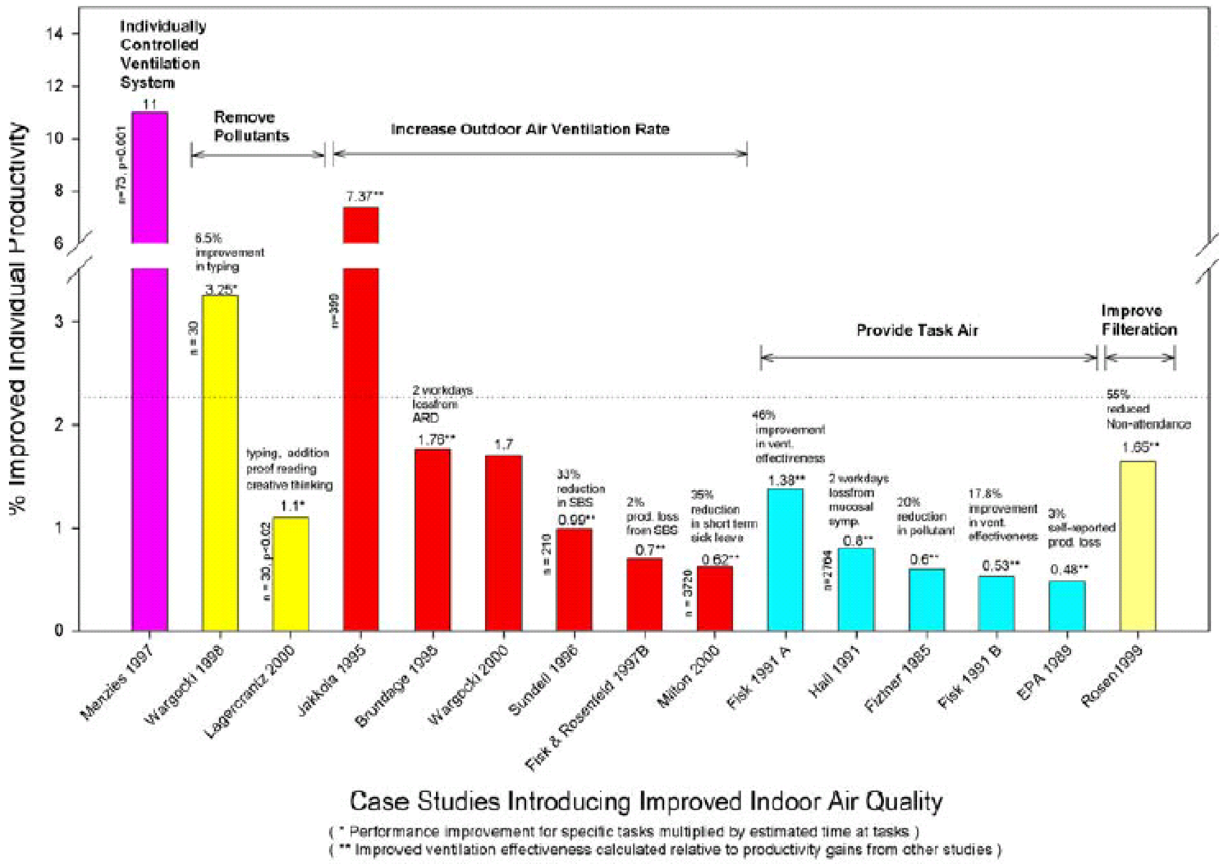


Figure 54 Impact of Improved Air Quality on Productivity

2) Façade Improvements

To further reduce NE01's heating demand, the current façade should be enhanced in two ways. The first is installing double glazed windows in place of the existing single glazed ones. The second improvement is the addition of insulation to the external walls of the building. A simple internal gas cement, calcium silicate or potentially EPS insulation could be installed along the façade by students, after the installation of new windows. It will be important to study the impact on moisture transfer through the walls to ensure no condensation occurs with the addition of moisture sensitive insulation. Although this material is not the best insulator available, it is low cost and easy to install. Other materials could also be considered, and may reduce heating by a slight margin, but is be more expensive to purchase and install. The combined façade changes improve the performance of the building by another 5%.

