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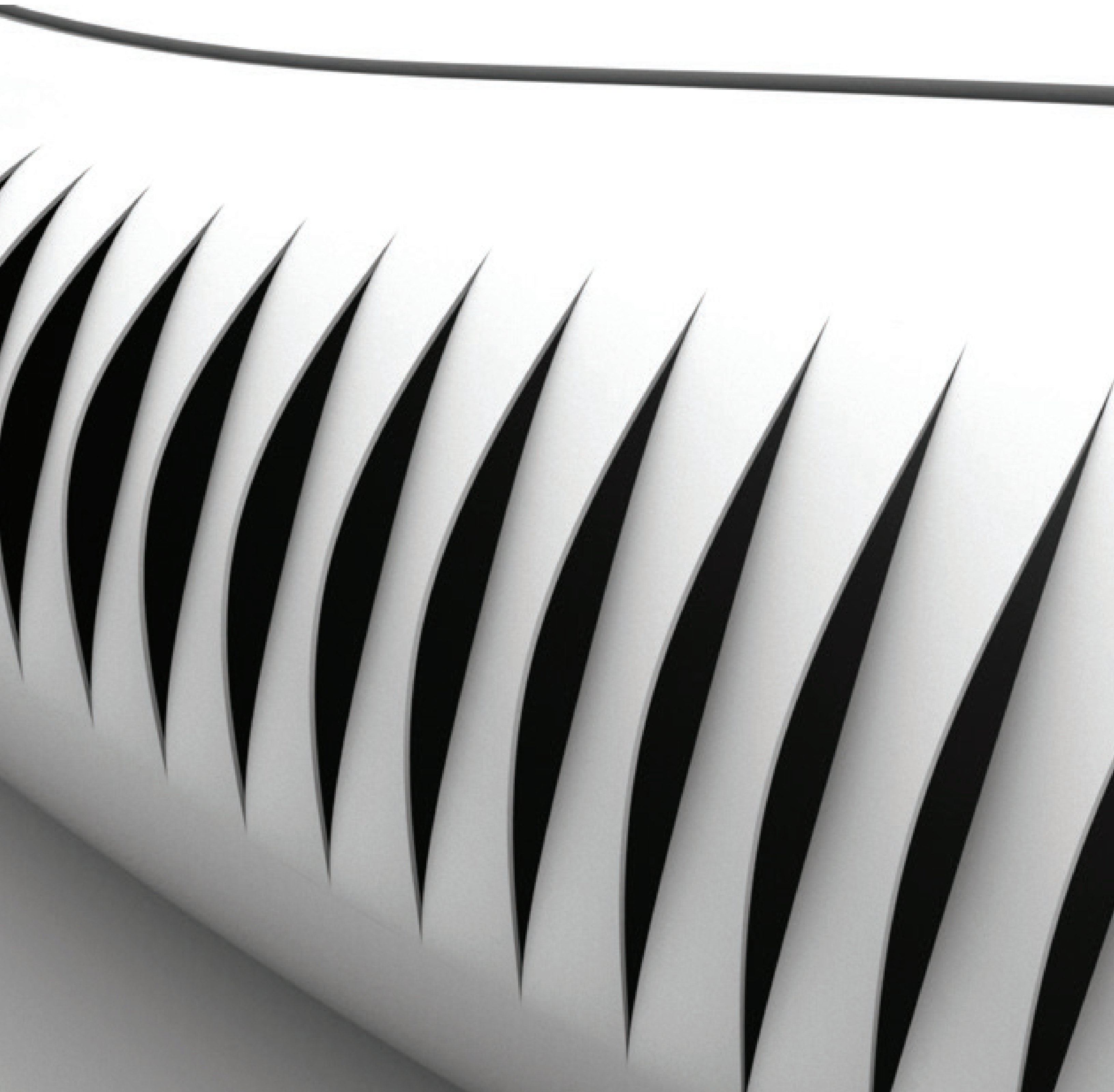

01.
A STUDY FOR CARBON NEUTRALITY: THE IMPACT OF DECISIONS, DESIGN AND ENERGY: *Transforming Residence Life*

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ABSTRACT
This research focuses on the factors that impact the carbon footprint of a residence hall building, particularly the steps and considerations required to achieve carbon neutrality. Beginning with a definition of what it means to be carbon neutral, the study dispels misconceptions and stresses the importance of carbon-conscious decision making throughout the life of a project. The research explores a methodology dependent on multi-disciplinary collaboration involving the entire project team, in which all building components are continuously measured and analyzed for performance optimization. While this research provides technical and methodological insights for professionals well-versed in sustainable design principles, the study also serves to educate clients interested in the "how" and "why" of sustainable design. This study details the cause and effect of several possible interventions and provides a platform to test strategies, some regionally based and others applicable to other building types and geographical regions.

The case study reveals the need for a paradigm shift in building design to reduce the carbon footprint. This paradigm shift involves viewing the building as a holistic system where different mechanical and design aspects work together finding synergies for performance efficiency. Important and impactful factors include material selection and manufacturing processes, building assembly methods, construction, indoor climate conditions, building and site design, integration of active and passive systems, clean/renewable energy generation sources and building operations and maintenance. The building user also becomes instrumental in overall carbon reductions. The effort to achieve carbon neutrality must incorporate student behavioral patterns and the potential to change the wasteful behavior through educational programs.

KEYWORDS: carbon emission, carbon footprint, zero energy design

DEFINITIONS:
CO2e: "The universal unit of measurement used to indicate the global warming potential of each greenhouse gas. Carbon dioxide (CO2) is a naturally occurring gas that is a byproduct of burning fossil fuels and biomass, land-use changes and other industrial processes. CO2 emissions are reported in CO2e; the standard unit is Mt-CO2e or metric tons or tons of carbon dioxide equivalent."[1]
Carbon Footprint: "The Carbon Footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."[2]
Zero Energy Design: A Zero Energy Design is mainly concerned with the reduction of the operating energy requirements for a building, focusing on the operating use of zero fossil energy. By definition, a carbon neutral design incorporates Zero Energy Design strategies.

1.0 INTRODUCTION

What is Carbon Neutrality? Carbon neutrality is the equivalent of having a net zero (neutral) carbon dioxide (CO_2) footprint, which requires balancing a measured amount of released carbon emissions with an equivalent amount of sequestered or offset carbon emissions. A carbon-neutral building must mitigate the carbon emissions released in the materials fabrication, construction and continued operations of the building by generating more energy than it consumes over its lifespan through renewable resources. In a carbon neutral building, every step of the design process requires assessment of the resulting impact on the building's carbon footprint. The most difficult value to calculate is the embodied energy associated with materials selected for construction. Embodied energy refers to the energy that was used to make a product. It entails the total energy for an entire product lifecycle, including raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition. Most of these materials have an initial embodied energy that comes from non-renewable energy consumed in the acquisition of raw materials, processing, manufacturing, transportation and construction. In fact, the manufacturing of building materials accounts for most of a building's carbon footprint. Even though the processing may have taken place years before the project is designed, this carbon impact must be included in the calculation of the building's overall carbon footprint. Therefore, careful material selection and measurements are critical in achieving carbon neutrality. Figure 1 illustrates this initial impact during the manufacturing and construction period. Once the building is built, the goal is to offset this initial impact and maintenance reinvestments by operating the building with design and energy strategies that mitigate the initial carbon emissions. In other words, carbon neutrality is not achieved the day the building opens but is achieved over the life of the building.

Why is carbon neutrality important? Without human activity, nature has a balanced carbon cycle (Figure 2). For instance, a growing tree absorbs CO_2 and transforms it into oxygen by means of photosynthesis, a process that converts CO_2 into organic compounds using sunlight energy. Trees help maintain normal levels of CO_2 in the atmosphere by sequestering it and using it to build their trunk, roots and leaves. When a tree dies, it releases

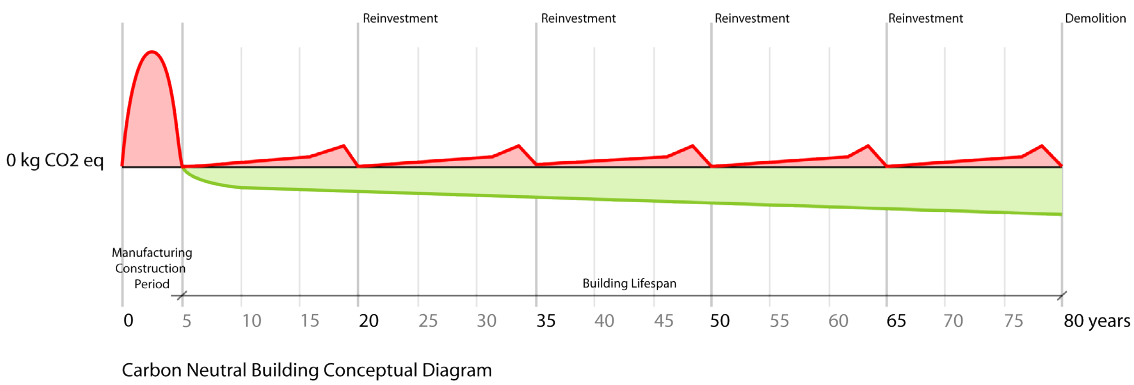


Figure 1: Carbon-neutral building conceptual diagram: Red illustrates CO_2 emitting activities and green illustrates design efficiency and energy production strategies to offset CO_2 emitting activities.

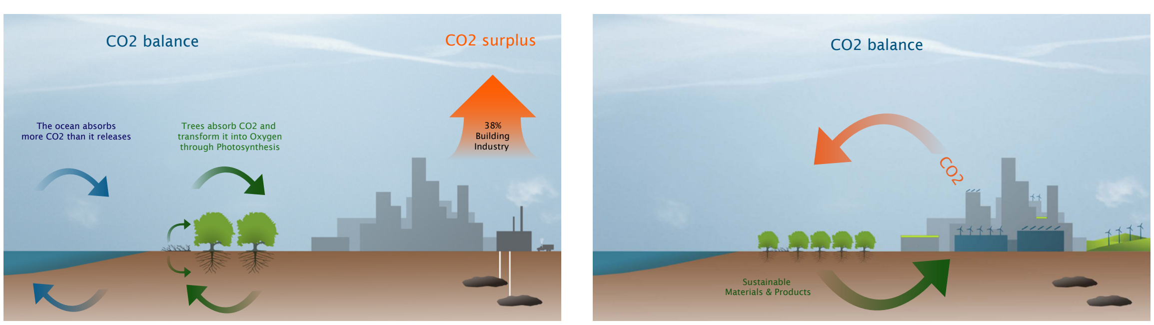


Figure 2: Unbalanced and balanced carbon cycles: natural vs. anthropogenic.

the CO_2 that was absorbed during its lifespan. Some of this CO_2 gets released back into the atmosphere (to be absorbed by growing trees) and another portion is absorbed by the soil as nutrient for other plant life.

The health of the planet's water is equally important. For example, the ocean exchanges CO_2 with the atmosphere, absorbing more than it releases and sequestering CO_2. This balance, however, has shifted in recent history, perhaps more acutely since the Industrial Revolution. In the United States, the building industry accounts for 38% of all CO_2 emissions released into the atmosphere[3]. Nature cannot keep up with these large amounts of emissions, thus resulting in high levels of pollution. Fossil fuel combustion currently used to power material processing and transportation plays a big role in this unbalanced cycle. Clean renewable energy sources are an alternative to fossil fuels and can begin to lower the percentage of CO_2 emissions caused by the building industry, as well as other human activities. Land alteration, especially deforestation, also contributes to high levels of CO_2 in the atmosphere. Responsible site selection therefore becomes an important component of sustainable design. Although reversing this unbalanced cycle is possible, the process will be gradual because the atmosphere tends to retain CO_2, which means that carbon emission reductions will not be immediately reflected. Designing, constructing and operating carbon-neutral buildings are important steps in reducing CO_2 emissions associated with the building industry.

Various strategies can be implemented to create a carbon-neutral building. The design approach explored in this study suggests a paradigm shift, in which reduce, reuse and recycle are no longer the top decision drivers but rather are encompassed by larger planning concepts. An inverted pyramid diagram illustrates the process of decision making based on the constant assessment and measurement of the CO_2 consequence, shown in Figure 3. The prevalence of each phase correlates to the level of impact that those decisions will have on the building's carbon footprint. At the top of the diagram, the optimization phase has the greatest potential impact on the building's carbon emissions and energy load. The decisions made in the optimization phase set the framework for the design team and will therefore influence the decisions made in each subsequent phase. For example, the less carbon emissions resulting from decisions made in the first three phases, the less energy must then be offset in the fourth phase. As the inverted pyramid narrows, the interventions become less impactful and more costly. It is therefore essential that careful assessment precedes each decision throughout the design process. The following sections will discuss in greater detail how these strategies were explored, tested and applied through the residence hall building case study.

