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A ZERO NET ENERGY BUILDING PILOT STUDY:

Low Energy Strategies for Weygand Residence Hall at Bridgewater State University

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ABSTRACT

Residence Halls provide a unique educational opportunity for students, since they can learn about and experience a lifestyle that embodies sustainable practices and engages them as active participants in reducing energy use for the building. The Massachusetts State College Building Authority (MSCBA) and Bridgewater State University (BSU) took advantage of a Zero Net Energy Building (ZNEB) pilot study to research design strategies and building systems that will advance the planning and design of future residence halls. Perkins+Will led a collaborative design and construction team, which included Rist Frost Shumway Engineering and Bond Brothers Construction. Working closely with MSCBA and BSU, the team developed a detailed case study that ultimately led to successful identification and implementation of low energy strategies for the Weygand Residence Hall at BSU.

This article defines the framework and decisions that were made at each step of the journey from conceptual design and projected energy calculations to building operations and maintenance. A ZNEB requires significant energy load reductions by implementing energy-efficient design strategies, including the optimization of building envelope, smart and efficient system selection and a renewable energy generation plan. High occupancy and significant energy demand in residence halls necessitate consideration of new ideas about energy consumption as well as policy changes to enable paradigm shifts in user behavior to reach a ZNEB goal. This study positioned BSU to implement several strategies that reduced energy consumption at Weygand Hall and provided lessons learned for future residential hall designs.

KEYWORDS: zero-net energy building design strategies, building performance, residence halls

1.0 INTRODUCTION

1.1 Zero Net Energy Pilot Study

Simultaneous with the project design for Weygand Residence Hall for Bridgewater State University (BSU), the project team conducted a Zero Net Energy Building (ZNEB) pilot study. The purpose of the study was to answer the question: what would it take to make this residential hall a ZNEB project? With ZNEB as an inspirational goal, the team focused on researching low energy

strategies pertinent to residence halls. We identified challenges of getting to ZNEB in this particular building type, and prioritized incorporating strategies that maximized energy efficiency within budget. Our measure for success was trifold: identification of challenges and opportunities using new and proven technologies, implementation of low energy strategies supported by energy modeling and cost analysis, and clear documentation of the process to help MSCBA understand lessons learned to overcome similar challenges in a future residential hall with a ZNEB goal. This study led to a comprehen-

sive investigation on the energy consumption for Weygand Hall. Working in collaboration with MSCBA, BSU, consulting engineers, and the contractor, the study's methodology followed four overarching steps toward energy reduction: 1) minimizing building loads (passive strategies), 2) maximizing energy efficiency (active strategies with mechanical, electrical, and plumbing systems), 3) generating renewable energy on site, and 4) reducing energy consumption from a building's operation perspective. Of these four steps, it is important to understand that the first three are driven by design decisions, while the fourth step is defined by operational decisions. In establishing these four steps, the process was holistic from the beginning, involving design and operations throughout the discussions.

This project was literally a platform for testing new technologies and measuring performance. Aside from the educational value of the study, MSCBA and BSU had great interest in implementing sustainable strategies investigated. Being able to leverage this knowledge for future residential halls led to rigorous analysis of strategies, including energy modeling, life cycle cost and simple payback analysis (Figure 1). When the project began in early 2011, no published ZNEB residential halls existed (and still to this date do not exist). Our key literature resources were mainly European. The book *Net Zero Energy Buildings: International Projects of Carbon Neutrality in Buildings*, by Karsten Voss and Eike Musall gave the team a great overview of low energy strategies for small to medium residential projects¹. None of the examples were actual residential halls and none achieved ZNEB but many of the synergies between efficient building systems and low energy strategies allowed our team to envision ideas for testing and analysis. This book became a wealth of precedent studies to revisit when our own explorations seemed failed. The design team also looked closely at the Passive House Institute, especially for envelope strategies such as super insulation and keen attention to wall and window interface details². For life cycle analysis methodology, the team referenced *A Life Cycle Approach to Buildings: Principles, Calculations, Design Tools* published by Detail Green Books³. This resource helped us understand different approaches for life cycle assessment as they relate to design, economics and tools. It was with this understanding that the team decided to create a succinct payback spreadsheet to track upfront cost, energy and utility cost (not published in this spreadsheet version) and life cycle cost. Several iterations of this spreadsheet were analyzed, and it became a valuable design tool to make decisions based on energy efficient synergies between strategies, the integration of systems, and the

cost value to the project. With energy modeling calculations that considered energy demands for the building, the engineering team was able to analyze yearly energy reductions produced by the different strategies. Then, the contractor's cost estimating team, assigned first cost value to each strategy which allowed the team to calculate payback in years. While the engineering team focused heavily on energy aspects and making sure the energy model data was accurate, the contractor was able to offer envelope and detailing suggestions that are not explicitly considered by energy model software. The chart below illustrates the final iteration with accepted strategies. The lower portion of the chart lists renewable strategies being considered that will get the building to ZNEB. The two main strategies analyzed are a Photo-Voltaic (PV) panel array and a Wind Turbine. Both remain under consideration for the project: the PV panel array strategy requires additional surface beyond the PV-ready building roof, while the Wind Turbine (currently under study) would be located at the top of an adjacent campus hill to capture prevailing winds. Early iterations of the chart included strategies studied, but not accepted. These were: super insulation, triple layer glazing, interior light shelves to harvest daylight, natural (non-continuous) restroom exhaust and suite ventilation, and plug load controls. The rejection of these strategies is discussed in Section 2.

There were three tiers for prioritizing the acceptance of strategies. Priority was given to strategies with minimal upfront cost impact (these were mainly passive strategies), second priority focused on energy efficient system (the valance and geo-exchange combination proved to be most energy efficient through energy modeling and design), and third priority considered impact to user behavior, such as the window kill switch strategy and the policy change to ban individual micro-fridges in the suites.

1.2 Energy Challenges in a Residential Hall

Residential halls consume high levels of energy because they are occupied 24-hours a day, 7-days a week, unlike an office building. In this case, the project includes 500 new beds of student housing and a new location for the Wellness Center. The inherent high energy use of the program offered economy of scale for systems and energy conservation ideas. In the following section we discuss how we took advantage of this economy of scale to reduce energy loads (Figure 2).

Other energy challenges inherent for this building type can be addressed through plan layout and building shape. For instance, residential halls are typically or-

ACCEPTED STRATEGIES				
Strategy Description	upfront cost - ACTUAL	% of project budget	annual \$ savings	payback (yrs)
Geo-exchange Heat Pumps 63 Closed Loops	\$ 764,190.00	1.47%	\$ 34,526.00	22.13
Valances compared with fan-coil system	\$ (419,364.00)	0.00%	\$ 10,574.00	0.00
Shower Drain Energy Recovery 35 plumbing stacks	\$ 72,000.00	0.02%	\$ 10,000.00	7.20
Lighting Efficiency 27% reduction from baseline	\$ 82,000.00	0.04%	\$ 19,535.00	4.20
Improved Wall & Roof Insulation R-29 Walls, R-49 Roof	\$ 241,953.00	0.04%	\$ 3,326.00	72.75
Improved Glazing 0.22 U-Factor, 0.44 SC	\$ 49,198.00	0.01%	\$ 13,728.00	3.58
Fiberglass Window Frames	\$ 1.00	0.00%	\$ 4,078.00	0.00
External Shading heat mitigation	\$ 141,732.00	0.00%	\$ 1,578.00	89.82
Window "Kill Switches" prevents energy waste	\$ 105,000.00	0.20%	*	*
Temperature Set Points (82° F / 68° F)	\$ 1.00	0.00%	\$ 20,624.00	0.00
No Micro-fridges	\$ 52,942.00	0.03%	\$ 15,981.00	3.31
Comprehensive Accepted Building Strategies	\$ 1,089,653.00	2.10%	\$ 133,950.00	8.13

UNDER STUDY - TO GET TO ZNEB				
Strategy Description	cost - ESTIMATED	% of project budget	annual \$ savings	payback (yrs)
PV Panels - Weygand Hall Roof Only	\$ 1,224,500.00	2.35%	\$ 40,376.00	30.33
PV Panels - ZNEB Potential	\$ 9,500,000.00	18.27%	\$ 314,261.00	30.23
Wind Turbine	\$ 4,752,000.00	N/A	\$ 747,804.00	6.35

Notes:

1. Based on \$52M project budget, bid in 2012, union labor rates located in Bridgewater, Massachusetts
2. Accepted strategy costs are derived from actual project data and reflect dollar increase of material above base code
3. kBtu/SF/yr refers to "site" energy consumption
4. Based on 50% reduced occupancy during summers

Figure 1: Cost Analysis Matrix—This chart was continually updated to track strategies throughout the ZNEB study. Energy modeling was used to determine projected payback and the contractor provided up front cost information. This iteration uses as-built numbers and payback calculations for accepted strategies.

ganized with a double loaded corridor, restricting daylight access into the corridor. Minimizing Lighting Power Density (LPD) is extremely important for energy reduction; thus the design concept for Weygang Hall is based on a courtyard, surrounded by the living-learning pods

oriented along single-loaded corridors with study spaces. The porosity of the courtyard is an important aspect of the student's experience and also help extend natural light deeper into the building (Figure 3).