3) Integration of Heat Recovery in Ventilation System

A final intervention to reduce NE01's heating demand is the implementation of heat recovery. Although excess heat from the buildings exhaust air is already being used through recirculation for "free heating," employing heat exchange rather than air recirculation improves air quality immensely, and can reduce heating needs even more. Due to the variation in air handling units and ventilation systems throughout the building it is difficult to recommend one overall strategy for implementing this intervention. The units should be investigated individually for the potential to integrate heat recovery and eliminate the use of air recirculation. In the case that NE01's entire ventilation system is replaced, air handling units with high efficiency heat recovery should be selected. Through the addition of building-wide heat recovery, a further energy reduction of 15% is achieved.

4) Lighting Upgrades

The combination of LED lighting and lighting controls in various common spaces (bathrooms, cafeteria, corridors, and staircases) is recommended to reduce the electricity demand of NE01. By introducing LED lighting in these spaces, dimming is possible, and does not reduce the lifespan of the light bulbs. This is a cost effective solution for achieving a greater overall reduction, in addition to the above mentioned strategies. Finally, with both occupancy sensors and LED bulbs, an additional 7% is achieved.

5) Additional Interventions

Natural ventilation and a shading system should be implemented in order to address comfort issues in the cafeteria atrium space.

In the case of a need to replace the hot water systems for bathrooms, electrical instantaneous hot water heaters should be used to reduce total electrical and gas needs while reducing time for hot water delivery.