1.1 Impact of Materials: Comparative Study

Many manufacturing companies have been transforming their processes to incorporate more sustainable

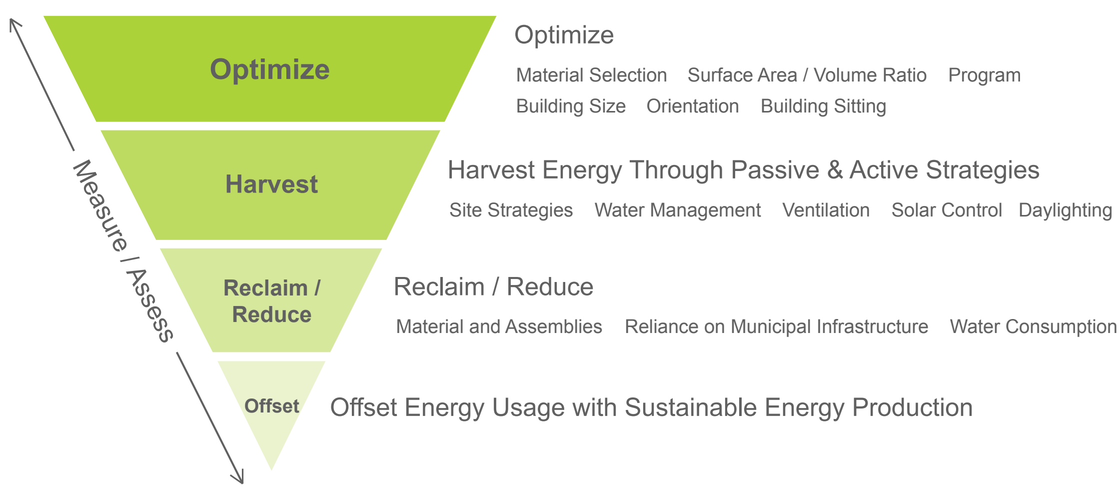


Figure 3: Design approach diagram.

practices. For instance, cradle to cradle programs are now common in many industries. Cradle to Cradle is a biomimetic approach to the design of systems modeled on nature's processes. Materials are viewed as nutrients circulating in healthy, safe metabolisms. It is a holistic, economic, industrial, and social framework that seeks to create efficient and waste free systems. Despite these efforts, the variety of materials necessary for building construction requires extensive manufacturing, which accounts for a significant spike in carbon emissions at the beginning of a project. To understand the impact of various materials and construction assemblies, six different assemblies were investigated as part of this study. This initial investigation considered an institutional Residence Hall as building type and assumed a basic bar volume located in New York City with a 60 year lifespan. The footprint of the building was 520'-0" x 60'-0" with a regular bay system of 52'-0" and four levels of 11'-0" height floor to floor (Figure 4).

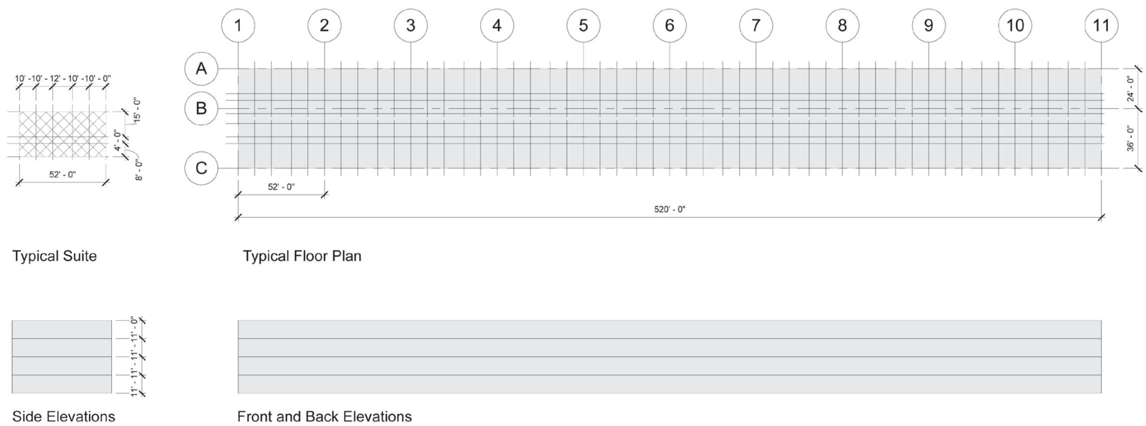


Figure 4: Building parameters used to investigate carbon footprint impact of six different construction assemblies. Top left: typical suite module, top right: building plan, bottom left: side elevations and bottom right: back and front elevations.

Residence Hall: A Comparative Carbon Footprint study of 6 different construction assemblies

Case Study Name	Columns & Beams	Floors	Roof	Foundation	Walls: Envelope	Walls: Long Int. Walls	Walls: Short Int. Walls	Walls: Bedrm Int. Walls
Steel Frame/Masonry	stl frame WF	hollow conc	hollow conc	concrete slab on grade	brick & 6" heavy ga. steel studs	4" light ga. steel studs	4" light ga. steel studs	4" light ga. steel studs
Block and Plank		hollow conc	hollow conc	concrete slab on grade	brick & 6" heavy ga. steel studs	4" light ga. steel studs	8" CMU	4" light ga. steel studs
Conc. Frame/Mtl.studs	conc frame	lt. frame wd truss 1/2" plywd decking	lt. frame wd truss 1/2" plywd decking	concrete slab on grade	wood Cedar siding 6" heavy ga. stl studs	4" light ga. steel studs	6" heavy ga. steel studs	4" light ga. steel studs
Metal Framing		open web stl joist reinf conc topping	open web stl joist reinf conc topping	concrete slab on grade	wood Cedar siding 6" heavy ga. stl studs	4" light ga. steel studs	6" heavy ga. steel studs	4" light ga. steel studs
Conc. Frame / Wood	conc frame	lt. frame wd truss 1/2" plywd decking	lt. frame wd truss 1/2" plywd decking	concrete slab on grade	wood Cedar siding 2"X6" wood studs	2"X4" wood studs	2"X4" wood studs	2"X4" wood studs
100% Wood	Wd frame	lt. frame wd truss 1/2" plywd decking	lt. frame wd truss 1/2" plywd decking	concrete slab on grade	wood Cedar siding 2"X6" wood studs	2"X4" wood studs	2"X4" wood studs	2"X4" wood studs

Figure 5: Comparative carbon footprint study for six construction assemblies.

The study first considered two typical construction assemblies used in residence halls: 1) Brick cavity walls with steel structure and 2) Block-and-plank floor system. Four additional assemblies also used in residential applications were studied as well: 3) Concrete frame structure with metal stud walls and wood envelope, 4) Metal framing structure with wood envelope, 5) Concrete frame with wood stud walls and envelope and 6) 100% wood frame with wood studs and envelope (Figure 5).

Some constants between these six assemblies remained: floors included a layer of gypsum wall board (GWB) and latex paint under them; roofs included membrane, vapor barrier, insulation and layer of GWB under; envelope walls included insulation, vapor barrier, GWB and latex paint; and all interior walls included a layer of GWB and latex paint on both sides. Comparison was performed using Athena Impact Estimator for Buildings, a computer modeling program developed by the Athena Institute. It considers the environmental impact of material manufacturing, including resources extraction and recycled content, related transportation, on-site construction, regional variation in energy use, transportation and other factors, building type and assume lifespan, maintenance, repair and replacement effects, demolition and disposal, and operating energy emissions and pre-combustion effects.

Comparative analysis was performed focusing specifically on the following criteria:

- Embodied primary energy use
- Global warming potential
- Solid waste emissions
- Air pollutants
- Water pollutants
- Weighted resource use

The comparative analysis revealed a series of important carbon emission statistics. The research showed that concrete floors had one of the highest pollutant potentials. Two factors likely yielded this result: first, obtaining cement is an energy intensive process and secondly, transportation has a profound impact if the precast concrete is shipped from Canada, as is often the case in New York State. The pollutant potential of concrete was shown to be higher than steel and timber. According to the United Kingdom's National Green Specification, for every ton of cement produced, approximately 1 ton of CO_2 is produced from chemical reaction and the burning of fossil fuel[4]. Additionally, cement production is responsible for about 7-10% of the world's total CO_2 emissions. While these staggering statistics are concerning, concrete manufacturers are investing in research to remediate concrete's CO_2 footprint[5]. There are cement substitutes available such as Pulverized Fuel Ash (PFA), also known as 'fly ash,' that can replace up to 30% of regular Portland cement and Ground Granulated Blast-furnace Slag (GGBS), which can replace up to 90% of Portland cement. Steel assemblies also have a high pollutant potential due to embodied energy in the manufacturing process despite the fact that the industry already incorporates reused scrap metal in its manufacturing. One of the comparative charts in the Athena Impact Estimator for Buildings program focuses on eutrophication. This is an increase in chemical nutrients—compounds containing nitrogen or phosphorus—in an ecosystem, and may occur on land or in water. This excess of nutrients results in excessive plant growth and decay, which in turn reduces the amount of oxygen in the water and constitutes severe reductions in water quality, fish, and other animal populations. When steel structure was included in the construction assembly, the eutrophication potential increased. It has been difficult to determine at this point what factors take place in the steel manufacturing process to yield this result. Another interesting result of the study is that wood and steel stud walls are comparable

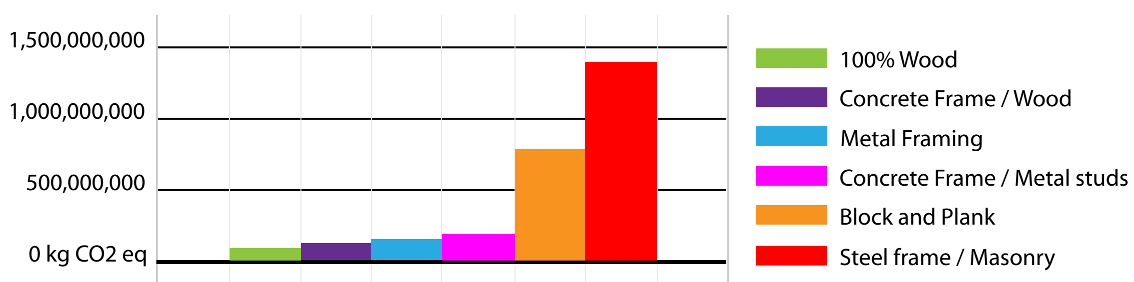


Figure 6: Carbon footprint impact of six construction assemblies.

in pollution potential both in manufacturing and construction process. Steel studs already incorporate large percentages of recycled content, while wood studs might be considered in buildings with a long lifespan if carbon sequestration is intended.

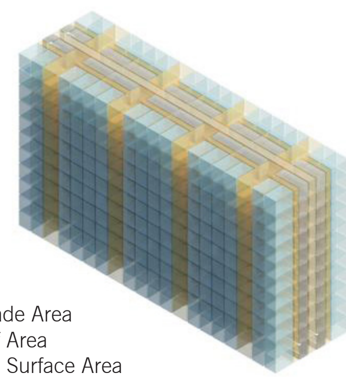
The six construction assemblies studied were ranked for their carbon footprint (see Figure 6). The following chart illustrates how ‘Steel Frame/Masonry’ and ‘Block and Plank’ resulted in the most CO_2 pollution. The analysis showed these two assemblies to be particularly polluting in the manufacturing and construction process categories. The assembly that incorporated 100% wood, ranked lowest in carbon footprint. This was expected as wood is a rapidly renewable material and also naturally sequesters CO_2. The three assemblies that follow it are only a few degrees more polluting, with the main differentiator being their structural material.

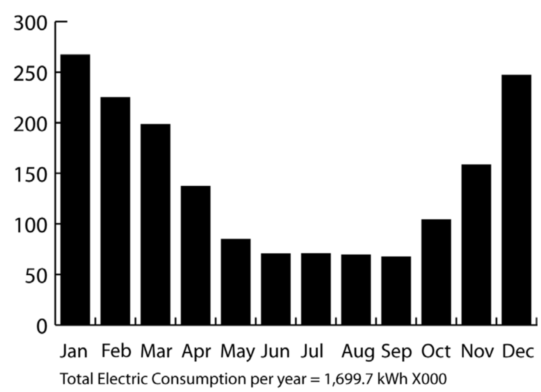
Many factors should be considered in the material selection process, including material performance, its use and location in the building, regional availability, durability given the intended exposure and use, indoor air quality safety, etc. When assessing construction assembly options, ability to act as thermal mass must also be considered. The key issues to understand in terms of materials’ carbon footprint are the extraction of raw materials, their processing and manufacture and transportation involved from extraction to construction site. Furthermore, some materials produce more waste than others during the construction process. In some cases, this can be mitigated by specifying optimum sizes. The end-of-life of the material and its potential for reuse or recyclability should also be considered. If this potential

Figure 7: Volumetric compositions: “Thin Tall Tower,” “Thin Low Bar,” “Cube with Atrium,” and “Village Grouping.” Energy model data courtesy of Cosentini Associates.

“Thin Tall Tower”

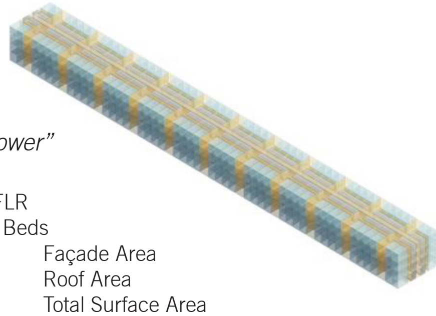
12,480 GSF/FLR
11 Floors, 350 Beds
64,320 SF Façade Area
12,480 SF Roof Area
76,800 SF Total Surface Area
1,497,600 CF Volume
137,280 GSF Program Area
SA / V Ratio = .05
1,699,700 kWh Total Electric Consumption per Year

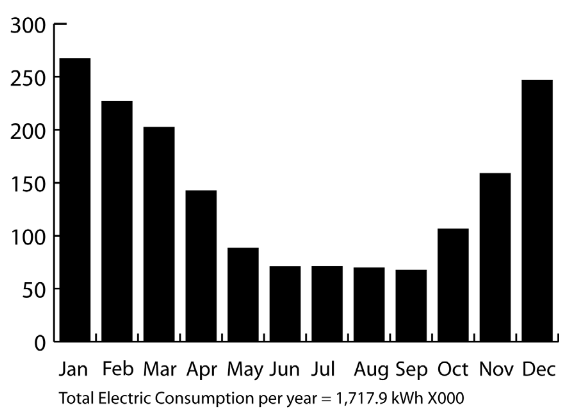




“Thin Low Tower”

34,320 GSF/FLR
4 Floors, 352 Beds
60,896 SF Façade Area
34,320 SF Roof Area
95,216 SF Total Surface Area
1,510,080 CF Volume
137,280 GSF Program Area
SA / V Ratio = .06
1,717,900 kWh Total Electric Consumption per Year



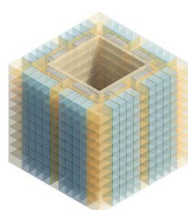


exists, dismountable connections should be detailed. Overall, optimization and reduction of materials should be part of a carbon footprint minimization plan.