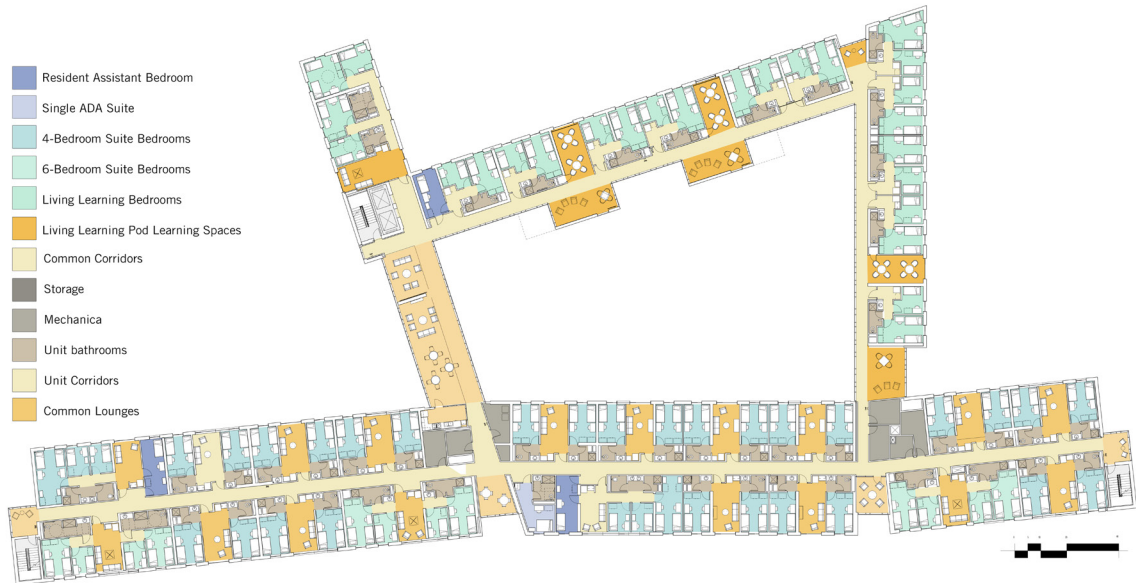


Figure 2: Typical Residential Floor plan—Located on East Campus, the hub of residential life on campus, the 500 beds are grouped in two prime categories: suites and living / learning pods. The suites are programmed in three types that include 4-bed doubles, 4-bed mixed singles and doubles, and 6-bed mixed singles and doubles. Twelve Residential Assistants' suites are split among the three residential levels. A Residential Director apartment at ground level has private access, which is also connected to the rest of the building.



Figure 3: Courtyard at Night—The ground level is open on one side through a loggia that frames a view to the campus lawn. Hundreds of commuting students experience the courtyard on their way to class. At a campus level, this courtyard links to a series of residential green spaces providing students more intimate spaces to retreat and gather as a community.

2.0 STEPS TO A ZERO NET ENERGY BUILDING

Our research methodology followed four steps. It was approached as a cyclical process as strategies were investigated, tested, analyzed, retested and vetted. There could also be synergies between strategies, which mean that an idea investigated in one step might influence another idea attempted under a different step. Similarly, strategies might cancel each other out or be redundant. We found that this methodology streamlined our decision-making process and helped focus the research on energy usage. In the following sections we discuss these four steps and some of the investigated salient strategies (Figure 4).

Step 1 focused on strategies that have no cost associated with them because they harvest natural resources, such as daylight, or incorporate strategies that enhance the performance of the envelope and systems. Step 2 focused on energy efficient strategies that will in turn reduce energy consumption. Step 3 investigated renewable energy production systems to power the building. Step 4 focused on building operations, an important step in achieving ZNEB. At this step, the responsibility is in the hands of the owner. This is where policy and educational outreach becomes an integral part of maintaining low energy consumption behavior.

Before beginning these steps, the team agreed to adopt the ZNEB definition as set forth by *The Massachusetts*

Zero Net Energy Buildings Task Force, which states that ZNEB is optimally efficient and over the course of a year generates energy onsite using clean renewable resources in a quantity equal to or greater than the total amount of energy consumed onsite. With the engineering team, Energy Use Intensity (EUI) baselines were established based on 168,000 GSF for the Residential Hall and 12,000 GSF for the Wellness Center. Benchmarks were defined as follows:

- 104 kBtu/sq. ft. based on CEBECS data⁴
- 8 kBtu/sq. ft. EO 484 (2020)⁵
- 55 kBtu/sq. ft. Weygand Hall goal (this goal was exceeded at 54 kBtu/sq.ft.)⁶.

Energy modeling and simple payback analysis were conducted at every step to fine tune strategies and meet energy goals, as shown in Figure 1. The design team, the owner, the user and the contractor, met regularly to discuss analysis results and determine how to move forward. It is important to point out that strategies should be vetted early on. However, when cost is a determining factor, some flexibility is needed to better gauge market cost. This may require revisiting strategies later in the process. For instance, for Weygand Hall many strategies were accepted at the end of the design development phase, but others more dependent on market cost, were reconsidered during the construction documentation phase and even during construction. Throughout the process, the design team shared an Excel file that

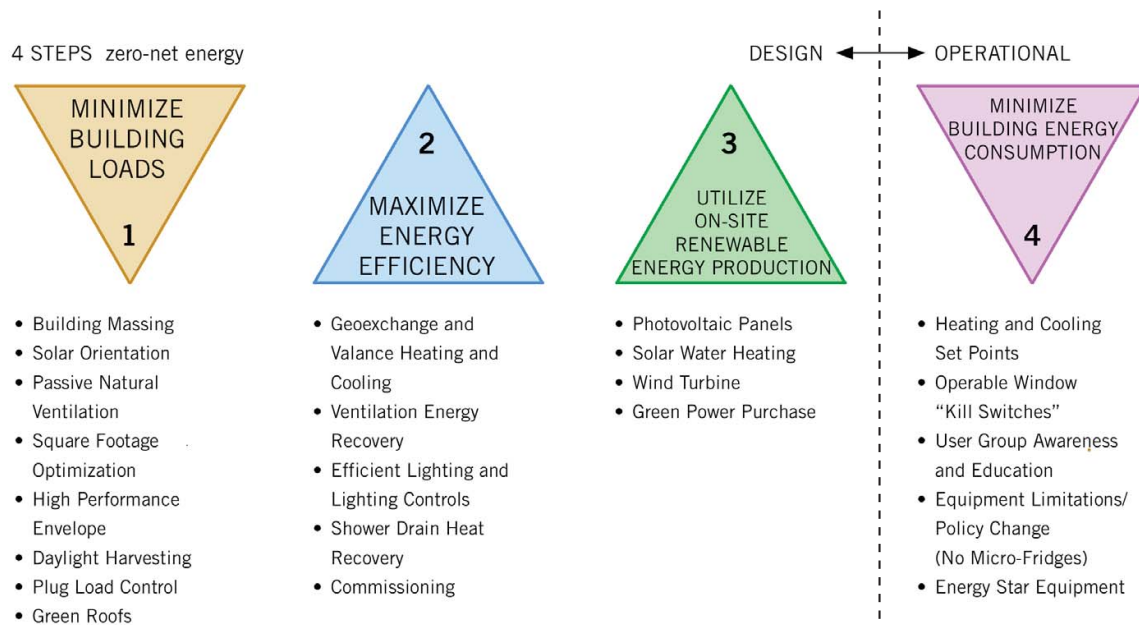


Figure 4: Four Steps in the ZNEB process—Research process was guided by these 4 steps.

tracked strategies. This was a live document that helped educate each other, vetted pros and cons and kept the process transparent (Figures 5, 14, 18, 19).