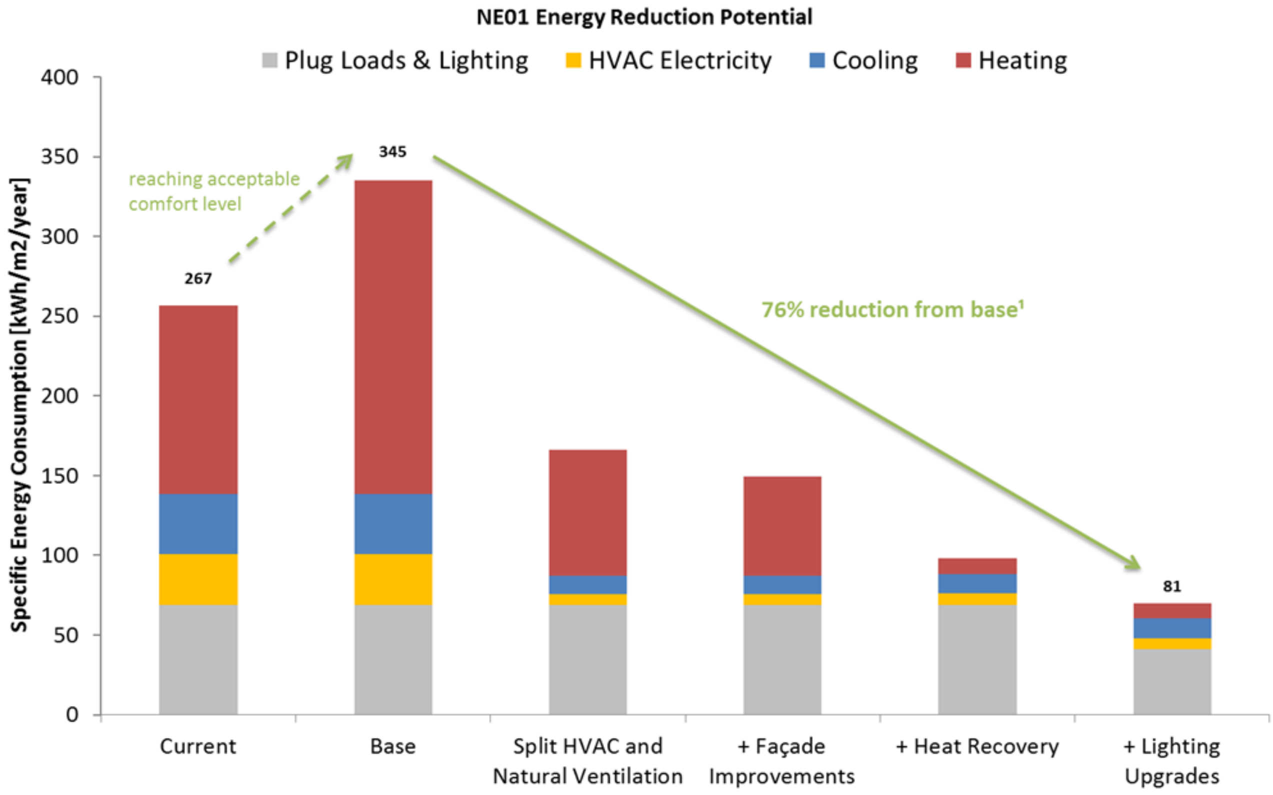


Figure 55 Potential NE01 Energy Reduction

Based on the four recommendations outlined above, a constant plug load of 33 kWh/m^2/year, and a cooling load reduction based on the BCIT weather data simulation and the calculated cooling load, an energy reduction for NE01 of 76% could be realized from the base case. This represents an actual reduction of 70% from the current energy consumption of NE01.

Appendix A: Equipment Inventory

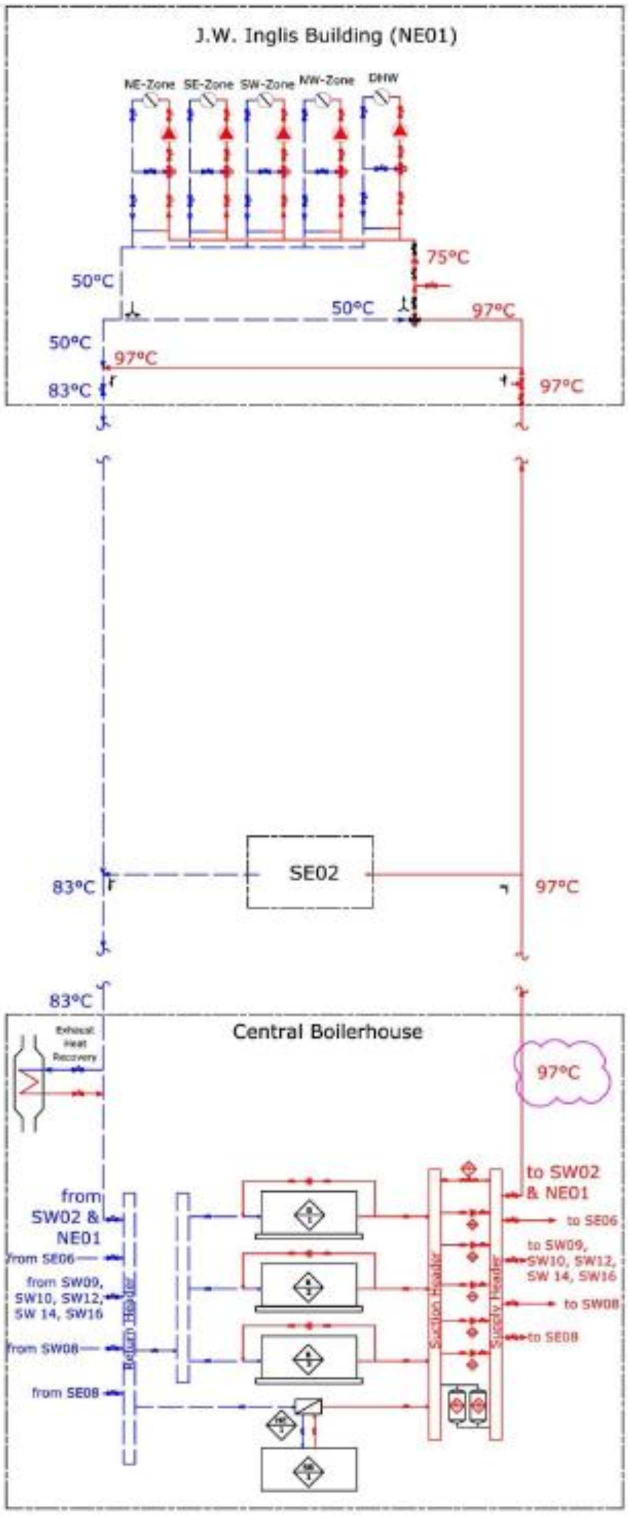
Equip. Codes	System Description	Room Code	Model	Rating (hp)	Qty.
AHU-217D	Carpentry & Sheet AHU Supply	217D	480/3	15	1
AHU-217D	Carpentry & Sheet AHU Return	217D		7.5	1
AHU-144	Old Plant Area AHU Supply	144	480/3	15	2
AHU-144	Old Plant Area AHU Return	144		7.5	2
AHU-163	Refrig&Millwright AHU Supply	163	480/3	15	1
AHU-163	Refrig&Millwright AHU Return	163		7.5	1
AHU-02	West Side AHU Supply		480/3	30	1
AHU-02	West Side AHU Return		480/3	10	1
AHU-01	East Side AHU Supply		480/3	30	1
AHU-01	East Side AHU Return		480/3	10	1
EF-NE1-215-050/215-051/215-052/215-053/317-03, Z02259/72/75/79/80/81/82/83/84/88/89/90/91/92	Exhaust Fan	116	150SONB	0.25 - 1	19
Z02274/72, NE1-144G-02	Supply Fan	215	60-26.50-1150	1	3