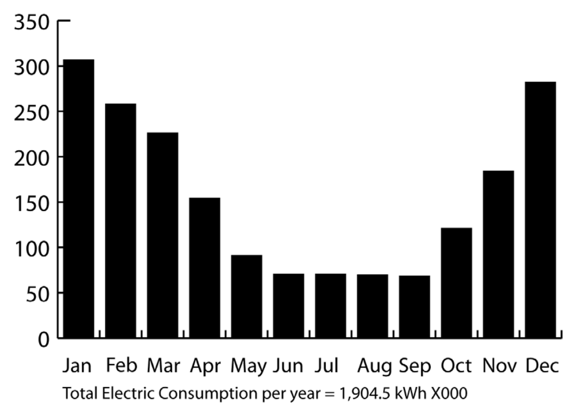
1.2 Energy Optimization: Surface Area / Volume Ratio

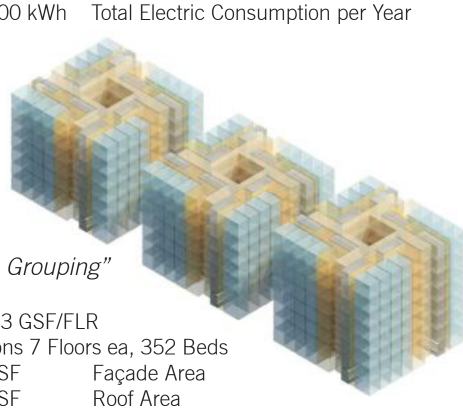
The energy required for operating a building is directly related to its form and solar orientation. The surface area to volume ratio relationship is important because the skin of the building is the surface through which heat escapes. Controlling heat exchange, strategic sun exposure and shading and water retention and extraction are important parts of balancing energy requirements throughout the seasons. Four different volumetric configurations were analyzed for energy efficiency using eQUEST, a QUick Energy Simulation Tool, a free software available through the Department of Energy (DOE-2). It is a comprehensive hour-by-hour simulation; daylighting and glare calculations integrate with hourly energy simulation. The data noted here was inputted into this energy model software. Each configuration assumed ideal solar orientation and incorporated forms typical of Residence Halls (see Figure 7). The energy model established a common denominator for all schemes: R-21 in roof, R-8 continuous insulation with R-13 batt insulation in walls, R-10 board perimeter insulation at floor slab for a distance of 2 feet, 30% glazing all around envelope surface, U-55 [imperial] glazing and SHGC - 0.40. The R value is a measure of thermal resistance in materials, which refers to the material's ability to conduct heat. In the U.S.A., R-values are given in units of ft^2•°F•h/Btu. The bigger the number, the better the building insulation's effectiveness. Increasing the thickness of an insulating layer increases the thermal resistance. R-value is the reciprocal of U-value. The

"Cube with Atrium"



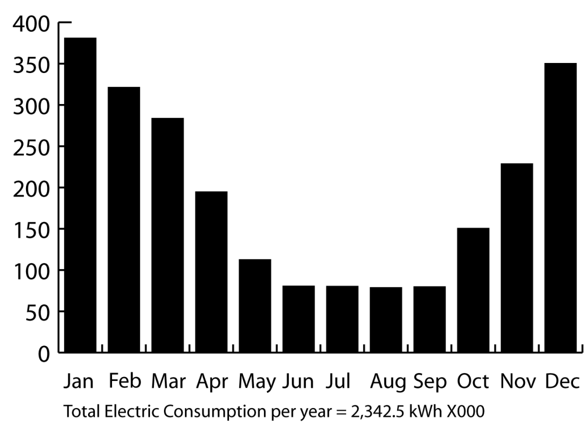
12,544 GSF/FLR
11 Floors, 350 Beds
62,920 SF Façade Area
16,900 SF Roof Area
79,820 SF Total Surface Area
2,028,000 CF Volume
137,984 GSF Program Area
SA / V Ratio = .04
1,904,500 kWh Total Electric Consumption per Year





"Village Grouping"

7,100 x 3 GSF/FLR
3 Pavilions 7 Floors ea, 352 Beds
86,176 SF Façade Area
32,028 SF Roof Area
118,204 SF Total Surface Area
1,916,882 CF Volume
156,200 GSF Program Area
SA / V Ratio = .06
2,342,500 kWh Total Electric Consumption per Year



U-value (or U-factor), more correctly called the overall heat transfer coefficient, describes how well a building element conducts heat. The Solar Heat Gain Coefficient (SHGC) measures how well a window blocks heat from sunlight. The SHGC is the fraction of the heat from the sun that enters through a window. SHGC is expressed as a percentage between 0 and 1. The lower a window's SHGC, the less solar heat it transmits. For the purpose of this comparison, cooling loads and assumed shading was a constant denominator. The floor breakdown was also the same in all schemes:

75% suites
5% laundry
8% corridor
2% mechanical
5% lobby
5% lounge

The initial hypothesis assumed the "Cube with Atrium" scheme was going to have the best performance given its compact shape. Instead, the analysis indicated a tighter volumetric composition that exposes the least amount of surface is most desirable for energy efficiency. The schemes "Thin Tall Tower" and "Thin Low Bar," both with double loaded corridors, performed best, followed by "Cube with Atrium" which had single loaded corridors. The worst performer was the "Village Grouping" scheme where increased surface area and circulation cores contributed to inefficiency. Since this analysis was devoid of materiality, it allowed a focused look at energy performance given surface and volume ratios. However, surface to volume ratios are not the only indicator of energy performance. Efficient location of circulation cores, appropriate insulation, total square footage and efficient floor plate with adequate program fit outs are important too. In many situations, site constraints might have an impact in form efficiency and possible solar orientation. These initial volumetric studies were based on large residence hall programs. The case study section that follows below considered lessons learned from this explorations and adopted strategies for a smaller residence hall program.

2.0 CASE STUDY: RESIDENCE HALL AT ROGER WILLIAMS UNIVERSITY

In order to further test sustainable strategies for achieving carbon neutrality in a Residence Hall, a site was selected for a case study at Roger Williams University in Bristol, Rhode Island. The site was already designated as a district for future housing in the Residence Life Master Plan. The site is also adjacent to a 349-bed Residence Hall that Perkins and Will (Boston Of-

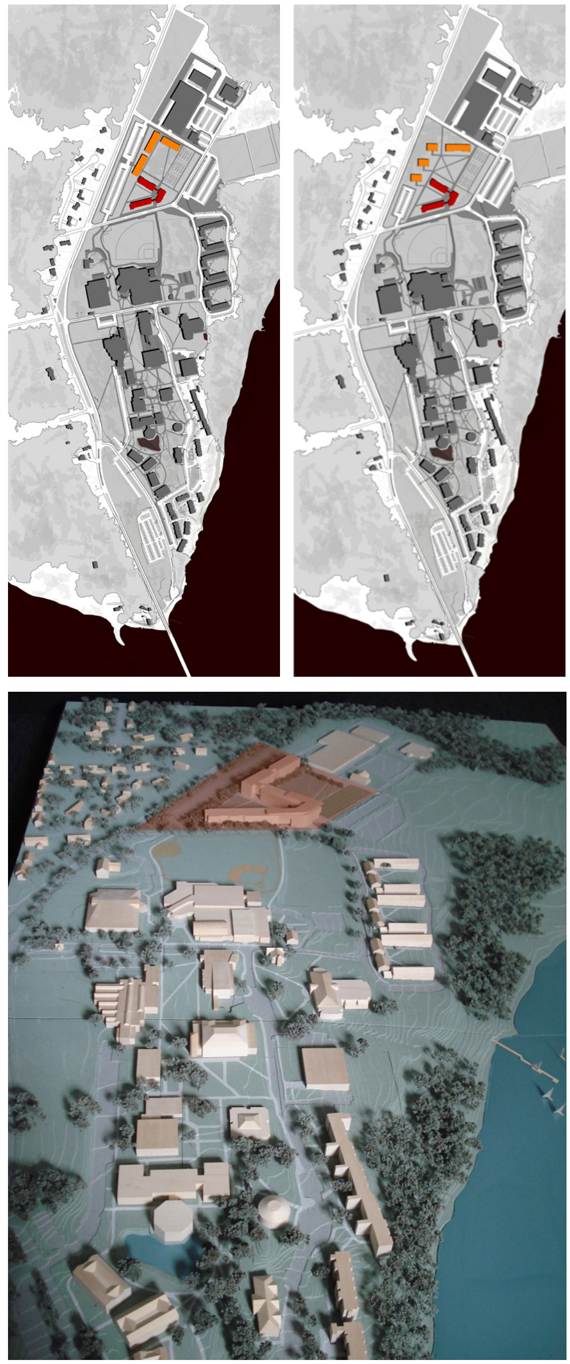


Figure 8: Residence master plan, proposed master plan revisions and campus model indicating site area.

fice) designed and completed in fall 2009. This existing building was designed to achieve LEED Silver certification, which led the design team to learn about regional conditions and the University's commitment to sustainability. The University is promoting sustainability through educational programs for the campus community, teaching students how to incorporate sustainable strategies into their everyday lives. A group of students called Eco-Reps conduct new student orientations that educate on energy and water conservation and recycling.

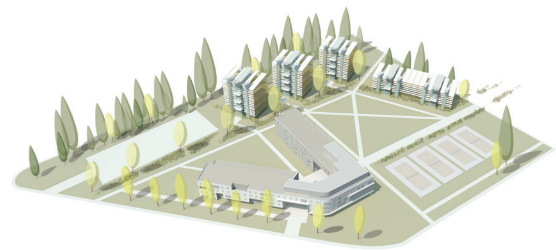


Figure 9: Site precinct illustrating existing "U" shape residence hall, campus green connections, a "low bar" residence hall (subject of the case study), three future residential towers, tennis courts, an existing parking area and seasonal landscape.

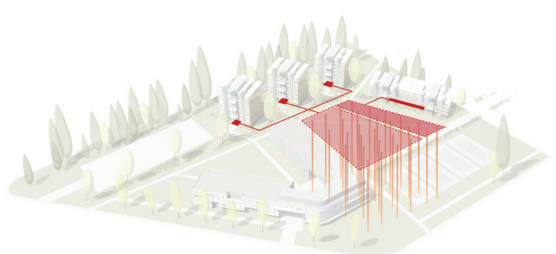


Figure 10: Geothermal wells located in campus green and zoned to accomodate to future growth.

The University's goal for the 2009/2010 academic year is to increase recycling in Residence Halls by 20%, as well as improve rates of water and power conservation.

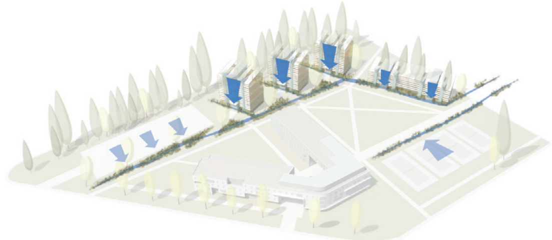
The Residence Life Master Plan located future Residence Hall buildings north of the existing Residence Hall (Figure 8). The orientation of these proposed buildings followed a directionality established by the northern campus grid and created a green space connected to the existing Residence Hall. The case study proposed maintaining the established design composition, but proposed rotating the future residence halls to align with true South. This simple move retained the integrity of the original Residence Life Master Plan while capitalizing on a solar orientation that would maximize the inclusion of passive sustainable strategies.

The University has projected a future need of approximately 500 beds. This precinct would house 512 beds; 128 of which are included in the case study, with the remaining 384 beds to be housed in the future residential towers within the precinct. With this bed count and challenge to make the building carbon neutral, the case study considered a series of site passive and active strategies. An important factor in the controllability of systems is the students' awareness of the systems and how they work. Students should be educated about the sustainable strategies included in the design and how to maximize the effects of those strategies through their own behavior and practices, such as operating the windows to control cross ventilation.

2.1 Site and Building: Passive and Active Strategies implemented

Working from the University Master Plan, the case study also sought to minimize site disturbance and to create an appropriate density, shading with seasonal landscape that incorporates native plants, pervious pavement and zoning for future growth and geothermal wells (Figure 9).

Geothermal wells are located in the green space adjacent to the existing and new buildings (Figure 10). Geothermal power is power extracted from heat stored in the earth. One way of reaching the heat source is by digging a well. A geothermal heat and cool pump is the central heating and/or cooling system that pumps heat to or from the ground. When the ground is considered a 'finite' heat source, the pump uses the earth as a heat source in the winter and as a heat sink in the summer. This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems. When the ground heat is considered an 'infinite' heat source, it usually means that a constant flow of water runs through it replenishing the ground heat constantly. This design allows running the system in extracting mode only because it is not necessary to recharge the ground heat. The first phase requires 5 standing column wells, each 1,500 feet deep and spaced 60 feet on center. Geothermal system selection should be based on geography. Standing column wells typically work well in New England and would work for this location. In other areas, such as the Midwest, the well system will most likely be closed loop which would include 50 wells 400 feet deep spaced 15 feet on center. The two possible scenarios for implementing ground source heat pump are discussed in detail in the following sections.



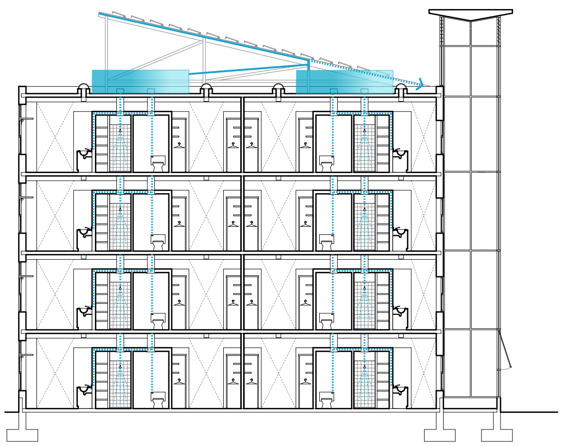


Figure 11: Site water management captures storm water runoff in bio-swales. Strategies at a building scale are represented in the building section.