2.1 STEP 1: Minimizing Building Energy Loads

Step 1 focuses on energy reduction strategies necessary to achieve zero-net energy consumption, such as, building massing and orientation, optimized square footage, daylight harvesting, envelope optimization, and lighting and plug load control (Figure 5).

Building Massing and Solar Orientation Weygand Hall's orientation was influenced by site constraints, such as preserving a primary pedestrian path through campus, creating a defined boundary between the residential campus and the existing train rail, and formally linking the new courtyard to a series of existing courtyards in neighboring buildings. The building is primarily oriented north-south (tilted 12 degrees from north), considering the solar heat gain on the long southeast and southwest elevations. In the New England region, solar heat gain is desired beginning in the middle of the fall season, when temperatures are more consistently in the lower digits, and continue this trend through middle to late spring. The strategy to mitigate solar heat gain during the summer on those long facades included higher insulation values for the building skin, material selection (elevations with east and west exposures have less glazing) and solar shading devices at larger glazing areas. Another mitigation strategy was the creation of the courtyard, because it becomes a shaded oasis for much of the summer day, which allowed the design team to place more glazing in those elevations (Figure 6). During colder months, these glazed courtyard elevations will accept solar radiation to help heat the common spaces.

Harvesting Wind through Natural Ventilation By studying wind roses, seasonal winds and prevailing winds were determined. We learned that frequent winds are sustained from southwest, which factored into the casement windows being oriented to this direction to capture more wind flow into the building (Figure 7).

The University has traditionally used double or single hung windows for residential halls. While a large volume of air is able to flow through those window types, there were three concerns that led the design team to consider the advantages and disadvantages of awning, single hung and casement windows. The three concerns of these windows were safety of the students, the ability to achieve a tight seal to prevent air leakage (particularly

heat escaping in winter), and the ability for students to place a portable electrical fan unit on the window sill (Figure 8). It was ultimately decided to provide casement windows with interior tamper-proof screens to allow maximum air flow into open windows without compromising safety. The following are the key advantages and disadvantages analyzed in conjunction with other strategies and systems:

Awning Window Type:

- Compression air seal at weather strip
- Ideal for valance system
- Half of window opens to scope air in
- Hard to capture prevailing winds
- More light penetration (no middle rail)
- "Kill Switch" installation
- Screen on inside / crank mechanism
- Student's fan units on window sill
- Appropriate to scale and character.

Single Hung Window Type:

- Not air tight due to the inherent sliding motion
- Not ideal for valance system: Valance are passive devices relying on convective air, excessive air infiltration disrupt performance
- Half of the window opens
- No effort to capture prevailing winds
- Middle rail disrupts light penetration
- "Kill switch" installation/operation OK
- Screen on outside / slide mechanism
- Student's fan units on window sill
- Smaller scale residential character.

Casement Window Type:

- Compression air seal at weather strip
- Ideal for valance system
- Entire window opens to scoop in air
- Window angle captures prevailing winds
- More light penetration (no middle rail)
- "Kill switch" installation/operation OK
- Screen on inside / crank mechanism
- Student's fan units on window sill
- Appropriate to scale and character.

Considering an existing window fan use culture in residential halls at BSU, the team planned for operable window use and studied "kill switches," which were accepted under Step 2.

Square Footage Optimization One way of reducing energy is to scrutinize program needs, discover the right programmatic adjacencies and optimize program layout in the building. In turn, the building cost is reduced

STEP 1 minimize building loads

Strategy	Energy System Option	Impacts	Advantages	Disadvantages
Orientation	Reduce Southwest Envelope Exposure	building footprint relation to campus space created	reduces energy loads	has to be balanced with future building sites
Natural Ventilation	Harvest Wind	windows	casement windows scoops air flow into building	none
Square Footage	Optimize Program Layout	programmatic square footage and adjacencies	optimizes building volume, right sizes building	square footage tradeoffs, smaller spaces
Envelope	Green Roofs and Cool Roofs	roof and waterproofing, soils substrate, vegetation	storm water retention, reduce heat island effect, amenity	installation cost, operation and maintenance, some require watering
Envelope	Optimize Roof Assembly	roof thickness, insulation quantity, Goal is R=60 Roof	reduce heat loss through roof	initial cost, possible increase of roof thickness
Envelope	Optimize Wall Assembly	wall thickness, Code Wall R=15.6 but goal is R=40	reduce heat loss through walls	initial cost, possible increase of wall thickness
Envelope	Energy Efficient Glazing	glazing and mullion, Code Window R=2.2	reduce heat loss through glass and reduce mean radiant temperature	thicker heavier assembly
Envelope	External Solar Shading	window and envelope detail	reduce heat gain	initial cost, maintenance
Daylight Harvesting	Optimize Daylight	optimize window wall ratio, glazing selection and light shelves or screens	reduce lighting electric consumption	initial cost of light shelves or screens
Lighting	High Efficiency Lighting Fixtures	light fixture selection, power loads	lower electric consumption and reduced internal heat	limits fixture selection
Mixed Mode Ventilation	Motor Actuated Windows Controlled by BMS System.	envelope, windows, controls	"free cooling", system shut off	
Mechanical System Decoupling	Operable Windows with Window "Kill" Switches	windows, 4% of floor area operable	casement windows scoops air flow into building	added system components
Intermittent Bathroom Exhaust	Intermittent Restroom Exhaust	ductwork, controls, occupancy sensors, make-up air, access	systems shuts off when not in use	maintenance, complexity, potential poor odor & moisture control
Lighting, HVAC Control	Occupancy Sensors	occupant behavior	reduce energy consumption	initial cost
Plug Load Control	Reduce Plug Loads	controls (occupancy sensor or card key switch)	reduce energy consumption	initial cost and maintenance, policy and enforcement
Plug Load Control	Green Power Strip	policy and enforcement	reduce energy consumption	policy and enforcement

Figure 5: Step 1 Matrix of strategies considered for minimizing energy loads.

by constructing what is needed and having less spatial volume to heat or cool with mechanical systems. In early conversations with users, it was determined that students were willing to compromise space within their bedrooms and suites in exchange for larger and more common spaces such as lounges, study rooms, common kitchens and games and recreational space (Figure 9). Throughout the project, requirements for universal access were not compromised and common spaces were distributed and balanced through the building's plan. This exercise of space optimization is a delicate balance between programmatic needs, future flexibility and public-private space allocations.

High Performance Envelope The New England region is heat-dominated, which means that the main energy concern is preventing heat loss during cold months. As a result, two of the most energy efficient strategies for the building's envelope is maintaining a low ratio of glazing (60 percent solid walls – 40 percent glazing) and insulating walls and roof with high thermal resistance (R-value). We studied super insulating the building and established an aspirational goal of R40 for walls and R60 for roof. We also developed details with insulation continuity to prevent thermal bridging. In this process we defined the following qualities:

- Sealed holes, cracks and penetrations
- Air tight construction (windows / doors / wall-roof)

A Zero Net Energy Building Pilot Study

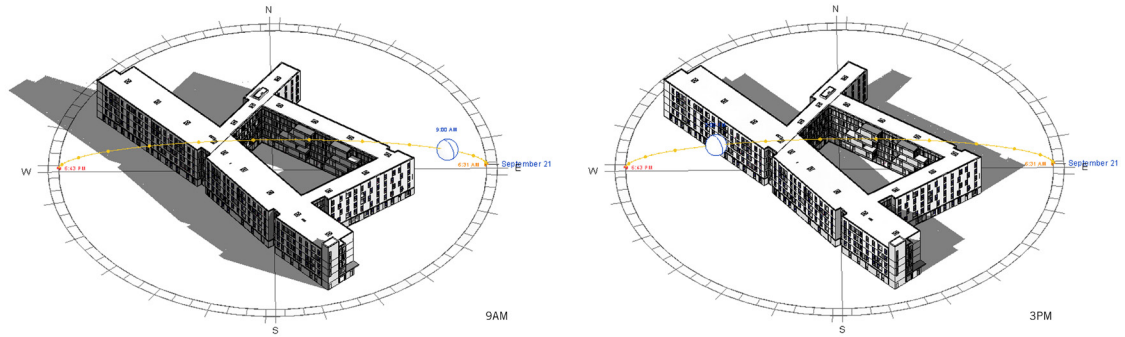


Figure 6: Building Shading Studies—These diagrams illustrate sun angles in the morning and afternoon of September 21. The courtyard is in shade for much of the day. Similar studies were performed for winter and summer seasons.