Part Tag	Part Description	Make	Model	Rating (hp)	Power in kW	Qty.
P	Pump		480/3	5	3.7	4
BO-01,02,03	Boilers	Hydrotherm	MR300	300	87.9	3

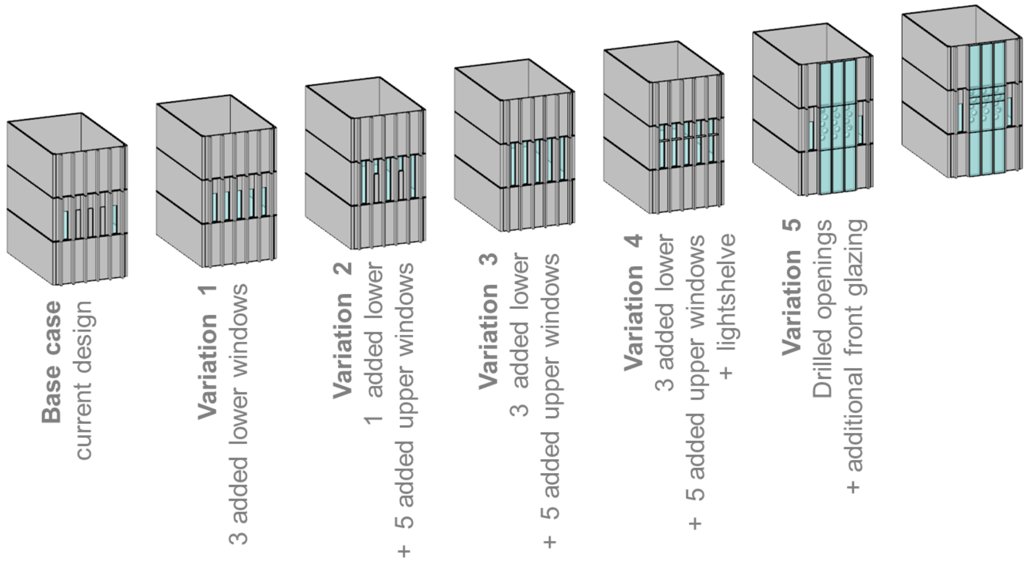
Heating Source	Annual Energy Consumption (GJ)	Annual Energy Consumption (kWh)
District Heating (measured)	4923	1 367 609
Local Boilers (estimate)	1000	277 800
Local Boiler Pumps	-	15 707
Space Heaters	N/A	Included in Plug-Loads