Scenario 1: "Finite" Heat Source
This scenario assumes well water and ground are a finite heat source. This means that on an annual basis, there needs to be an overall balance in the extraction of heat. This balance is achieved by using the earth as a heat source in the winter and as a heat sink in the summer. During winter, heat from the ground is used to heat the building and for domestic water heating. During summer, heat is put into the ground as the building is cooled. If these heat flows are not balanced, the ground and well water will cool down (if too much heat is extracted), or heat up (if too much heat is rejected), reducing the efficiency of the system or resulting in system failure. In other words, in the "finite" heat source scenario, the system will be heating-dominant and a supplemental heat source would be required. This supplemental heat source can be fulfilled with solar thermal collectors and air to water heat exchangers.

Scenario 2: "Infinite" Heat Source
This scenario assumes there is significant water migration through well field to model the well field as essentially an "infinite" heat source or sink. This represents an ideal scenario if no cooling loads are desired and will have limited applicability. This scenario alleviates the need to balance the heating and cooling loads, so the system could theoretically be used solely in the heating mode. The "near field" ground temperature will still be affected by the system.

Water Management strategies considered at site scale include capturing storm water runoff in bio-swales (Figure 11). Bio-swales are a type of bio-filter or landscape swale drainage designed to remove silt and pollution from surface runoff water. They are filled with vegetation, compost, and/or riprap. As the water flows through them, pollutants and silt are trapped while at the same time the runoff is treated before releasing it to the watershed or storm sewer. Pervious paving would also allow water to infiltrate through the ground thus preventing storm water from escaping the site. At the building scale, a series of strategies were considered: rainwater harvesting, on-site graywater treatment, graywater reuse and low-flow showerheads, faucets and toilets. Benefits for capturing and reusing water would be difficult to calculate in analyzing the overall carbon emission reduction. For the purpose of the study, we explored water treatment and harvesting through passive strategies thereby reducing the energy used to treat water off-site.

Ventilation strategies considered seasonal prevailing winds. While spring winds prevail from northeast, northwest and south directions, fall winds come primarily from west and south. In the winter, prevailing winds are northwest (Figure 12). Evergreen trees on the north side mitigate winter winds (Figure 13). The siting of the buildings redirect winter winds towards the shared green space.

Southern summer winds are captured through operable windows in the lounges that allow the winds to permeate the building envelope (Figure 14). During humid days in the summer months, occupants can use ceiling fans to mitigate uncomfortable conditions. To over design a cooling system would be inefficient given the limited number of uncomfortably-hot days in the New England summer. Instead, occupants should be made aware that 3% to 5% of the time thermal comfort may not be achieved. Occupants should also be educated on how to operate the windows for efficient air flow. Buildings are sited in a staggered pattern to prevent wind flow blockage. A natural ventilation passive flow system redirects wind through the building (Figure 13). Deciduous trees shade the building's South façade and heat chimneys assist in removing warm air from interior spaces. An important advantage of using natural ventilation is that the building does not need to be mechanically cooled, therefore, the energy load required for a cooling system is dismissed. In this case, the only energy load considered for cooling is the electricity to run ceiling fans during hot and humid summer days.

The building plan is organized in 8 suites, each shared by 4 students. Each floor has access to two stairs, an elevator, a recycling room, a janitor's closet and an internal corridor. The living room of each suite is located adjacent to the common lounges. This planning strategy not only creates a strong sense of community, but also allows for summer ventilation through operable windows (Figures 15 and 16). Students in each suite have the capacity to control cross ventilation through the unit by

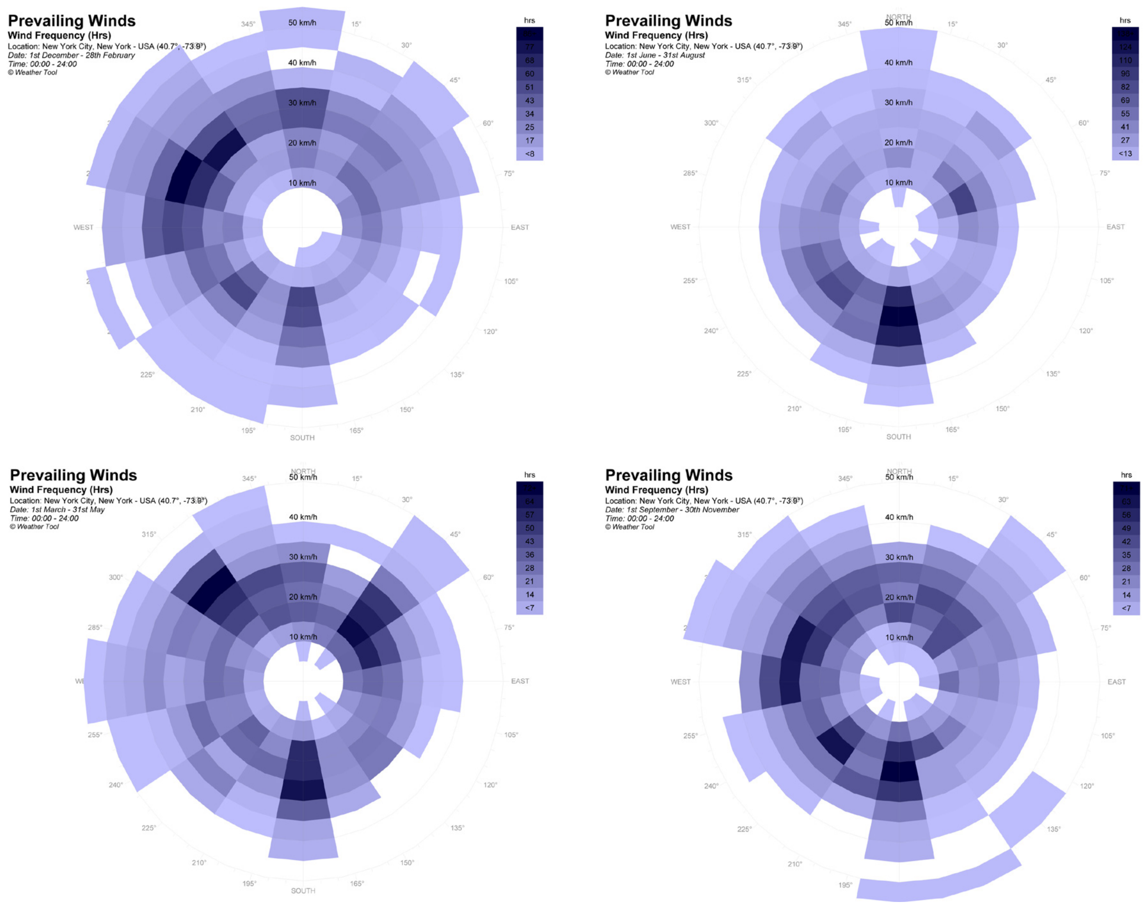


Figure 12: Winter, Summer, Spring and Fall wind frequencies.

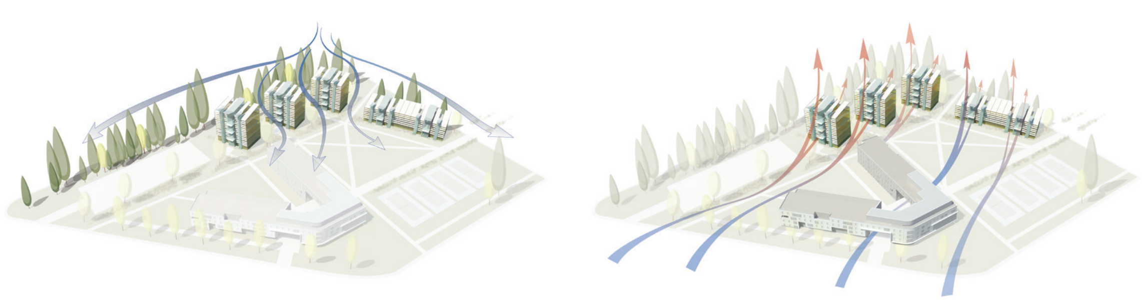


Figure 13: Winter and Summer winds.

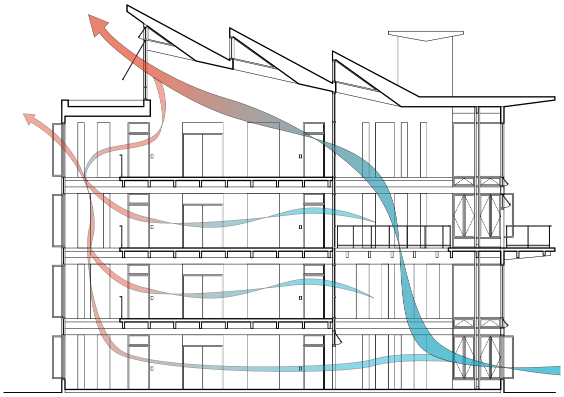



Figure 14: Section through lounges illustrate exterior and interior operable windows allowing wind to move through the space. These common spaces are identifiable in the building volumetric composition as “four-season” porches. Heat chimneys flank the common lounges and serve to ventilate southern-exposed suites during summer months.

opening windows. Wetcores are detached and lowered from the ceiling to facilitate wind flow across the suite. The depth and height of the living rooms and bedrooms were studied for passive air flow. The ceiling height of the spaces was set to 11’-0” in order to allow for a better cool-warm air cycle within spaces (Figure 17). In support of this strategy, an operable window was introduced above a 2’-0”-deep light shelf. Other considerations for passive air flow included offseting window openings to maximize air mixing and lifting furniture from the floor by six inches, while keeping it low from the ceiling to prevent air blocking. Also, living room windows were conceived as doors that could swing open to bring in air.

Solar angles were studied to minimize heat gain during the summer and capture heat during the winter. The building is oriented primarily north-south with passive and active heat gain systems facing south. Shading is incorporated in the south façade to prevent heat gain during the summer. In the main skin of the building, this shading device is actually a photovoltaic panel system which sits on a frame that is attached to the façade and roof (Figures 18 and 19). The angles of the panels could be permanently fixed to a degree that captures the sun during the higher demand season. For this location, at latitude 41.6 degrees N, a fixed angle could be set at 60 degrees representing the highest demand season. Some manufacturers would recommend the fixed angle should equal the latitude. However, to achieve best performance of the photovoltaic panels, it would be best to use a system that could be angled differently every season. Various companies now offer

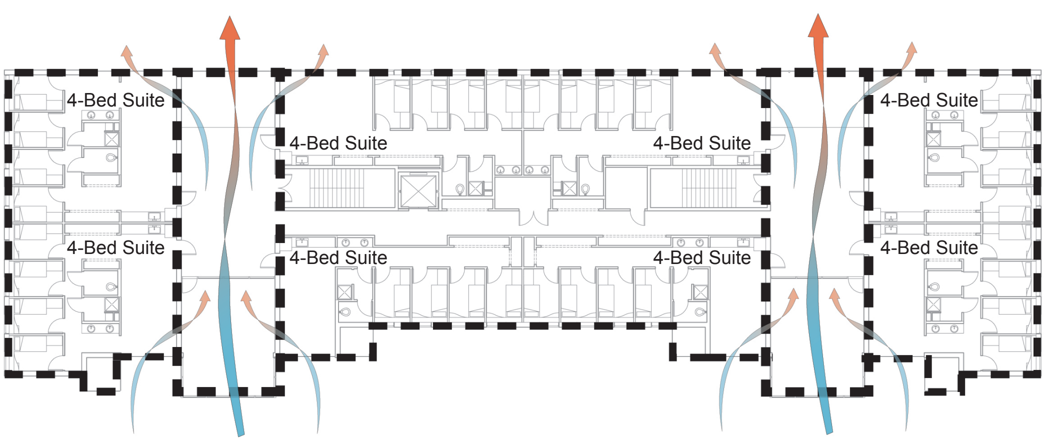


Figure 15: Building Plan illustrating summer winds crossing through lounges and how winds are directed into lounges from adjacent living rooms. The dashed lines represent the capacity to “zip-down” the building’s envelope through operable windows to allow cross ventilation.

these types of systems, an example being a louver system to which a photovoltaic film could be attached. The louver system can be programmed to respond automatically to the season's solar position. In the lounges, solar shading is provided by cantilevered roof elements.

In winter, the lounges capture solar heat and retain that heat gain with thermal mass (Figure 20). The lounges, much like four-season porches, have a southern portion separated by glass. The outer glass has a lower performance, making more heat gain possible. This heat is transferred to the concrete floors and the masonry walls that define the lounges. The floors and walls then transfer the heat gained to the adjacent living rooms. Heat is also captured in the heat chimneys which are enclosed by low-performing glass to control heat gain (Figure 21). Some of this heat is directly transferred into the suites. A basic solar collector concept works as follows: The amount of heat that a solar collector can capture is a function of the temperature of the air or water inside the collector. Although counterintuitive, the lower the temperature, the more heat it collects.

The solar chimney works as follows: outside air is introduced at the bottom of the chimney in the winter. Solar energy is absorbed by the chimney walls, heating this air as it moves up the chimney. It is then brought into a ventilation air unit, where it is heated further by the heat recovery wheel, which is a rotary heat exchanger that operates on the air-to-air principle of heat transfer. Additional heating (if required), is produced by a hot water heating coil. The conditioned air is then distributed through the building. At the same time, exhaust air from other building systems is passed through the other side of the heat wheel, transferring its heat to the ventilation air. In the summer, outside air bypasses the chimney and windows inside the chimney can be opened from the suites to allow cross ventilation.

Other winter heating strategies are illustrated in Figure 22. The heart of the heating system is a water-to-water heat pump, which consists of all the major components found in any piece of cooling equipment (refrigerator, air conditioner, chiller, etc). The major components are the evaporator (cold coil), condenser (hot coil), compressor and expansion valve. The compressor (electric) does the work to absorb heat from the evaporator with refrigerant and transfers it to the condenser. The key to the system is a phase change of the refrigerant (liquid to vapor and back again), due to the pressure change created by the compressor and expansion valve. The

Figure 16: Plan of corner suite illustrating summer cross ventilation and section through suite wetcore.