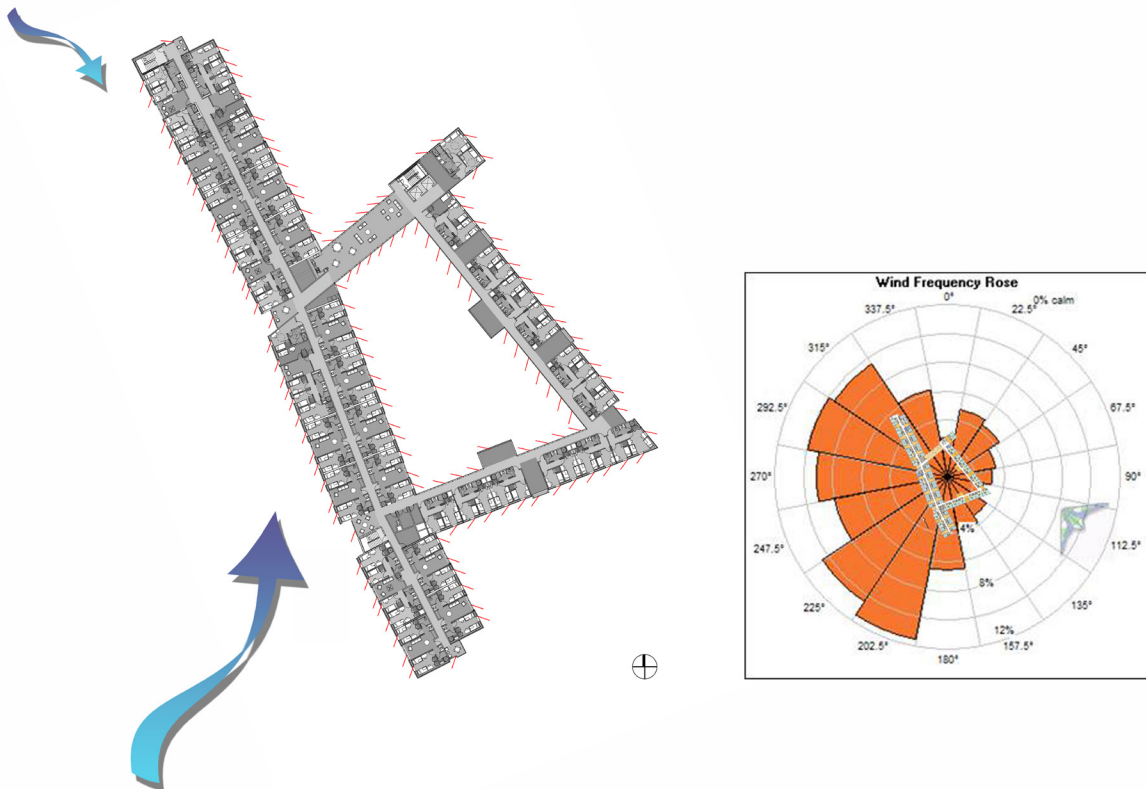


Figure 7: Natural Ventilation Diagram—Casement windows were oriented in the direction of the prevailing southwestern winds to “scoop” more air into the building.

- Insulated foundations and under slab
- 40% glazing (maximum)
- Heat recovery ventilation to provide fresh air.

Since the R-value required by code is R15.6 and the industry standard is R19, we analyzed different types of insulation to improve these R-values for the envelope while maintaining a thin wall and roof assembly. The criteria for considering these insulation materials include climate relevance, ease of installation, durability (resistance to degradation), and ease of replacement at the end of life, cost effectiveness, toxicity, flammability and environmental impact. Also, the owner was concerned about risks associated with using emerging technologies and materials that are unproven. Due to this concern, the design team focused mainly on ideas, materials and systems with proven technologies.

For the most part, the insulation materials studied have been in use for many years but some are more common in the construction industry of the New England region. The considered types of insulation included:

- Aerogel for skylights
- Spray polyurethane foam (SPF)
- Insulating Concrete Forms
- Rigid Panels
 - Walls: Extruded-Polystyrene (XPS R5/in.)
 - Expanded-Polystyrene (EPS R4/in.)
 - Roof: Isocyanurate Boards (R 6.67/in.)
 - Polyisocyanurate (Polyiso R 6.5/in.)
- Structural Insulated Panels (SIPs)
- Fiberglass batts and blankets (R-2.9 to R-3.8)
- Natural fiber
- Cotton batts (blue jeans)
- Loose-fill (including cellulose, R 3.7/in.)
- Straw bales
- Reflective insulation and radiant barriers.

Of the materials listed above, the building uses SPF for sealing cracks and holes, rigid panels for roofs and walls, fiberglass batts for interior acoustical separation and mineral fiber for rain screen and spandrel glass applications.

The strategy for improving the roof and wall assembly was mainly based on higher insulation values but the team also considered a white roof membrane and quality materials with proven durability. There were three roof scenarios analyzed for rigid panels of Isocyanurate boards:

- R 6.67/in. x 9" total = R 60 value (aspirational goal)
- R 6.67/in. x 5" total = R 33 value (base)
- R 6.67/in. x 7" total = R 46 value (alternate)
- R 6.67/in. x 6" total = R 38 value (built).

The wall insulation strategy required an R-value analysis of different wall assemblies and combinations of insulation types. Two specific wall assemblies that were considered (brick and composite panel rainscreens) are discussed in more detail to illustrate the design process, decision-making and specific issues relating to thermal performance (Figure 10).

For the brick assembly wall, the team initially considered fiberglass batt or sprayed foam insulation inside the metal stud wall, as supplemental insulation to reach a higher thermal resistance. This idea was ultimately not pursued because when metal studs come in contact with exterior sheathing, they act as a thermal bridge through which 15 percent of thermal resistance is lost. In this scenario, providing 4" of exterior rigid insulation was more cost effective. The maximum thickness of the exterior rigid insulation was determined by the longest brick anchor available to span from the brick all the way

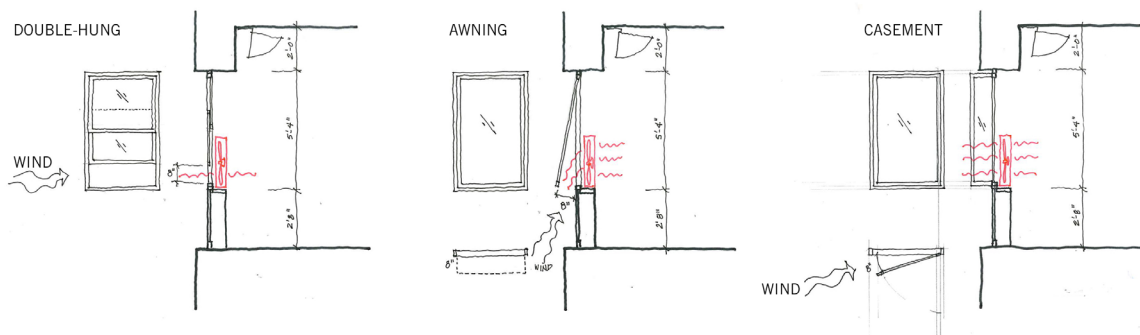


Figure 8: Window Type Study—With MSCBA and BSU, the design team determined three window types to study: awning, single hung and casement windows, studying the advantages and disadvantages of each.



Figure 9: Game Room Photo—At ground level there are a variety of amenities, such as a living room, study areas, game room, mailboxes, laundry, and multipurpose rooms.

back to the exterior sheathing. The total R-value of the brick wall assembly is 27. Similarly, the phenolic panel rainscreen wall assembly excluded fiberglass insulation inside the metal stud wall. Initially, rigid insulation was specified for this wall but more refined research determined that mineral fiber insulation was a better technology based on flame spread testing. The thickness of the mineral fiber insulation was specified as 4" with an R-value of 18 (total wall assembly R-value of 21). During construction, 5.5" of insulation was ultimately installed due to an excess of air space within the cavity. NFPA requires the air space be exactly 1", therefore additional insulation was installed to accommodate this requirement, increasing the total R-value of the wall assembly to R25.

Glazing areas were improved in three ways. First, the team specified low emissivity (Low E) coated glass, a product that emits low levels of radiant energy without compromising transparency and visibility. In addition, the glazing has two layers of glass with argon gas infill that further helps achieve a higher thermal resistance. Triple glazing insulated unit with argon gas infill was studied but not pursued due to cost and the fact that

the mullions and hardware needed to be upgraded to carry the additional glass weight (Figure 11).