System Description	Part Tag	Part Description	Rating	Power in kW
Air Conditioning Unit	SF-02	Supply Fan	0.5 hp	0.37
Air Conditioning Unit	SF-01	Supply Fan	1 hp	0.7
Air Conditioning Unit	SF	Supply Fan	0.5 hp	0.4
Chilled Water System	CH	York Millenium Chiller	250-300 tons	879
Chilled Water System	P-01	Chilled Water Pump	25 hp	18.6
Chilled Water Plant	P-02	Condensor Water Pump	25 hp	18.6

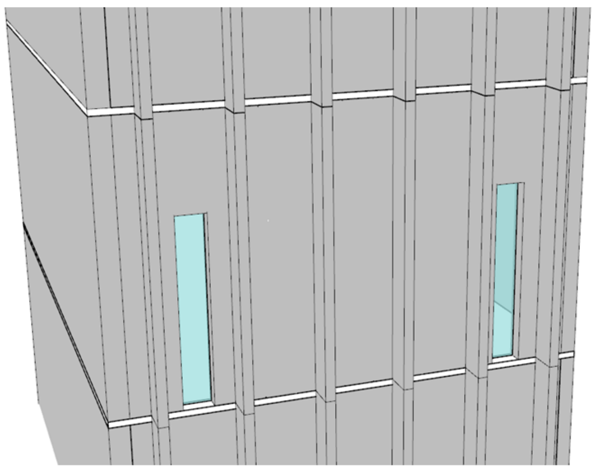
Appendix B: Schematic System Diagrams

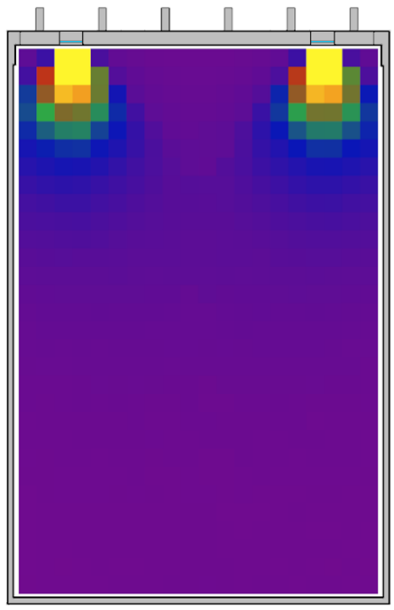


Appendix C: Full Daylight Study Results



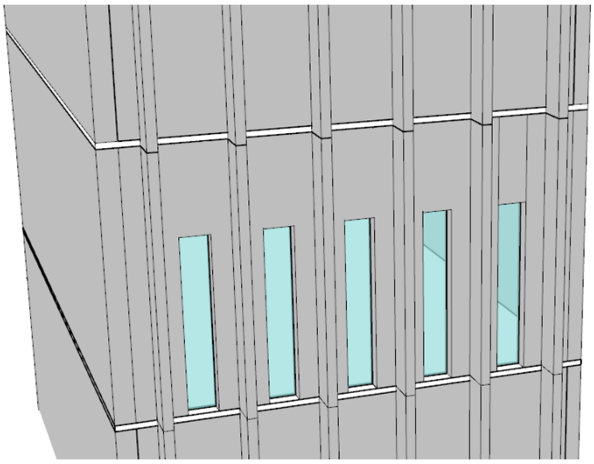
Simulation result; Daylight Factor [%]
Base case
current design