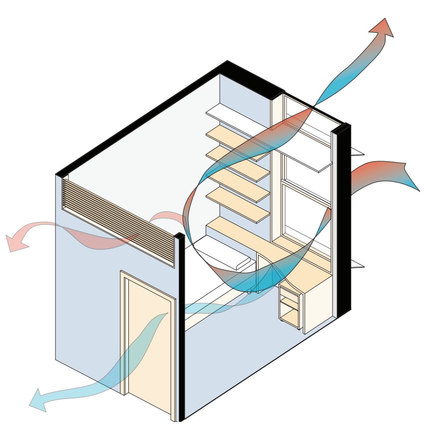


Figure 17: Cool/warm air cycle within bedroom.

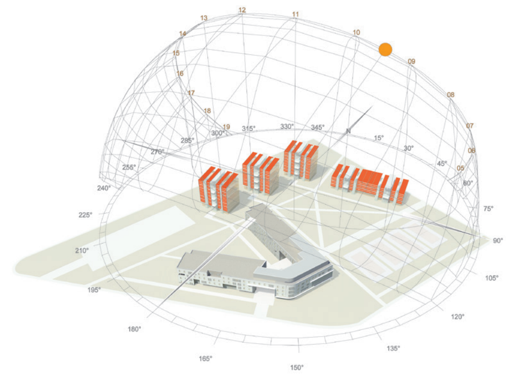


Figure 18: Solar angle study. Orange surfaces represent photovoltaic panels attached to the building's south façade and roof.

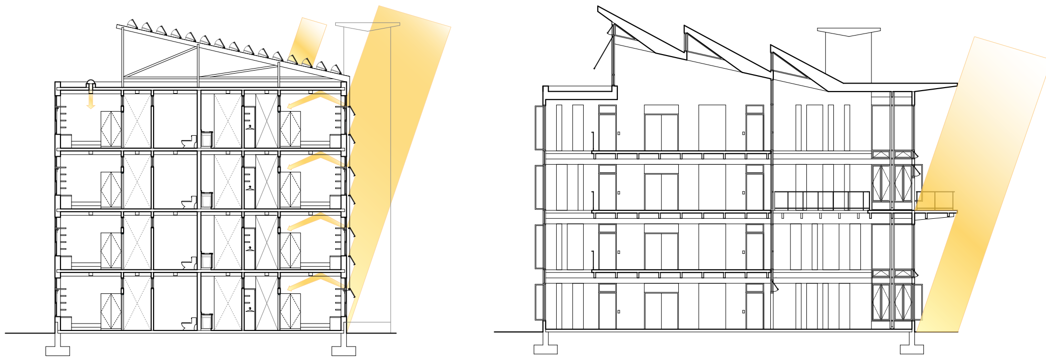


Figure 19: Section through bedrooms (left) illustrate a shading device that also acts as a photovoltaic panel system. South-facing bedrooms have light shelves to increase daylighting. Where possible, light tubes are incorporated in the top level of the building. Section through lounges (right) indicate cantilevered roof components that provide summer shade.

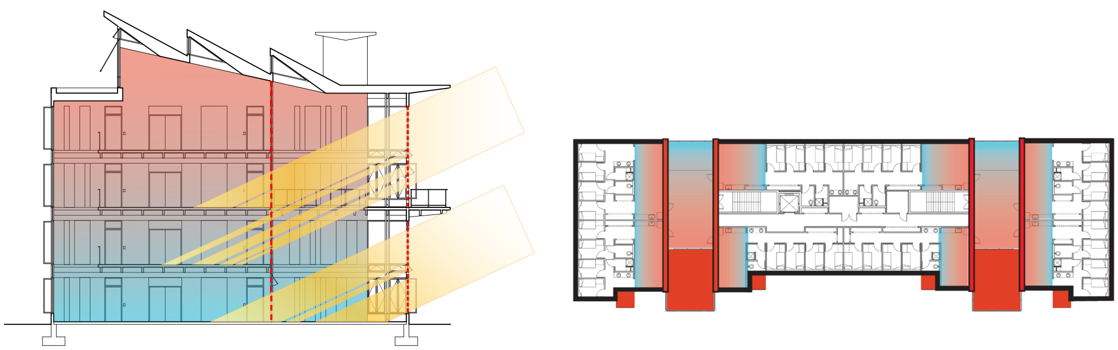


Figure 20: Thermal mass and thermal zones in the lounge and living room areas.

phase and pressure change result in significantly different temperatures in the evaporator and condenser. In a ground source heat pump, ground water is pumped from the ground to the evaporator and heat is extracted from the ground water and transferred to the condenser. A separate hot water loop absorbs heat from the condenser, where it is then pumped to heating coils to be used to heat the building and domestic water. The heat pump can also be used to create chilled water by reversing the refrigerant flow (through automatic valves in the unit) in the heat pump, taking heat from the chilled water loop and rejecting it to the ground water loop. Supplemental heating can be provided with solar thermal collectors and a water-to-air heat exchanger.

Daylighting studies were modeled using Ecotect software for the suite's living room and a typical bedroom (Figures 23 and 24). These models helped establish appropriate daylighting levels in both spaces, zone the building to meet general lighting needs and develop spatial proportions to optimize daylight for tasks. An interior 2'-0'"-deep light shelf bounces light through the spaces, optimizing daylight for tasks such as studying in the bedrooms or socializing in the living area. The optimal opening for the living room is 50% glazing in the exterior wall with a horizontally oriented window opening. The overall living room dimensions varied slightly for northern and southern exposures. For the bedroom, 30% glazing in the exterior wall was more appropriate given the small size of the space and a vertically oriented window opening was more appropriate for the light levels needed.

2.2 Materials Selection and Assembly

In general, the study of material assemblies considered performance (including durability, strength and maintenance), the lifespan of the building (determined to be 80 years), materials' end-of-life (potential for reuse, recyclability, deconstructability), availability of local reclaimed materials and the material's inherent carbon footprint. A balance of all these concerns was essential in establishing the following selection:

- Footings: 4" slab on grade concrete
- Structure: Glued laminated columns and beams
- Floors: Concrete slab on glued laminated wood structure

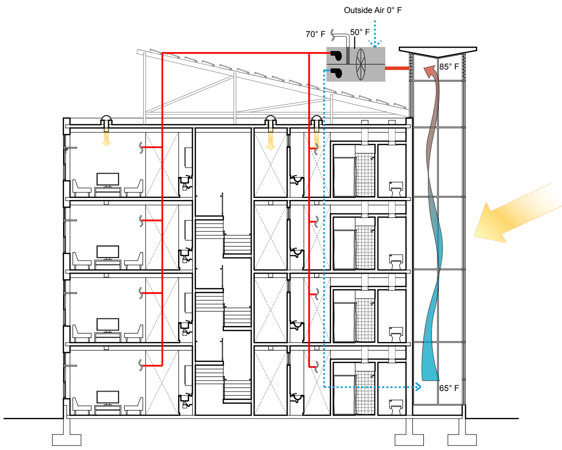


Figure 21: Heat chimneys. Design of heat chimney and air to air system, courtesy of Cosentini Associates.

- Roof: Wood joist
- Envelope Wall: Cedar wood siding, plywood, light weight plywood web, blown cellulose insulation, gypsum fibre board
- Interior Walls: 4" Wood studs, gypsum fibre board and latex water based paint
- Windows and Doors: FSC Wood / Glazing: Low-e T in Argon Filled Glazing, U (imperial units - assembly, not the center of glass) = 0.29, SHGC = 0.27, VLT = 0.66
- Millwork: FSC Wood

The use of these materials is represented in the lounge space illustrated in Figure 25. This communal space was seen as an opportunity to expose materials in a didactic way: The Forest Certified glue laminated wood sequesters CO_2, the argon-filled glazing controls heat gain, reclaimed/salvaged bricks represent waste redirected from landfills and reduces need for newly-manufactured materials, the furniture contains high recycled

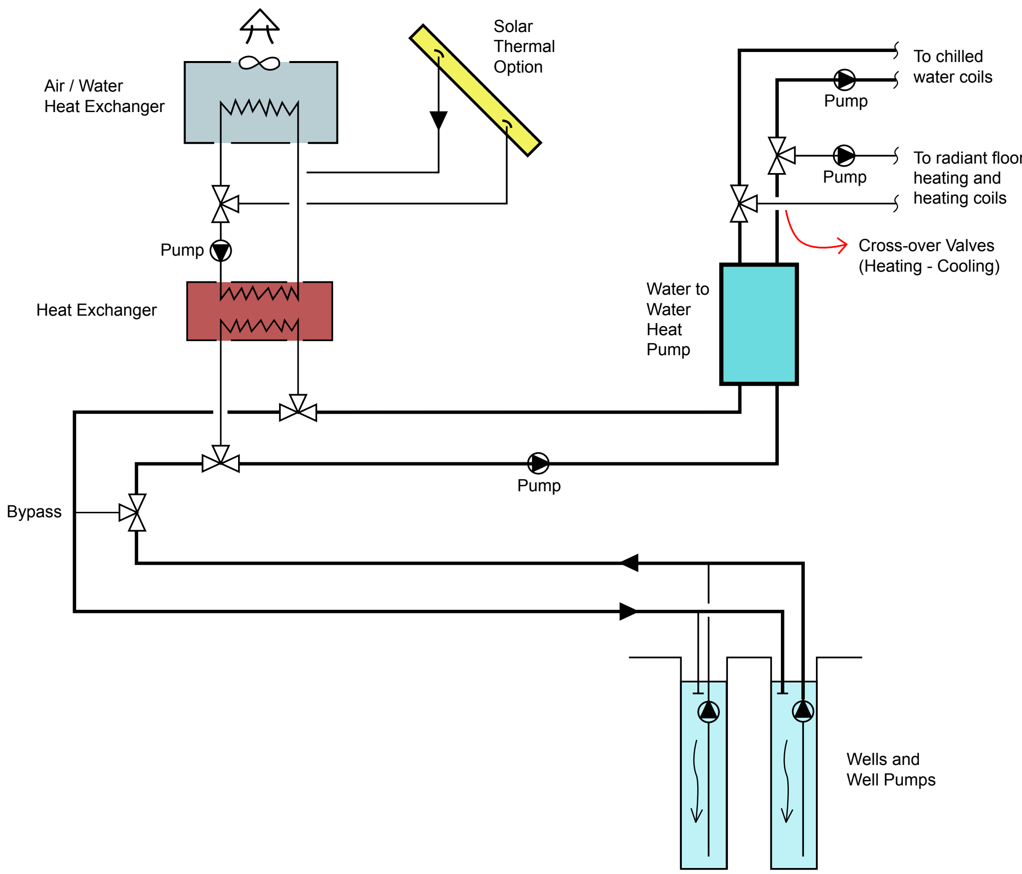


Figure 22: Heat Pump Flow Diagram, courtesy of Cosentini Associates.

content, the concrete contains high percentages of fly ash and local or modified aggregates, latex water-based paint throughout maintains air quality and dismountable detail connections allow for future material reuse.

Locally sourced reclaimed materials were researched in partnership with Planet ReUse, a brokerage company that locates, provides samples and secures reclaimed materials across the nation. Locally reclaimed materials usually come from buildings that are being demolished or renovated. Since these materials have already being manufactured and transported to the area, the main idea is to reuse them instead of taking them to landfills.

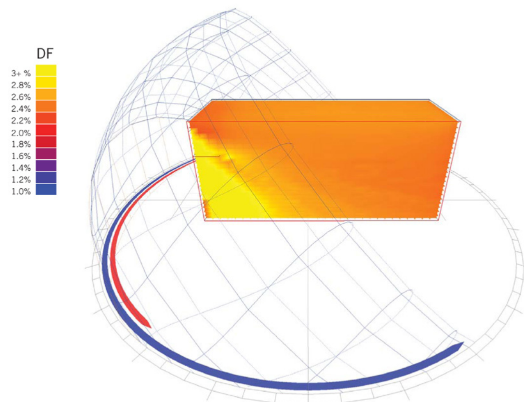


Figure 23: Living room daylighting study, Ecotect graphic generation.

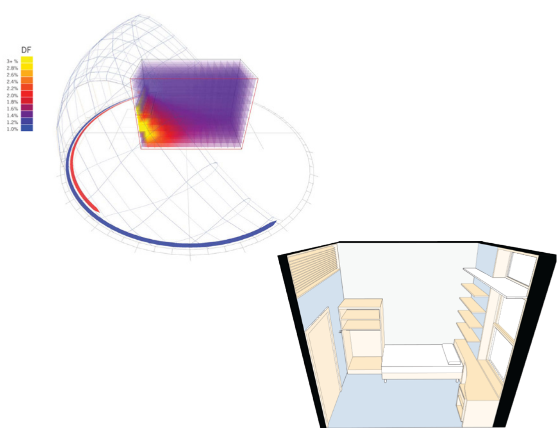


Figure 24: Bedroom daylighting study: to the left an Ecotect graphic generation and to the right, a perspective view of a typical bedroom illustraing the light shelf integrated with wood shelving. The orientation of the room diagram corresponds to the Ecotect image to the left.

The following is a partial list of locally-available materials:

- Interior commercial solid wood/core doors
- Exterior siding (cypress, cedar and other species)
- Light fixtures (depending look/energy requirements): sconces, 2'x4' and 2'x2' fixtures both strip and direct/indirect
- Structural steel (if structural steel framing is used)
- Interior wood for built-in shelving, beds, etc.
- Rigid insulation in certain areas
- Plastic laminate or solid surface tops/counters
- Reclaimed carpet tile in carpeted areas
- Exterior wall/face brick
- Paver brick for sidewalks and courtyard paths.

Since prefabrication minimizes construction waste, energy use and design costs, the possibility of prefabricated modular construction was investigated at building scale, suite scale and on the scale of individual spaces such as the kitchen and bathroom. In partnership with Kullman, a prefabrication contractor from New Jersey, a steel frame prefabrication scenario was studied. A cost estimate in 2009 dollars was provided by Kullman at $185-200 per SF, including complete inside of building and envelope, mechanical systems, elevators, and stairs. This cost estimate was for a building of about 57,000 SF with 120 beds. At the scale of the overall building, the building could be divided into components that could ship in 14' wide by 60' long maximum modules (Figure 26). Because prefabrication minimizes construction time at the site, the estimated schedule was 120 working days for shop construction, 15 days for setting it in place and 30 days for finishing work if no major mechanical systems were to be incorporated.