Second, fritted panels with 40 percent and 60 percent of frit density were specified at the large curtain wall areas of the courtyard to reduce the solar heat gain by an estimated 15 percent. In Figure 3, the fritted glass is perceived in the lighter shades of glazing. The third improvement to the glazing system was to use fiberglass window frames for all windows in the building (not curtain wall mullions). Although metal frame manufacturers for windows and curtain wall have been developing better thermal break technologies to prevent heat transmission through the metal, our research indicated a very low heat transmission through fiberglass frames that translated in greater comfort for the interior spaces. There are fiberglass manufacturers that also include a suspended film between the glass, which equals the performance of a triple glazed unit but without the increased weight. The team studied including the suspended film technology but determined it was not feasible due to cost premium and lack of competitiveness in manufacturers around the New England region.

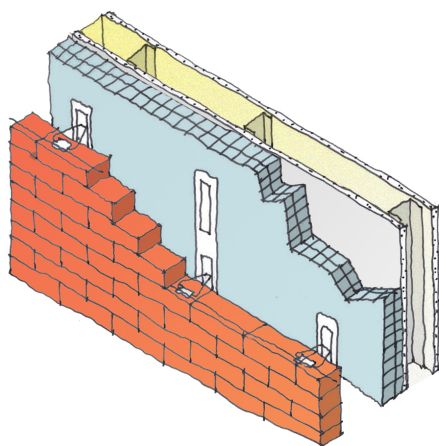
Exterior shading ideas included strategies utilizing louvers, exterior screens and exterior shading (brise-soleils). Through solar shading studies, it was determined that horizontal exterior shading in southeast and southwest exposures was the most effective (Figure 12). These shades were designed to admit more light in the winter and block light during the summer months (Figure 13). Along with the fritted glass, these shades provide heat gain and glare control, while allowing views to the outdoor. On the southwest façade of the courtyard, the shading devices and the cantilevered Learning Pods act together to shade the corridor and interior study areas.

Daylight Harvesting— Daylight harvesting strategies studies included a variety of ideas but only some were adopted for performance optimization and maintenance reasons. The different strategies and reasons for adopting or rejecting them were:

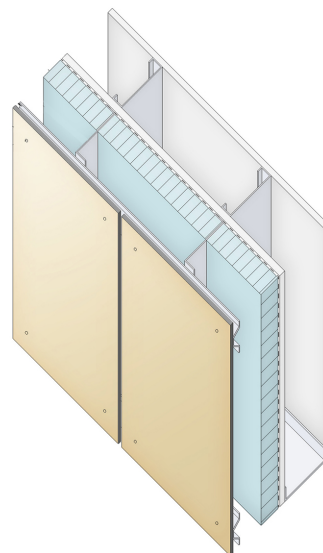
- *Thinner building footprint*: adopted wherever possible, particularly the living-learning part of the building.
- *Optimal window / wall ratio (40 percent / 60 percent)*: adopted throughout the envelope to maintain adequate thermal values without compromising daylight and outdoor visibility.

- *Glazing selection*: high visibility glass was specified to admit more light.
- *Light shelf*: This light redirecting mechanism was studied to extend light penetration into bedrooms and living rooms but it was rejected as the spaces were shallow enough to admit appropriate daylight levels. Also, both interior and exterior light shelf require periodic cleaning, otherwise a 70 percent efficacy reduction will occur. This represents a maintenance issue taken into consideration.
- *Glare reduction with shades*: Accepted with privacy shades for the bedrooms (0 percent opening in shade fabric) and glare control shades for the living spaces (5 percent opening in shade fabric). In the living rooms, shades allow for unobstructed views, reduced heat gain and surface brightness control.
- *Tubular daylight*: devices were rejected due to the many roof penetrations needed and the fact that the roof real estate may be used for renewable energy strategies in the future, such as PV panels.

Plug Load Controls— Along with daylight harvesting ideas, the building design includes high efficient lighting with reduced lighting power density, 27 percent reduction from baseline, and individual room lighting controls. There are occupancy sensors in every space,



BRICK WALL ASSEMBLY



PHENOLIC PANEL WALL ASSEMBLY

Figure 10: Wall Assemblies—Brick and phenolic panel exterior wall rainscreen systems.

so that lights are off while no one occupies the spaces. Another option to minimize energy loads was the use of plug load controls. The idea was to have separate color coded electrical outlets for appliances and equipment that the students tend to leave on even when they are

not in used, such as computers, printers, phone chargers, etc. These outlets are typically connected to a wall switch that can be turned off at once, disconnecting all electric service to the outlet. The University conducted a study to determine if this was a viable investment or

Characteristics	Baseline	Alternate	Specified / Installed
Manufacturer	Viracon VE1-2M or equal	Viracon VE1-2M or equal	PPG Solarban 60
Glazing Thickness	1/4"	1/4"	1/4"
Glazing Layers	Double	Triple	Double
Argon Gas	No	Yes	No
Low-e Coating	Yes	Yes	Yes
Winter U-value	0.29	0.13	0.29
Summer U-value	0.26	0.13	0.27
Shading Coefficient	0.44	0.37	0.44
Visible Light Transmittance	67%	43%	70%
Solar Heat Gain Coefficient	0.38	0.32	0.38
R-Value	4	5	4

Figure 11: Glazing characteristics chart.

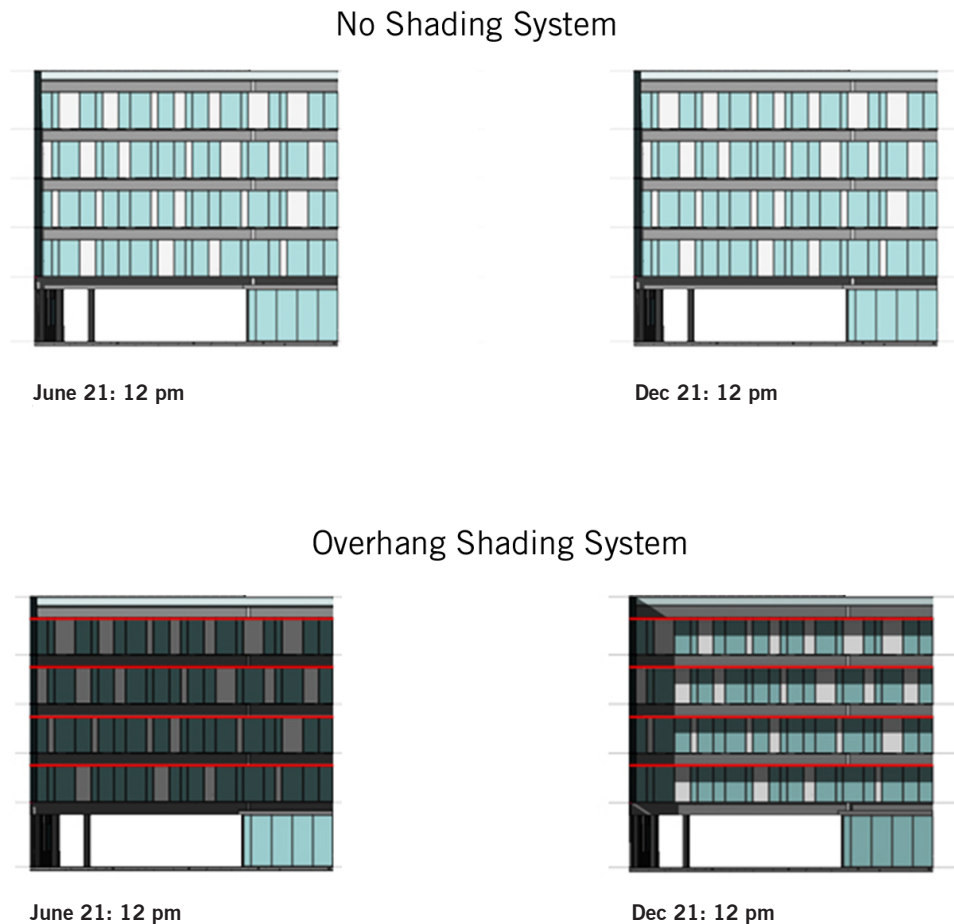


Figure 12: Shading studies informed the best locations for brise-soleil on the building façade.

if educating the students could offer the same energy conservation results. Two suites in a neighboring residential hall were used for the study. One was the experimental control in which no plug controls were installed, except that the students were told the importance of unplugging their equipment and how it would lead to energy conservation. The control room was metered for energy use. The second suite was set up with plug controls and metered. The students were told how to use the system. After a few months, there was no energy consumption difference between the two rooms, and both achieved similar energy reduction. The University interviewed the students in both groups and it

was determined that education and orientation led to the same outcome: an awareness to unplug and turn off equipment. With this result, the University decided not to invest in plug controls but rather develop a robust orientation program for residents. This idea was incorporated under Step 4, building operations.