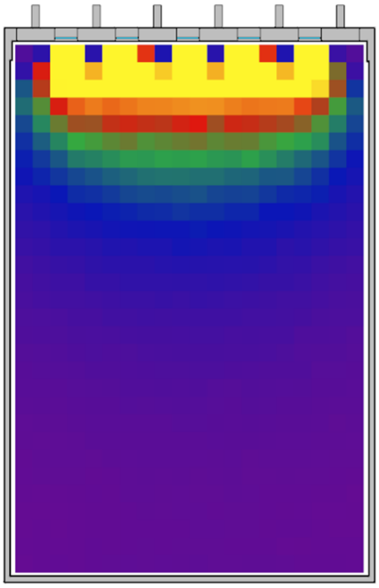




1.3% of area DF > 3%
Average DF = 0.32%

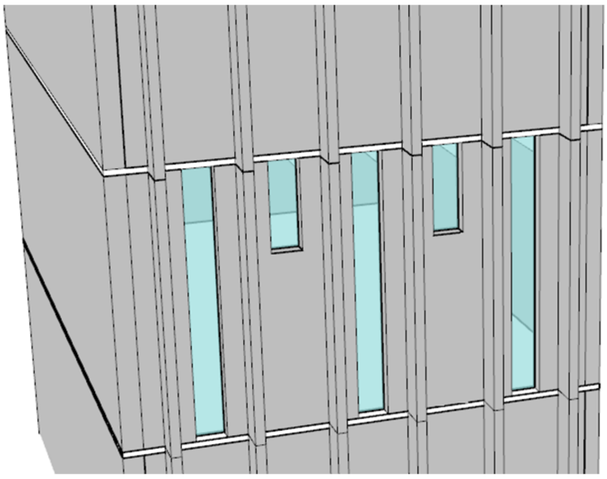
Simulation result; Daylight Factor [%]
Variation 1
3 added lower windows

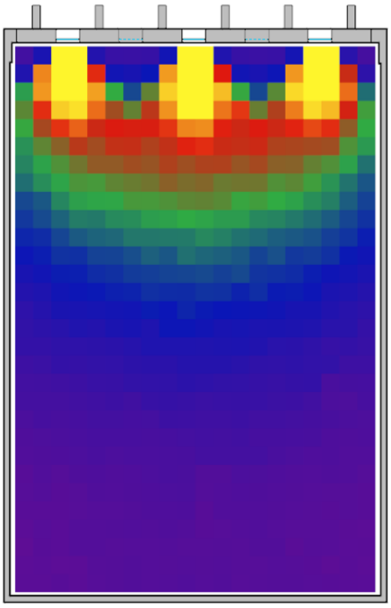




6.0% of area DF > 3%
Average DF = 0.84%

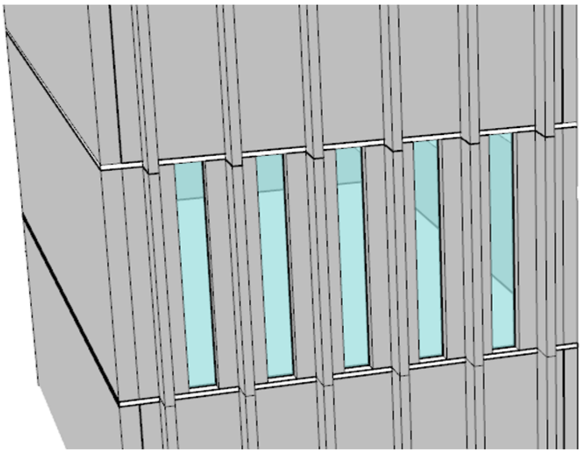
Simulation result; Daylight Factor [%]
Variation 2
1 added lower window
5 added upper windows