The suite was designed to comply with the maximum dimensions for shipping prefabricated modules. The suite could ship in three modules (Figure 27) or in indivudual components such as the kitchen, central wetcore and bedroom units.

The building's envelope was conceived as a super-insulated skin, with R40 values in walls and R60 in the roof. These higher R values moderate temperature changes, preventing extreme fluctuations. The building envelope consists of two types of glass. Low-performance glass used in the heat chimneys and south-facing four-season porches allows heat gain necessary to harvest solar energy inside the building. In this regard, these four-season porches and the heat chimneys act as thermal mass intake portals that heat inner masonry walls and the concrete floor during the winter. High-performance glass located in the inner layer of the four-season porch

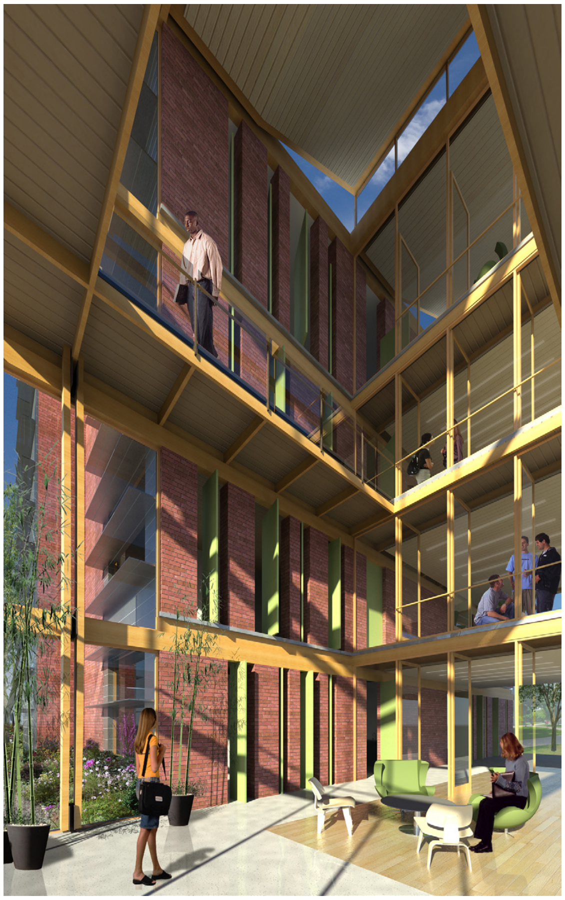


Figure 25: Typical lounge area, also referred to as a “four-season porch.”

modulates heat transmission. Operable windows located in this inner layer modulate adequate ventilation.

The building’s walls and roof could share a similar assembly concept (Figure 28). A lightweight plywood web with laminated flange provides flexibility in widths to increase insulation as necessary. Without compromising structural stability, the cedar wood siding could be reclaimed and backed by Forest Stewardship Council-Certified plywood. The interior blown cellulose has high recycled content and an R value of 3.70 per inch. Gypsum fiber board with a coat of water-based latex paint lines the interior spaces.

The materials’ embodied CO_2 and energy was measured using ‘Athena Impact Estimator for Buildings’ in order to understand their impact and the resulting offset requirements. A “baseline” design was compared against the case study’s “CO_2-neutral” design (Figure 29). The following numbers summarize the comparison. Unsurprisingly, the “baseline” design embodied far more CO_2 than the “CO_2-neutral” design. The greatest differentials are seen in the wall and beam and column assessments. The wall design of the “CO_2-neutral” residence showed nearly a 50% reduction in embodied CO_2 as compared to the “baseline” design. The wood structure also showed a significant reduction as compared to the steel structure of the standard design.

As a first step, optimization allows the design team to limit the amount of material needed to construct a building. By simply using less, the carbon footprint is reduced. The next step is to assess each possible ma-

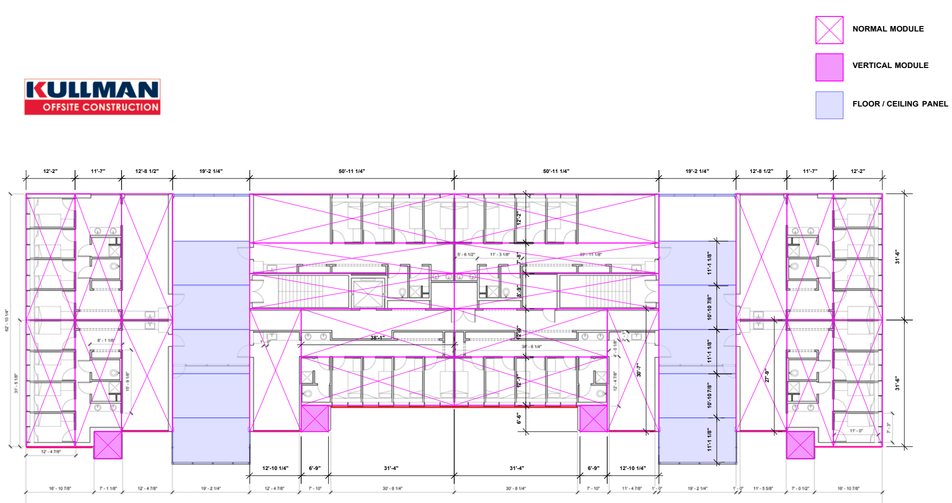


Figure 26: Building plan divided into shippable prefabricated modules. Modular division strategy courtesy of Kullman.

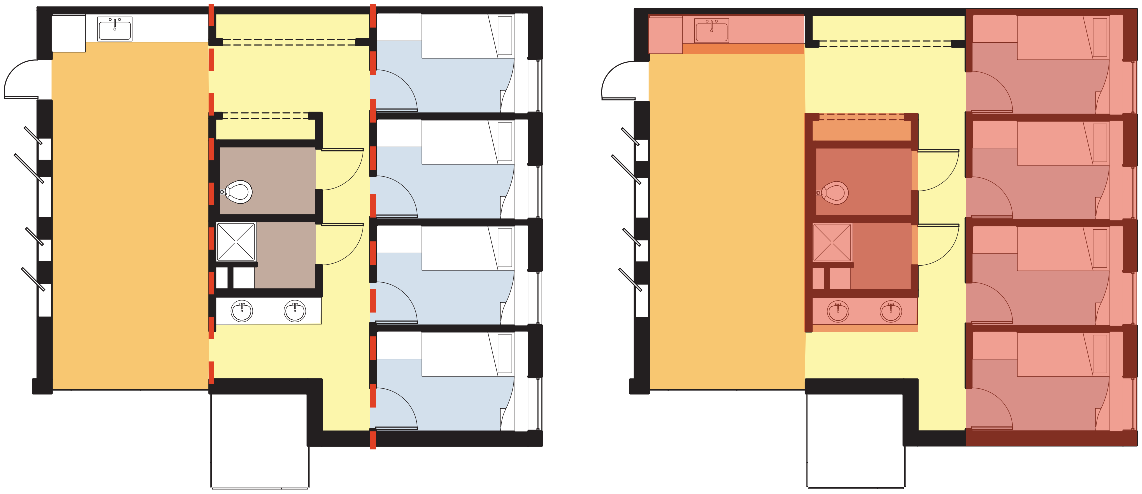


Figure 27: Suite could ship in three modules or in smaller components.

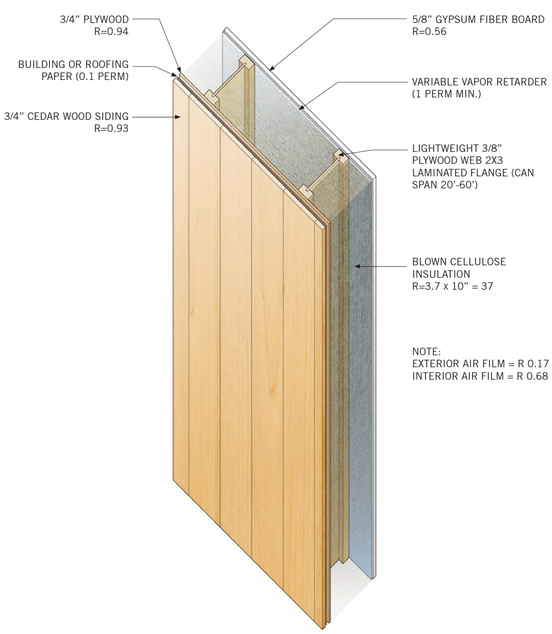
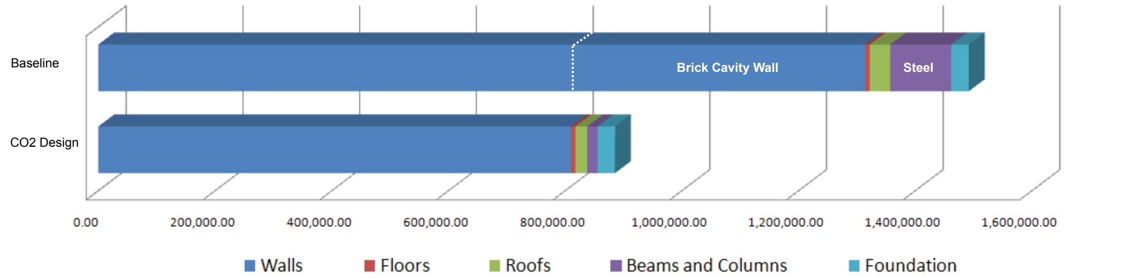


Figure 28: Wall assembly. The roof could have a similar assembly but would have a wider area for insulation to increase the assembly's R value from 40 to 60.

terial and make informed decisions based on the CO_2 impact analysis. As shown in this study, the selection of one material instead of another can make a significant difference in the overall carbon footprint of a building.

3.0 MODEL CONCLUSIONS AND ENERGY PRODUCTION OPTIONS

Based on energy usage assessment and strategies defined for the residence hall, a series of scenarios were studied to assess energy production options. eQUEST (QUick Energy Simulation Tool) was used to model the energy requirements of the building. This is the same software used for the studies presented in section 1.2: Energy Optimization: Surface Area/Volume Ratio. These scenarios, illustrated in Figures 30 to 32, demonstrate how occupant comfort levels play a role in energy loads, the advantages of daylighting and the benefits of incorporating Energy Star appliances and equipment. There are variations in the energy loads assumed for the following components: heating through electric baseboards or electric radiant floors, thermostat degrees set, daylighting inclusion or exclusion and refrigerator loads inclusion or exclusion. Constant assumptions in all three scenarios were electric hot water use and the inclusion of Energy Star appliances/equipment. Other common assumptions include: a building of 48,162 GSF, 4 levels and a total of 128 beds. The breakdown of the electric consumption per month is listed in each scenario and a corresponding color chart illustrates the values by electric load.



Baseline Design

Embodied CO_2 = 1,562,093.15 kg CO2 eq/kg

Embodied Energy = 26,632,030.21 MJ

CO2 Neutral Design

Embodied CO_2 = 926,140.72 kg CO_2 eq/kg

Embodied Energy = 14,008,460.83 MJ

Figure 29: Comparison on materials' embodied CO2 and energy: "Baseline" design vs. "CO2-Neutral" design.

In Scenario C, the refrigerator load was removed to understand the impact of the load in the overall calculation. It confirmed that the refrigerator is one of the biggest energy consumers. Therefore, an Energy Star refrigerator will significantly reduce energy load demands. The refrigerator accounted for 13.8% of the 20% reduction in miscellaneous loads that is achieved when all room appliances (including laundry equipment) are Energy Star.

The analysis of these scenarios highlights the importance of daylighting and its ability to reduce light fixture loads. When daylighting was accounted for, the area lights total energy consumption was reduced by 13%. It should be noted that Energy Star light fixtures could also contribute significant load reductions. When heating equipment's thermostats are reduced from 72 to 68 degrees, a decrease of 18% in space heat energy loads was achieved. This type of comparative analysis should be conducted throughout the design process in order to make the best decisions that will result in the most energy-efficient project possible.

3.1 Miscellaneous Equipment and Energy Usage

The case study carefully considered a list of miscellaneous equipment and appliances typically used by students and shared in a suite. Institutions could consider publishing a list of acceptable student-provided equipment that will minimize the building's operational cost and serve to support sustainable awareness. Some shared equipment such as the refrigerator could be provided by the Institution. Housing officials could also educate new student residents about everyday strategies to reduce energy usage in residence hall rooms. For instance, the residence hall might provide high quality-efficient overhead light fixtures, but students should be made aware of the most efficient light bulb type to be use in lamps they might bring with them. The following is a typical equipment list per bedroom and suite which has been modified from a typical list for energy efficiency and represents the data assumed in the project's energy model:

Equipment in each bedroom:
- Energy Star laptop computer
- Energy Star all-in-one printer
- Desk lamp
- Alarm clock
- IPod docking station
- Hair dryer
- Cell phone charger

Equipment Shared per suite:
- Energy Star refrigerator
- Energy Star microwave
- Energy Star TV
- Game systems
- Energy Star DVD

An energy analysis was developed to compare energy consumption using standard equipment versus Energy Star equipment (Figure 33). Data for this equipment was taken from the U.S. Environmental Protection Agency's Energy Star website, which list appliance's and equipment's kwh/yr energy consumption with assumed hours of use per day[6]. The website also provides savings calculators per equipment.