Green Roofs— Green roofs were considered to reduce heat gain on the roofs of the Living-Learning cantilevered Pods at the courtyard. The Pods have visual access to adjacent roofs, which led BSU to desire the aesthetics of a green roof. For maintenance reasons, the University preferred an extensive green roof system,



Figure 13: Living Learning Pods.

which uses removable trays of planting, instead of an intensive green roof system where the plantings are placed above the roof membrane. The Pod roofs are designed to receive the tray plantings if the University decides to install them in the future, but they are currently not installed due to cost and maintenance concerns. These roofs, as well as all the other roofs, have white membranes to reflect solar radiation and reduce heat island effect.

2.2 STEP 2: Maximizing Component Energy Efficiencies Systems

Step 2 considered efficient building systems, such as ventilation systems, heating and cooling with geo-exchange energy, lighting controls, efficient motor controls for fans and shower drain energy recovery among others. In studying different strategies, the team assessed the levels of minor and major energy saving

consequences (Figure 14). The systems that were incorporated into the project are described below.

Geo-exchange and Valance Heating and Cooling—Closed loop geo-exchange pumps and valance heating and cooling systems were studied, and it was found that they would provide significant energy savings. A geo-exchange system uses the earth for a heat source and a heat sink. Climates with extreme heat and cooling needs can extract the most efficiency out of a geo-exchange system. The building must be operational during all seasons to maximize efficiency since it relies on a balance loop of heat exchange. A simplified way to describe this is in terms of cooling and heating demands: cool earth temperatures are extracted in the summer leaving the earth with hotter temperatures, while hot temperatures are extracted in winter months leaving the earth at a cooler temperature. Residential halls are traditionally occupied only during the school

year; however BSU has summer programs and is able to prioritize occupying this building during the summer months to maximize energy efficiency. Through analysis, the design team, consulting engineers and GZA GeoEnvironmental, Inc., determined that Weygand Hall would require 63 wells for the geo-exchange system. The residence hall site is located directly next to an open campus quad for recreation and provides an ideal location for the wells (Figure 15).

Paired with valances in all resident bedrooms and living rooms for heating and cooling, this strategy will increase user comfort, decrease energy cost, and lower maintenance demands. Valance heating and cooling functions without fans or filters, using water in coils to regulate room temperatures. Air circulation is slow and efficient, keeping a consistent temperature within a space without draft currents. Design considerations were studied so that the valances are mounted close to the ceiling with options for architectural enclosures to conceal the coil and drain pan. It was decided early on in the process that ductwork and piping would be consolidated in one area of the suites in order for the ceiling height to accommodate the valance without compromising daylight and views (Figure 16).

The following is a summary of the pros and cons considered while selecting the geo-exchange and valance system combined strategy:

Pros:

- *Optimum energy efficiency*– the geo-exchange system's ground heat source/sink temperatures can be considered constant and are not affected by weather conditions, therefore the system is exempt from seasonal temperature changes.
- *No fan or filter maintenance*– the valance system does not require fan energy to force air circulation, rather heat or cold temperatures radiates from the pipes.
- *Improved air movement*– the valance system is slow in moving air to prevent draft currents. There is no risk of temperature stratification due to the height and depth ratio of the spaces.
- *Reduced maintenance*– the combined strategy of geo-exchange and the valance system has reduced maintenance cost since both the heating and cooling is provided by the same system and components. Geo-exchange site piping offers a 50+ year expected service life. All other mechanical components are protected from weather decay indoors and are easily accessible by personnel.

Cons:

- *High initial cost*– simple pay back studies indicated a 22-year payback. Since the MSCBA owns the residential halls for life, they determined that it was a sound investment for the building's life cycle.
- *Well field limits future development on top of the land*– the University's master plan envisions this

STEP 2 maximize energy efficiency

System Type	Energy System Option	Impacts	Advantages	Disadvantages
HVAC	Geothermal Close Loop Heat Exchange Pumps	site availability and mechanical space, drilling bore fields	increased COP, low carbon heating and cooling source	initial cost, well field space
HVAC	Air Source Heat Pump	fan-coil location, ductwork	similar performance to geothermal without well field costs	Reduced heating capacity & efficiency, maintenance, footprint
HVAC	Valance Heating & Cooling	room ceiling & wall clearances, floor-to-floor height	Passive heating & cooling, zero fan energy, filter-less, low maintenance	delayed response to set point change, unconventional, location in rooms
HVAC	Modular Water-to-Water Heat Pumps	mechanical system design	increased efficiency as compared to unitary equipment, redundancy	limited manufacturers of equipment
HVAC	Ventilation Energy Recovery	ductwork, HVAC controls, equipment capacity	reduce heating and cooling loads	initial cost and size of equipment
HVAC	Demand Based Ventilation	HVAC controls	reduced fan & thermal energy	additional sensors
Plumbing	Shower Drain Energy Recovery	drain piping	reduced DHW energy from non renewable sources	initial costs, additional drain piping
Electrical	Building Wide Lighting Control System	lighting control design	increased control over building lighting	initial cost
HVAC & Electrical	Commissioning	project close out	confirms system efficiency and operation	initial cost

Figure 14: Step 2 matrix of studied strategies.

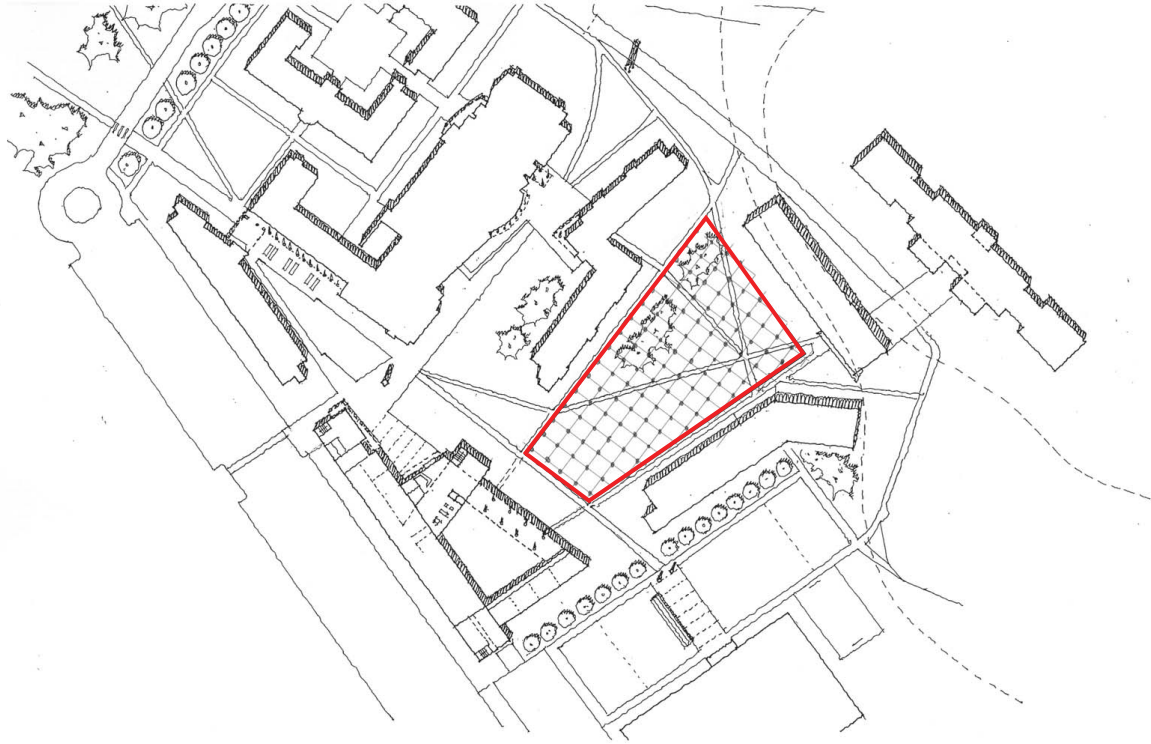


Figure 15: Field of 63 geo wells drilled on site.