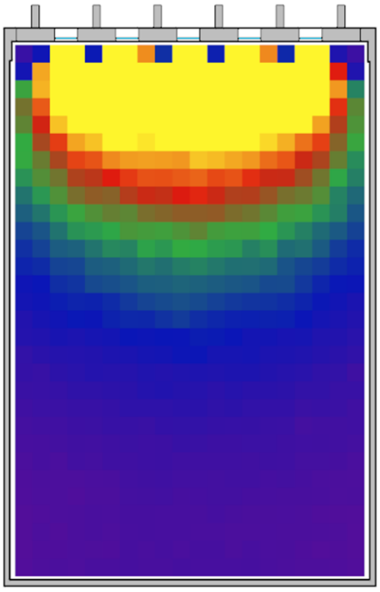




3.3% of area DF > 3%
Average DF = 0.99%

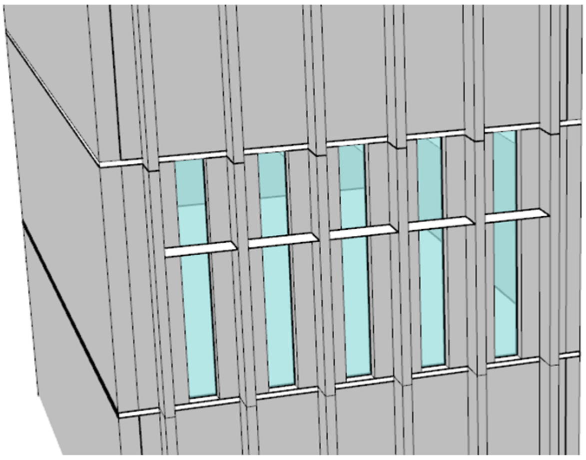
Simulation result; Daylight Factor [%]
Variation 3
3 added lower window
5 added upper windows

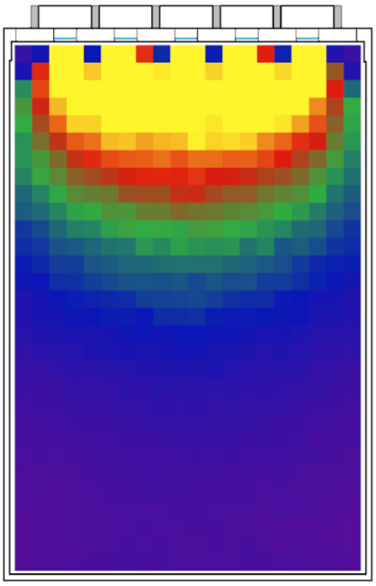




13.3% of area DF > 3%
Average DF = 1.37%

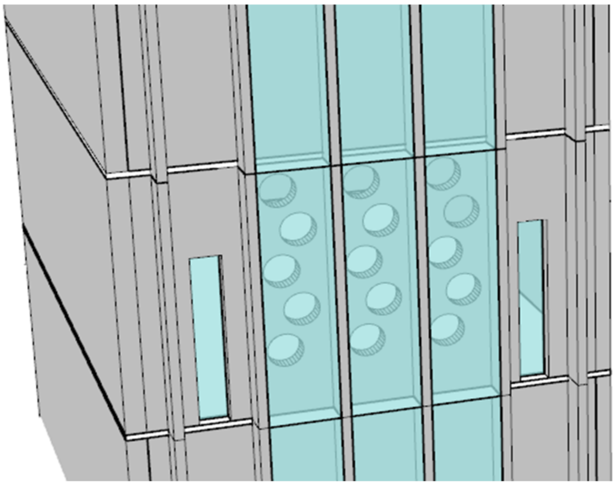
Simulation result; Daylight Factor [%]
Variation 4
3 added lower window
5 added upper windows
+ lightshelve

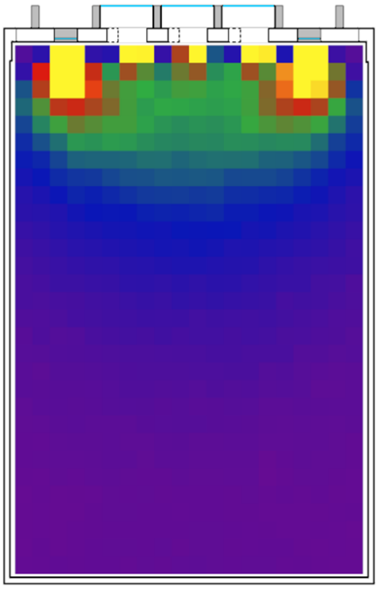




10.2% of area DF > 3%
Average DF = 1.24%

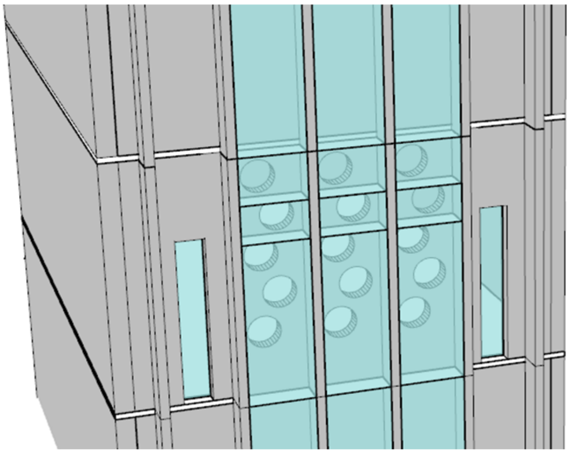
Simulation result; Daylight Factor [%]
Variation 5
Drilled holes
+ new front glazing
+ separation façade volume