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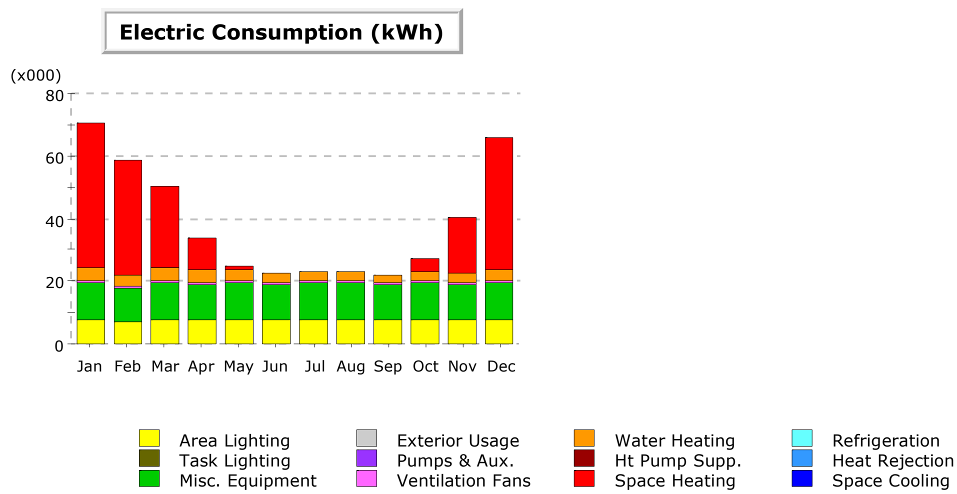

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	46.29	36.83	25.82	10.09	0.84	0.03	0.00	0.00	0.08	3.93	17.67	41.65	183.24
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.02	3.83	4.26	4.02	3.71	3.16	2.87	2.65	2.56	2.88	3.13	3.65	40.73
Vent. Fans	0.44	0.40	0.44	0.43	0.44	0.43	0.44	0.44	0.43	0.44	0.43	0.44	5.19
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	11.82	10.70	11.87	11.49	11.82	11.49	11.87	11.84	11.48	11.84	11.45	11.87	139.56
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	7.88	7.13	7.91	7.66	7.88	7.66	7.90	7.90	7.65	7.90	7.62	7.90	92.99
Total	70.46	58.89	50.30	33.69	24.70	22.77	23.08	22.83	22.20	26.99	40.29	65.51	461.71

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

- Electric baseboards set to 72 degrees
- Electric hot water
- No daylighting considered but reduced lighting loads applied
- Energy Star appliances/equipment
- Total Yearly = 461,710 kWh

Figure 30: Energy analysis scenario A. Courtesy of Cosentini Associates.

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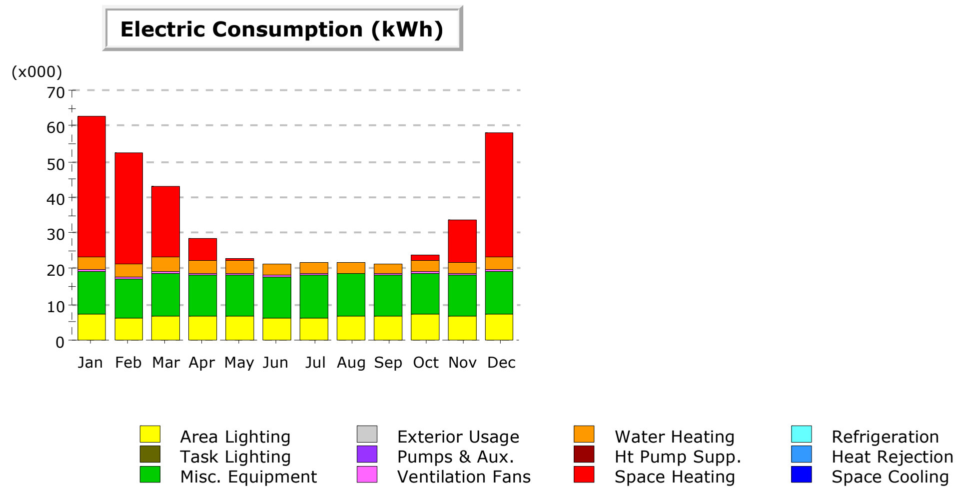


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	39.46	30.96	19.63	5.90	0.34	0.00	0.00	0.00	0.01	1.39	11.75	34.94	144.40
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.03	3.84	4.27	4.04	3.71	3.16	2.87	2.65	2.57	2.89	3.14	3.67	40.85
Vent. Fans	0.44	0.40	0.44	0.43	0.44	0.43	0.44	0.44	0.43	0.44	0.43	0.44	5.19
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	11.82	10.70	11.87	11.49	11.82	11.49	11.87	11.84	11.48	11.84	11.45	11.87	139.56
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	7.21	6.39	6.93	6.52	6.50	6.24	6.47	6.63	6.63	7.04	6.91	7.27	80.75
Total	62.97	52.30	43.15	28.38	22.81	21.32	21.65	21.56	21.12	23.61	33.68	58.19	410.74

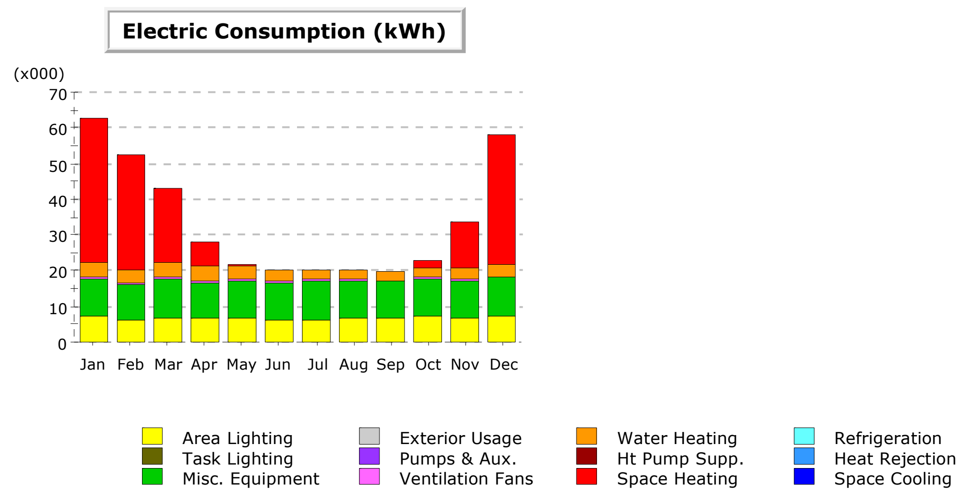
Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

- Electric radiant floors set to 68 degrees
- Electric hot water
- Daylighting controls / occupancy sensors considered = less lighting loads
- Energy Star appliances/equipment
- Total Yearly = 410,740 kWh

Figure 31: Energy analysis scenario B. Courtesy of Cosentini Associates.

Project/Run: Carbon Neutral - 6-24-09 - Rad Elec-elec HW-daylight-Estar-no refer   Run Date/Time: 06/24/09 @ 18:00



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	40.67	32.02	20.75	6.56	0.36	0.00	0.00	0.00	0.01	1.70	12.73	36.11	150.93
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.03	3.84	4.28	4.04	3.71	3.16	2.87	2.65	2.57	2.89	3.14	3.67	40.86
Vent. Fans	0.44	0.40	0.44	0.43	0.44	0.43	0.44	0.44	0.43	0.44	0.43	0.44	5.19
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	10.60	9.59	10.64	10.31	10.60	10.31	10.64	10.61	10.29	10.62	10.27	10.64	125.12
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	7.21	6.39	6.93	6.52	6.50	6.24	6.47	6.63	6.63	7.04	6.91	7.27	80.75
Total	62.95	52.25	43.04	27.86	21.62	20.13	20.42	20.34	19.93	22.70	33.48	58.14	402.85

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

- Electric radiant floors set to 68 degrees
- Electric hot water
- Daylighting controls / occupancy sensors considered = less lighting loads
- Energy Star appliances/equipment
- Refrigerator load removed = -10% of load
- Total Yearly = 402,850 kWh

Figure 32: Energy analysis scenario C. Courtesy of Cosentini Associates.

Based on the data collected per equipment, the standard consump tion per suite was 846 kwh/yr vs. the Energy Star Consumption which was 559 kwh/yr. The Energy Star total energy consumption represents a 66% reduction in energy consumption. The load percentages of both options are illustrated in Figure 34 by equipment/appliance use. In this illustration, the change in circumference reflects a 66% reduction in energy consumption. This analysis helped visualize the impact of including Energy Star equipment. Since computers and refrigerators are the biggest energy consumers, incorporating Energy Star versions would be more impactful. In actuality, the accumulative reduction of the overall load of equipment is what makes a noticeable difference in a building.

3.2 Energy Reduction Technologies

A series of existing and emerging technologies were studied as energy reduction strategies for bedrooms and shared suites. These included a magnetic card operated intelligent lock system, a universal no-waste charging station and green power strip. Traditional magnetic card systems can be replaced by Intelligent Hotel Card System, specially designed to meet the needs of modern hotels. These systems provide maximum security and individual style at low operational cost. Systems specifics vary by manufacturer but are universally designed to cut power to all equipment once the occupant leaves the bedroom. Some manufacturers produce a four-part system consisting of door locks, encoder for keycard, keycards and management software. This type of system can be programmed to cut power to all equipment in the room, or to specific items that are usually left on by occupants. It could also be programmed to change room temperature depending on time of day and occupancy. Many residence halls already use intelligent cards for security. Borrowing from the hotel card system, the residence hall card could also monitor occupancy and cut power to unused equipment that would otherwise be idle or wasting energy.

Another energy-saving technology is the universal no-waste charging station that allows different equipment to be recharged using the same platform. Ideal systems charge handheld electronics such as cell phones and iPods and cut power to each item once it is fully charged. The universal no-waste charging station might become obsolete in the future if the industry moves toward the production of an all-in-one device, such as the iPhone.

An existing product commonly known as the Green Power Strip is programmed to cut power to all equipment that is served by the same power strip once the computer is turned off. This product is most useful when all computer-related equipment is plugged into the same strip and is not used independent of the computer.

The universal no-waste charging station and the Green Power Strip are cost effective measures that could be

Annual Energy Consumption per person (kwh) for Miscellaneous loads

Miscellaneous Equipment	Standard		E Star		Note
	kwh/yr	%	kwh/yr	%	
Laptop Computer & Printer	293.601	34.69	66.044	11.8	1 per person
DVD	11.42478	1.35	7.39458	1.32	1 for 4 people
TV	76.35695628	9.02	63.32953067	11.32	1 for 4 people
Ceiling Fan	37.25568	4.4	34.0524	6.09	5 fans for 4 people
					(1per bedroom, 1in common area)
Alarm Clock	12	1.42	10	1.79	1 per person
Ipod docking station	48	5.67	46	8.22	1 per person
Hair Dryer	90	10.63	90	16.08	1 per person
Cell Phone	48	5.67	48	8.58	1 per person
Stereo	30	3.54	28	5	1 for 4 people
Refrigerator	154.75	18.28	123.75	22.12	1 for 4 people
Microwave	45	5.32	43	7.68	1 for 4 people
Total	**846.3884163**	99.99	**559.5705107**	100	

Figure 33: Comparative analysis of standard energy consumption vs. Energy Star consumption by kilowatt hour per year and by percentage. Data courtesy of Cosentini Associates.

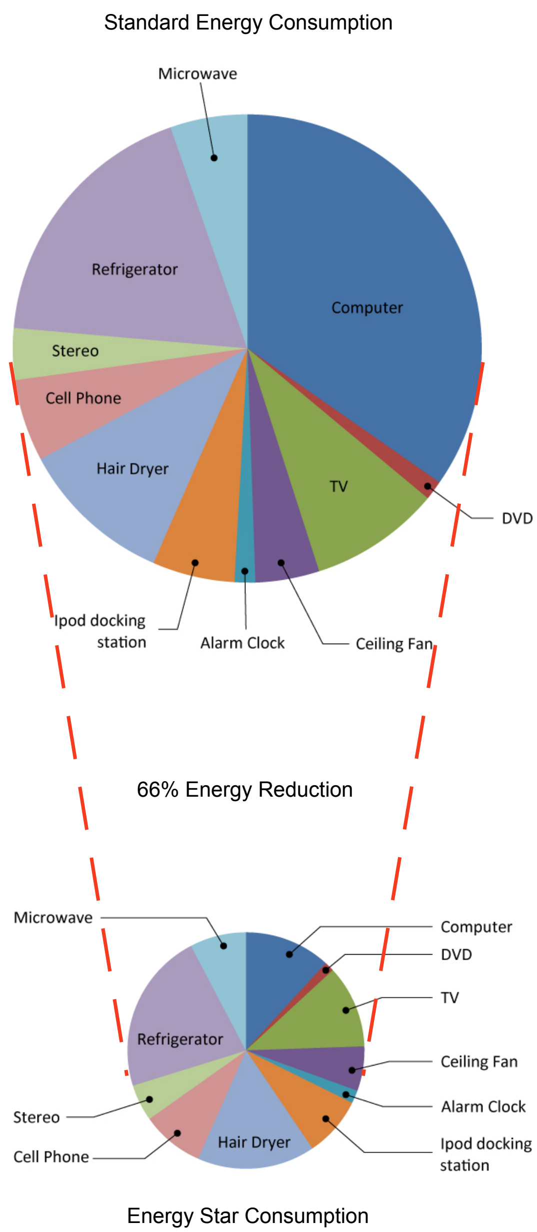


Figure 34: Comparative analysis of standard energy consumption vs. Energy Star consumption. Change in circumference size illustrates a reduction of 66% in energy consumption by using Energy Star equipment and appliances.
Data courtesy of Cosentini Associates.

suggested as part of the student's equipment list or could be provided by institutions.

The intelligent lock systems would have to be specifically designed to fit the institution's needs and monitored for efficiency.

3.3 Energy Analysis: Offsetting CO_2 Footprint

According to the energy model and analysis, the case study residence hall will produce a total of 922,734.16 kg of CO_2 over the life-span of the building. To offset these emissions with clean energy production, it is necessary to produce 25,631.50 kwh/Year of positive energy. Since the total building energy use is 454,280.00 kwh/Year, when this amount is added to the amount of necessary positive energy production, the total amount of required energy that the building needs to generate is 479,911.50 kwh/year. Figure 35 illustrates these calculations in greater detail and also highlights two interesting facts; the first is that the total local energy production required per square foot is 9.96 KWh/Year, which makes tangible the importance of optimization and reduction strategies in relation to building size. The second is that the total local energy production required per student is 3,749.31 KWh/Year, which underlines the importance of each student's participation in energy-saving initiatives.