- land as recreational; therefore it was possible to dedicate its use for geo-exchange wells.
- *Valance units can be difficult fit in low floor-to-floor*– the design team studied carefully the height of the perimeter spaces and the interface of the valance unit with the window.
 - *Simultaneous heat/cool requires 4-Pipe*– this duplicity of pipes is part of the valance system and was considered in the total first cost for this strategy.
 - *Unconventional equipment*– although unconventional for the USA or the New England region, these technologies have been used in Europe for many years. BSU and MSCBA were interested in incorporating these systems given the proven technology on the leading edge.

Shower Drain Heat Recovery– The team also identified the potential to save energy by reducing hot water loads. Shower drain heat recovery uses a copper piping system that recovers heat from warm water leaving the shower. This passive system reduces heating require-

ments for each shower because the recovered heat is used to continue heating domestic hot water. Weygand Hall's 140 showers, serving 500 residents daily, offer an economy of scale to multiply those savings. Since this system requires additional piping, initial cost and adequate space for the copper pipe was considered during design. With plumbing stacked on the four residential floors, Weygand Hall was able to provide one shower drain heat recovery pipe per stack, translating into 35 copper pipes to serve the entire building. The estimated payback on the initial cost is just seven years (Figure 17).

Enhanced Commissioning– In order to ensure building systems function as designed, MSCBA hired a commissioning agent. The commissioning process verifies through testing and adjusting that mechanical, electrical, plumbing and life safety systems are working efficiently. This strategy is crucial to the process, since energy savings may not be realized if systems do not work in the field as expected. Maintenance staff is also included in training and education meetings with the

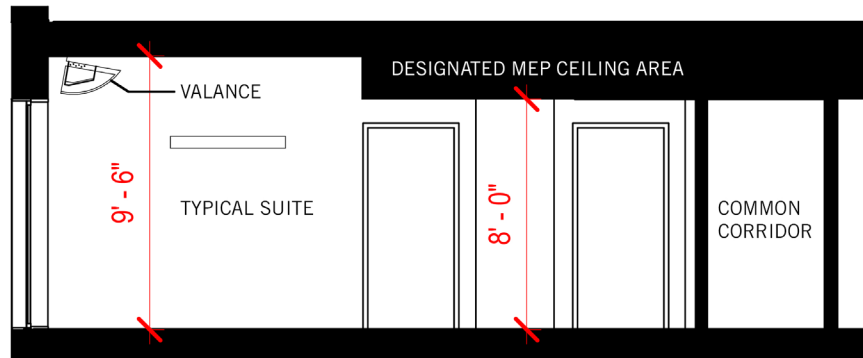


Figure 16: Sectional study of valance location above the window, designating an efficient MEP area within the ceiling while maximizing window height for daylight.

contractor and commissioning agent to ensure equipment is being used and maintained correctly.

2.3 STEP 3: Generating On-site Renewable Energy

Step 3 considered clean energy production strategies: photovoltaic panels (PV) on the new roof as well as surrounding campus structures, building integrated PV, solar water heating (SWH), on-site wind generation, and purchase of green power (Figure 18). These energy generating strategies have an initial high cost but offer energy cost savings through the life of the building. Simple payback studies were critical in determining which strategies were adopted immediately and which could be incorporated at a later date.

Photovoltaic Panels– It was estimated through energy modeling that 225,000 GSF of PV panels would be required to offset the building energy requirements and to reach ZNEB, depending on the combination of additional accepted strategies. This would require PV installation on Weygand Hall as well as another building on campus. If limited to the available Weygand Hall roof area, 29,000 GSF, PV panels installed would offset 12.4 percent of the annual energy consumption. Building integrated PV panels, PV panels mounted on the building façade or as part of the building shading system, were also studied. In the case of Weygand Hall, the initial cost did not offset the annual energy savings. Therefore, roof PV panel installation was prioritized. Since PV panels can be added at any point during the building lifetime, the roof of Weygand Hall was designed and built to be PV ready.

Solar water heating– SWH requires roof space similar to PV panels. Since the 5-story building has limited roof space, both strategies could not be efficiently accepted together. The SWH system was studied to provide hot water to building occupants throughout the year. Although gas and electricity back-up would be required for some winter days, the system would save annual utility costs for BSU. In parallel, the team studied and accepted Shower Drain Energy Recovery, as described in Step 2. The two strategies implemented together would not maximize energy savings or payback, and Shower Drain Heat Recovery was selected due to lower cost and higher energy savings as compared with SWH.

Wind Harvesting– With BSU's Facilities staff on board, the engineers studied wind harvesting opportunities on campus. A specific site near Weygand Hall was selected based on elevation, separation from third-party buildings, noise, and connection to campus operations center, and proximity to transportation for installation. Several turbine options exist with generation capacities between 100kW to 3MW. Due to interest in maximizing energy generation and payback on the initial turbine cost, the study focused on turbines generating 1.5 – 2 MW. A wind simulation for the site was set up and an estimated generation of 4,902,820 kWh of annual net production was determined with an example turbine chosen, which would power 30% of the BSU campus. Weygand Hall consumes an estimated 3,170,000 kWh annually, and would be brought to ZNEB with acceptance of a wind turbine. Any additional accepted strategies for Weygand Hall would provide additional power from wind generation for other existing or new campus



Figure 17: Copper pipe for shower drain heat recovery.

buildings. Wind energy use in this example would offset energy costs for electricity alone on campus, an estimated \$747,804 per year.

Green Power– The final renewable power strategy studied was the purchase of green power. The strategy requires no equipment or maintenance costs and can be renewed or revised over the building's lifetime. Purchasing green power ensures that the electricity the building consumes is replaced on the grid with renewable energy sources. MSCBA purchased 70% of the Weygand Hall's total energy usage, 2,792,009 kWh, for 2 years through a renewable energy company. Although this large amount of energy is purchased from clean power generation, since the renewable energy is

not generated on site, it cannot be counted towards the ZNEB goal.

2.4 STEP 4: Minimizing Building Energy Consumption through Operation

Step 4 investigated how user behavior shifts through policy changes and education could improve building function and user experience (Figure 19). The BSU Facilities and Residential Life departments were involved in sustainable charrettes throughout the design and construction process. In order to ensure success of all sustainable strategies implemented in the project and to maximize energy savings related to users interaction in the building, it was critical to have all parties input and commitment for the accepted strategies.

Temperature Set Points– Setting heating and cooling set points within the residence hall was identified early on in the process as an opportunity to reduce energy consumption. This strategy can reduce heating and cooling loads while providing adequate user comfort. The design provides the ability to adjust set points at any given point. Although the ZNEB study proposes 82 degrees as the set point for cooling at peak occupancy and 68 to 70 degrees for heating, the University believes that the set points through the heating and cooling seasons will more likely be acceptable to students in the range of 70 – 75 degrees. The University will analyze the success of this program over the year and adjust the set points if necessary in the future. Paired with an educational program weaved into Resident Assistant orientation, residents will be aware of the energy savings potential. Users can take pride in saving energy

STEP 3 utilize on-site renewable energy production

Strategy	Energy System Option	Impacts	Advantages	Disadvantages
Renewable Power	PV on Roof	roof	renewable energy source	initial cost, utility interconnect study/agreement
Renewable Power	PV on other campus surfaces (parking, roofs, land)	future building plans	renewable energy source, shading of vehicles	initial cost, utility interconnect study/agreement
Renewable Power	Building Integrated PV	building envelope, construction techniques	renewable energy source	initial cost, utility interconnect study/agreement
Renewable Power	On Site Wind Turbine	future building plans, local community	renewable energy source	permitting process, time
Renewable Power	Building Mini-Wind Turbine	building aesthetics, structural & electrical systems	educational, demonstrative	small energy production
Renewable Energy	Solar Hot Water	competes with space on roof for PV	reduced DHW energy from non renewable sources, increased COP as compare to PV	initial cost, additional equipment/space
Renewable Power	Purchase Green Energy	yearly utility cost	lower cost as compared to onsite equipment	slightly increased yearly utility cost, not ZNEB

Figure 18: Strategies for renewable energy resources.

while adjusting to feeling a couple degrees cooler or warmer than in a typical conditioned building. In this case, providing ownership to the users and knowledge about the building's systems will begin to shape positive attitudes towards building temperature and comfort levels.