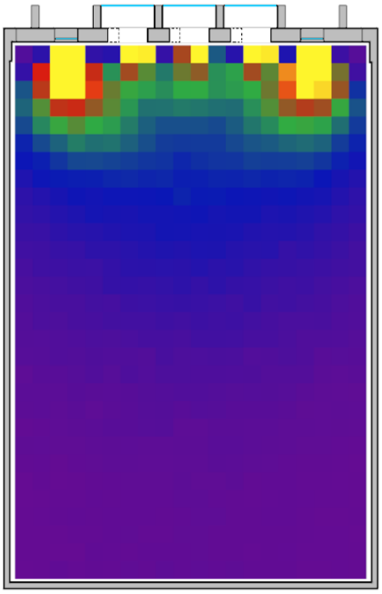




2.3% of area DF > 3%
Average DF = 0.67%

Simulation result; Daylight Factor [%]
Variation 6
Drilled holes
+ new front glazing
+ separation façade volume
+ lightshelves





2.3% of area DF > 3%
Average DF = 0.63%

Appendix D: Design Charette Notes

GOALS AND EXPECTATIONS

- Hear about different solutions
- ID opportunities
- Integrate building into living lab
- How can we reduce energy use by:
    - renos, systems, low maintenance
- Generate cost effective ideas
- Share user experience
- Interest in comfort
- Learn
- Deeper understanding of building
- How to balance comfort and energy
- Identify what upgrades are feasible
- Explore Energy Numbers
- Can we adapt the built environment?

WHAT WORKS?

- Good potential exposure
- Great views
- Atrium works / connects to outdoors
- Huge capacity for ppl
- Mingling of cross disciplines
- Blank canvas / no strong identity

Occupancy Schedules:

- Cafeteria – early
    - Separate groups, where does air comes from
    - Continuous exhaust
- Trades: 7:30am start → 2:30 dedicated classroom
- Classroom: 8:30am – 9:30pm
- Offices: 8:00am – 4:00pm [20% there 100% of time / 80% only there 25% of time]
- Saturday: Part-time studies
    - Exams
    - Studios/Labs

WHAT DOESN'T WORK?

- Basically – no user control
- Occupancy controls are inconsistent – switch for all lights
- New entry doors
- Poor space use
    - varying sizes/studios
    - booking system not accurate

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AIR QUALITY

Variable → 1st floor corridor, fresh, headaches, sleepy, stuff, smelly

    - Air goes off at 8pm
    - Manual override of system → mech shop
    - Where does exhaust air go? – bacon/eggs
    - Core is smelly
- Not cost effective – high to maintain → doors, lighting

THERMAL COMFORT

- Single pane windows
- Close to wall
- Heaters brought in – 10% students, many support staff
- 3rd floor overheats by skylight
- AHU is maybe undersized

POOR VISUAL COMFORT

- Not enough daylight
- Fluorescents (flickering)
- Dimming
- Glare
- New entry doors

OPTIONS / OPPORTUNITIES

- Decentralized System
- Task lighting vs top lighting
- Education
- Demonstrate potential
- Operative costs into something else
- Transfer occupants into other areas?
    - Low total occupancy
    - 80% occupation
- Living Lab – Build new classroom
    - Studio
- Recommissioning?
- Local DHW heaters
- HRV
- Light redirection
    - Taper window frames
    - Lighten color
    - Lighten fins
- Panel replacement?
    - Prove seismic
    - reno
- Increase comfort through materials
- Operable windows

- Outdoor connection
    - Roof top?
- Lit study space
- Covered outdoor space → non-smoking?
- Move parking spaces

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