The importance of measuring and assessing all design decisions and sustainable strategies incorporated throughout the project's development was discussed earlier. A final comparison of lifetime carbon footprint of a baseline design vs. the carbon-neutral design illustrates the impact of each strategic decision that leads to the creation of a carbon-neutral building. Figure 36 indicates carbon emissions in red and clean energy production in green. In the baseline design, carbon emissions are produced throughout the building's lifetime, while the carbon-neutral design only exhibits these emissions during the manufacturing and construction process. The remaining stages of the carbon-neutral design show only green, representative of the electric loads offset by clean energy production.

For clean power generation, two methods were considered: photovoltaic (PV) panels and wind turbines. These methods were further explored through three different options. The engineers of the study developed interactive charts with adjustable data in order to understand what percentages of energy production that best fitted the project needs. For the photovoltaic array calculations, optimal panel tilt considered the site's latitude. Given the project's location and the amount of solar energy available, if a PV array system was used, it was determined that it could generate as much as 35% of the energy required (Figure 37). This percentage also considered the amount of area available in the building to support the photovoltaic array and different tilt angles, which included both roof and south façade. Data to select and calculate PV panels was based on PVWATTS v.1, a performance calculator for grid-connected PV Systems available via internet (Figure 38)[7]. This calculator assumes energy production values for crystalline silicon PV systems. The financial metric represented in Figure 37 indicates a total installed cost of $951,486.18 that would be recuperated in a 37.76 year payback. Since the optimal percentage of PV panels that the project could support was 35%, wind turbine power generation contributed the remaining 65% of energy production, accomplished with a 1,000 kW wind turbine (Figure 39). This split of 35% PV panels and 65% wind power is illustrated as Option 3 of power generation in Figure 40.

To explore other energy generation possibilities, other options were explored (Figure 40). These options illustrate energy production of different size wind turbines and various amounts of photovoltaic panels. Option 1 is 100% photovoltaic panels, which would take 2/3 area of a football stadium. This option might be a good scenario if the project was located in an area of the country where solar energy was stronger or if the site could have supported such a large expanse of PV array.

Building Parameters		
Building Area	48,162.00	SF
Students	128.00	Students
Building Floors	4.00	Floors
Floor Area per Student	376.27	Floor SF/Student
Roof Area per Student	94.07	Roof SF/Student
Building Life Cycle	80.00	Years
Building Construction Carbon Footprint		
Original Construction CO2 Generated	922,734.16	kg CO2
Required Offset per Year	11,534.18	kg CO2
CO2 Generated per kWh	0.45	kg CO2
Required Positive kWh per year	25,631.50	kWh/Year
Required Positive kWh per SF- Year	0.53	kWh/SF-Year
Required Positive kWh per Student -Year	200.25	kWh/Student - Year
Building Energy Use		
Building Energy Use Electric & heat	413,530.00	KWh/Year
Building Energy Use DHW	40,750.00	KWh/Year
Total Building Energy Use	454,280.00	KWh/Year
Building Energy Use Per Square Foot	9.43	kWH/Year- SF
Building Energy Use / Student	3,549.06	kWH/Year - Student
Total Required Energy		
Original Construction Offset	25,631.50	KWh/Year
Building Energy Use	454,280.00	KWh/Year
Total	**479,911.50**	**KWh/Year**
Total Local Energy Production Required per SF:	**9.96**	**KWh/Year - SF**
Total Local Energy Production Required per Student:	**3,749.31**	**KWh/Year - Student**

Figure 35: Energy required to offset building CO2 footprint. Data courtesy of Cosentini Associates.

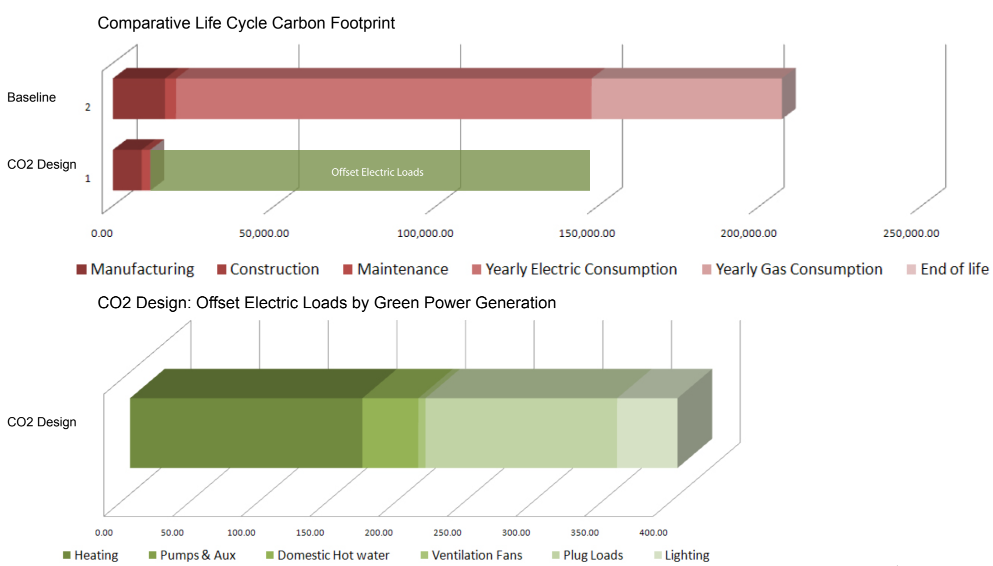


Figure 36: Comparative life cycle carbon footprint of a baseline design vs. a carbon-neutral design. Data courtesy of Cosentini Associates.

Photovoltaic Local Power Generation	Providence-41.7	Providence - 0	Providence - 90
January	335	171	333
February	387	238	360
March	466	368	340
April	476	448	269
May	481	511	220
June	467	522	185
July	498	543	208
August	495	481	258
September	395	337	259
October	415	275	347
November	300	163	279
December	275	133	275
Total	4,990	4,190	3,333
kWh/SF of Panel - Year	13.24	11.11	8.84
% Energy Generation from PV	**35%**		

% PV Derrived from Optimal Tilt	**100%**
% PV Derrived from Horizontal	0%
% PV Derrived from Vertical (South)	0%
Total PV	**100%**

Photovoltaic Panel Cost	Total For Carbon Nuetral Building	Total to Support Annual Operation
12,600sf		
Area of Panel Required Total	12,686.48	12,008.91
Area of Panel Required per Student	99.11	93.82
Area of Panel per SF Building Roof	1.05	1.00
Financial Metrics		
Installed Cost / watt	$7.50	$7.50
Pannel watts / SF	10	10
Installed Cost / Panel SF	$75.00	$75.00
Rebate Earned / Panel SF	$0.00	$0.00
Total Installed Cost	$951,486.18	$900,668.43
Installed Cost / Building SF	$19.76	$18.70
Installed Cost / Student	$7,433.49	$7,036.47
Electric Cost	$0.15	$0.15
Revenue (and avoided cost) per Year	$25,195.35	$23,849.70
Payback (Years)	37.76	37.76

Figure 37: Photovoltaic Panel energy generation chart. Data courtesy of Cosentini Associates.

PV Watts AC Energy & Cost Savings

Station Identification	
City	Providence
State	Rhode Island
Latitude	41.73°N
Longitude	71.43°W
Elevation	19m

PV System Specifications	
DC Rateing	4.0 kW
DC to AC Derate Factor	0.77
AC Rating	3.1 kW
Array Type	Fixed Tilt
Array Tilt	41.7°N
Array Azimuth	180.0°

Energy Specifications	
Cost of Electricity	.122 $/kWh

Results

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	3.37	335	40.87
2	4.31	387	47.21
3	4.87	466	56.85
4	5.26	476	58.07
5	5.35	481	58.68
6	5.57	467	56.97
7	5.85	498	60.76
8	5.76	495	60.39
9	4.68	395	48.19
10	4.54	415	50.63
11	3.27	300	36.6
12	2.82	275	33.55
Year	**4.64**	**4990**	**608.78**

Figure 38: This chart illustrates data used to select and calculate PV panels. This data was generated by PVWATTS v.1, a performance calculator for grid-connected PV Systems.

Wind Turbine Local Power Generation	Annual Production	Hub Height	Rotor Diameter
Turbine size	**Providence RI**		
2,000	5,174,000	270	252
1,500	3,749,000	330	275
1,000	1,995,000	270	177
10	14,000	60	23
3	5,000		14

% Energy Generation from Wind **65%**

% Wind Derrived from 2,000 kW	0%
% Wind Derrived from 1,500 kW	0%
% Wind Derrived from 1,000 kW	**65%**
% Wind Derrived from 10 KW	0%
% Wind Derrived from 2.5 KW	0%
Total From Wind	**0%**

Wind Turbine Cost	Total For Carbon Neutral Building	Total to Support Annual Operation
Number of Turbines	0.2	0.2
Installed Cost / watt	$1.00	$1.00
Rebate Earned		

Figure 39: Wind turbine energy generation chart. Data courtesy of Cosentini Associates.

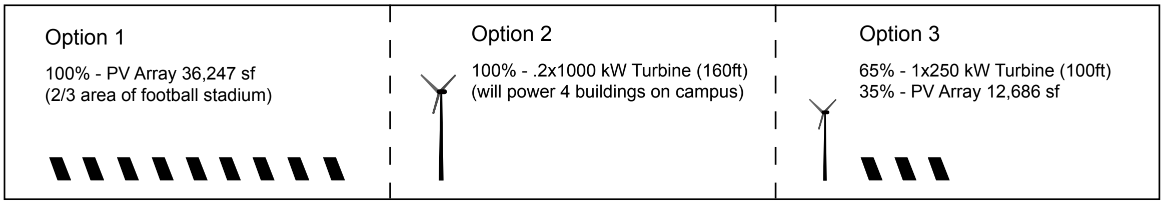


Figure 40: Exploration of Energy Production Options.

Option 2 is 100% wind power with a 1,000 kW turbine, which could actually power 4 buildings on campus. Option 3, already discussed above, is 65% wind turbine powered by a 250 kW turbine and 35% PV array, corresponding to the available surface area of 12,686 SF. In conclusion, green power generation solutions are largely based on what the region and the site can support and what is right for the project and institution's needs. Furthermore, some solutions, such as wind turbines, would need to be accepted by the institution and adjacent neighborhood, as visual access to the large scale turbines will change the aspect of the environment and landscape.

In the energy tests and analysis executed, expected outcomes included the fact that refrigerators are the biggest energy consumers in the suites. Other energy analyses yielded unexpected results. For instance, storing energy on site was considered in the early stages as an off-the grid approach. It became evident, however, that the building was better served by access to the grid during peak times to balance energy demands. The final energy model and analysis showed a 20,000 kWh/Year of energy surplus, which equals $4,000 yearly potential revenue for energy sold back to the grid. This potential revenue, coupled with the fact that Roger Williams University currently does not have on-site energy storage capacity, means that a connection to the grid would serve them best at the moment. This approach does not inhibit the possibility of future on-site energy storage if the University decides to explore synergies between buildings or districts within the campus.

The most important energy conclusion in regard to carbon neutrality is that the total energy production required to offset the lifetime CO_2 impact of the building, including the construction and manufacturing of materials, operations and building end-of-life, is a total of 25,631.50 kWh/Year. The architectural and energy design of the case study implemented strategies to support this objective.

4.0 CONCLUSIONS

The main objective of this study was to understand the implications, explore options and define strategies for designing a CO_2-neutral building. Strategies were developed with the premise that a CO_2-neutral building must mitigate the carbon emissions released in the materials fabrication, construction and continued operations of the building by generating more energy than it consumes over its lifespan through renewable resources. Given these parameters, special attention was given to modeling, analyzing and measuring material selection and energy consumption. Materials selected were studied for initial embodied energy and carbon footprint in order to determine the level of carbon emissions offset necessary. The energy model focused on power consumption reduction strategies and measurement of energy loads with the goal of offsetting the initial carbon footprint impact.

Design and sustainable strategies incorporated in the case study followed the methodology established in the inverted triangle diagram (Figure 3), where the most impactful decisions are those made at the beginning of the design process. Furthermore, the design of the physical space – from the overall project size, site orientation, building form and massing, to building assembly and interior space distribution – considered a holistic integration of passive and active strategies.

Passive strategies included:

- Optimization of surface and volume ratios that consider efficient building shape, solar orientation, efficient location of circulation cores, total square footage and efficient floor plate with adequate program fit outs.
- Thermal mass that uses masonry walls and concrete floors to moderate extreme temperature fluctuations by retaining and distributing heat.
- Natural ventilation that creates an efficient path for air flow and eliminates the need for air conditioning.
- Four-season porches and heat chimneys that assist in removing warm air from interior spaces.

- Daylight optimization that considers space proportions for appropriate daylight levels, integrating light shelves at the exterior windows to capture light deep into the space.
- Material selection that considers materials' embodied carbon footprint during the manufacturing process, optimization and reduction of material use, the overall health of the material and its effects on occupants, materials' quality and durability performance, regional availability and the end-of-life of the materials.

Active strategies included:
- Super-insulated building envelope achieving R40 walls and R60 roofs with attention to air leakage in assembly details.
- Geothermal wells for heating the building (radiant floors) and for domestic hot water.
- 75% lighting load reductions with efficient light fixtures.
- Daylighting controls/occupancy card system/green power strip to reduce energy waste.
- Energy Star appliances that further reduce energy consumption and could become part of the institution's acceptable student-provided equipment.

Even with the inclusion of the sustainable strategies described above, a successful CO_2-neutral building requires a monitoring system that facilitates an efficient operation and optimal building performance. Each institution's commitment to sustainability also plays an important part in assuring these strategies are executed successfully and make sense in the context of their campus. Educational programs for users focused on building performance could further enhance the building's sustainable design and lead to a higher rate of user accountability.

In summary, a CO_2-neutral building design is a regionally based product. Explorations and strategies uncovered in this study, although particular to a specific residence hall program and site, offer insight into the challenges in designing a CO_2-neutral building. Data measurement and verification along with building and energy models are essential components in the methodology. Collaboration between team members from the outset of the project is also important to fine-tune sustainable decisions, synthesizing all strategies into a cohesive and integrated design solution.

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