Restroom Exhaust and Suite Ventilation— This indoor air quality strategy is discussed here since the decision making was heavily weighed from a user and optional point of view, although it technically belongs under Step 2. The design team studied the possibility of providing intermittent restroom exhaust control by users as needed and in part dependent on natural ventilation. This would have required students to be aware of when to turn on the restroom exhaust switch. This strategy is typically used in single residential applications but after discussions with BSU, it became clear that user awareness was not going to be enough to mitigate lack of ventilation complaints. In addition, this strategy requires more local fans or sophisticated air flow control devices (automatic dampers). Continuous exhaust systems were installed in every bathroom with a 75-100 cfm/ fixture. This system will control odor and moisture and be low maintenance. It was determined that the energy recovery in the system limited the energy penalty.

Window "Kill Switches"— Since the building design includes operable windows for each suite and in some common areas, the design team identified a need to minimize heat loss through open windows. Each operable window on floors 2 through 5 in the resident bedrooms and living rooms is equipped with a switch that indicates if the window is open or closed. The switches are factory installed in the window frames and are wired to the facilities building management system. The sequence of operation fully shuts off flow of hot or chilled water to the space when the window is in the open po-

sition. The presence of the switches in this case, prevents energy from being wasted through occupant misuse. The window switches act as an insurance policy, preventing misuse by the occupants. In addition, the operable windows with switches can be considered similar to that of an economizer system, with mechanical heating/cooling systems off at times when outdoor conditions permit. Energy modeling with these spaces in economizer mode indicates the potential savings of 25,000 kBtu of site energy saving per year.

Policy Changes and User Awareness— The Sustainability Charter, developed by the design team and BSU's Facilities Department, includes a Comprehensive Operational Plan. This plan includes a list of equipment allowed for students to bring into the residential hall (Figure 20). Mini-refrigerators are one of the biggest energy users in a residential hall and were not included on the list of allowed equipment. BSU and MSCBA made a commitment to eliminate these from Weygand Hall by purchasing full-size refrigerators for each suite. This program will also create ownership for building users who will be aware and proud of their contribution to energy savings. Although up-front costs are slightly higher, payback on this strategy is estimated at 3 years. In addition to efficient refrigerators, all common kitchen and laundry equipment within the residential hall are energy efficient models.

Parallel to the strategies listed above, the hope is for user awareness programs to foster a culture and community of Sustainable Ambassadors who will educate peers and future residents about sustainable living environments. As attitudes change and excitement grows related to green buildings, the strategies will strengthen based on how the building users function within the residence hall. BSU is also committed to conducting yearly educational orientations for residents and con-

A Zero Net Energy Building Pilot Study

STEP 4 minimize building energy consumption

Strategy	Energy System Option	Impacts	Advantages	Disadvantages
Non Traditional Heating & Cooling Operating Parameters	Heating/Cooling Set point Control	Occupant comfort	Reduce Energy consumption	possible complaints from occupants
User Group Education Awareness / Buy-in	Occupant education and awareness	Campus policy	Reduced energy consumption, reduced occupants complaints	time, cost
No Micro Refrigeration	Occupants Share Refrigerator	Privacy, building policy	reduced energy consumption	enforcement, complaints from occupants
Operations	Post Occupancy Evaluation	additional metering and analysis	forum to allow comfort and performance issues to be addressed	time, cost
Equipment Selection	Energy Star Rated equipment	Policy and Enforcement	reduced energy consumption	Enforcement, slight initial cost increase

Figure 19: Step 4.

Comparison of Electric Items Permitted in Residence Halls at Selected Institutions

ITEM	INSTITUTION					
	MIT	Harvard U.	Middlebury U.	Roger Williams U.	BSU	BSU - ZNEB Policy
Desk Lamp	Y	Y	Y	Y	Y (no halogen)	Y (energy efficient bulb, no halogen)
Alarm Clock	Y	Y	Y	Y	Y (battery)	Y (battery)
Radio/iPod dock	Y	Y	Y	Y	Y	Y
Small Fan	Y	Y		Y	Y	N (not energy star rated)
Computer	Y	Y	Y	Y	Y	Y
Surge Protector	Y	Y		Y	Y	Y
TV				Y	Y	1 per suite, energy star
DVD/VCR				Y	Y	1 per suite, energy star
Telephone	N	Y		Y	Y	Y (energy star, cordless)
Mini Refrigerator	Y	N*	Y (24 in. cubes)	Y	Y (up to 1.4 amps)	Y (up to 1.4 amps, 1 per suite)
Microwave	N	N	Y	N	Y (under 1000 watts)	Y (under 1000 watts, 1 per suite)
Blender		N**	Y**		Y	N
Coffeepot		N**	Y**		Y	N
Hair Drier	Y	Y	Y	Y	Y	Y
Hair Straightener/Curler	Y	Y	Y	Y	Y	Y
Electric Razor	Y	Y	Y	Y	Y	Y
Cell Phone + Charger	Y	Y	Y	Y	Y	Y
Green Strip Power						Smart Strip (SCG5)

* Allowed if purches from selected provider

** Allowed if there are kitchen facilities

Blank cells mean information was not available or item is not regulated

Figure 20: Comparison of allowed electric appliances on campuses compared with BSU's new ZNEB policy, developed in parallel with Weygand Hall project.



Figure 21: Whole building diagram of all accepted strategies.

tinue to enforce energy conservation behavior through Residential Assistant events (Figure 21).

3.0 CONCLUSION

The design team identified and studied strategies from conceptual design through project completion for reaching net zero energy goals. Building design considered sustainable strategies without compromise of aesthetic goals, ensuring a holistically designed building. In lieu of a typical linear process of adding several proven strategies and getting a result, the original aspirational goal for ZNEB was set early in the process and developed as a reiterative and integrated approach. Within the four steps described, project specific strategies were then tested, analyzed and vetted to maximize energy efficiency towards the ZNEB goal. Tracking clear cost and energy use data for each strategy provided confidence as strategies were accepted and implemented into the project. The study not only provides knowledge for future projects, but pushed the project to implement strategies that might not otherwise have been studied.

Strategies with significant energy savings on their own combined with many small scale strategies add up to save 54% energy from the code baseline at Weygand Hall. Two renewable energy plans for the project offer potential for reaching the ZNEB goal: a PV-ready roof and a campus wind study that if proven satisfactory could lead to a wind turbine on campus. This wind

turbine, will have the capacity to provide clean energy for the Residential Hall as well as other buildings on campus. Although a wind turbine has a high initial cost, BSU's Facilities group encouraged the wind study because a turbine could generate power at a campus-district level. This campus wide strategy aligns with Bridgewater State University's commitment to minimize global warming emissions⁷. The wind turbine is an example of an important outcome in the ZNEB pilot study. The many charrettes and educational sessions, elevated discussions and allowed MSCBA, BSU and the design team to gain in-depth understanding of technologies and systems integration.

The ZNEB pilot study's measure for success was met as the team identified challenges and opportunities using new and proven technologies, implemented low energy strategies supported by energy modeling and cost analysis, and documented the process in a report that incorporates lessons learned for future residential halls with a ZNEB goal.

Accepted Strategies (Figure 21):

1. Fiberglass Windows; Double-pane with argon gas
 - Proven better thermal transmittance value through research and manufacturer testing information
2. Exterior Solar Shading and Interior Shades
 - Brise soleil system: benefits validated through

- solar shading analysis and energy modeling
- Interior shades reduce glare and allow for user operability based on time of day and season
- 3. Lighting Controls
 - Reduced lighting power density
- 4. Extensive Green Roof (Project Alternate)
 - Lightweight, low maintenance, and long life
 - Flexibility to add later to roof without adding structural support
- 5. Geo-exchange & Valance Systems
 - Reduced maintenance, energy consumption, and equipment sizes
- 6. Shower Drain Energy Recovery
 - Preheats water to reduce energy needed to produce hot water
- 7. Photovoltaic Panels (Project Alternate)
 - Roof is available for future PV panel installation to reduce building electricity loads
- 8. Green Power purchase
 - MSCBA purchased green power equivalent to 70% of the building's annual energy use
- 9. Temperature Set Points
 - Heating and cooling set points to provide additional energy savings
 - Can be adjusted to further save energy as user awareness influences user comfort levels
- 10. Window "Kill Switches"
 - Implemented on all student suite operable windows
 - Saves energy use when windows are open during comfortable days by shutting off heating or cooling systems
- 11. Allowable Student Equipment List
 - Change in policy: students are no longer able to bring individual microwaves and mini-refrigerators. In turn, the University will provide one microwave and large energy Star refrigerator per suite.

Acknowledgments

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*Jordan Zimmermann (Project Captain and LEED expert) and Yanel de Angel (Sustainability Champion)

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