Sustainable Housing Futures at Carnegie Mellon University
Final Project

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12-747 Sustainable Buildings
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Executive Summary

The built environment has definitively become integral pieces of modern sustainability systems. Buildings' often-huge energy and water consumption needs, demanded by necessary applications including heating and cooling, sinks and showerheads, insulation, lighting and landscaping. To this end, there are proven environmental, financial, and social benefits of pursuing certain sustainable improvements in buildings.

This report proposes seven sustainable features identified as feasible and impactful for a new undergraduate dormitory on the campus of Carnegie Mellon University in Pittsburgh, PA. Specifically, the Residence on Fifth ("the Res"), a first-year undergraduate, apartment-style dormitory, was used as reference for the proposed new building.

The seven features include: green roofs, efficient showerheads, building orientation and windows, effective insulation, intelligent HVAC, LED lighting, and effective landscaping. All seven have been assessed for technical and financial feasibility, in addition to their contribution to a reduced environmental footprint for the building. Qualitatively,

1. Green roofs lower average roof temperatures compared to traditional concrete roofs, capture and evaporate precipitation, and provide added aesthetic.
2. Efficient showerheads can lower the high water demands of a high-occupant building like a dormitory by limiting water outflow at a comfortable level.
3. Building orientation, in concert with efficient, high "r-value" windows, utilizes natural sunlight and ventilation to reduce heating and cooling loads.
4. Similarly, added insulation with appreciable "r-values" further reduces artificial heating and cooling loads, particularly in colder winter months.
5. Automatic HVAC systems can optimize heating and cooling functions of the building while still ensuring occupant comfort.
6. LED lights provide more plentiful and durable light at a less expensive cost on the lifetime scale.
7. Effective selection of certain types of plants and irrigation systems can considerably reduce outdoor water demands.

This report is authored by Yoolhee Kim, Anand Krishnan Prakash, Mikael Matossian, Yifang Xu, Siyao Zhu, and completed as a final project for the Fall 2016 12-747 Sustainable Buildings course at Carnegie Mellon University.

City, Region, and Background Information

The report does a study on the climate and environment and recommends sustainable practices for dorm buildings in the area of Pittsburgh, PA. We will be focusing on dorm buildings for the implementing our recommendations and analyzing the cost and energy benefits, and will be using the Residence on Fifth, a CMU dorm building, as a reference for this project.

A lot of steel related business used to run in Pittsburgh, but now the IT sector is beginning to boom. Lot of universities are based in Pittsburgh and hence there is a large student population. The majority of the electricity consumed is generated from fossil fuels.

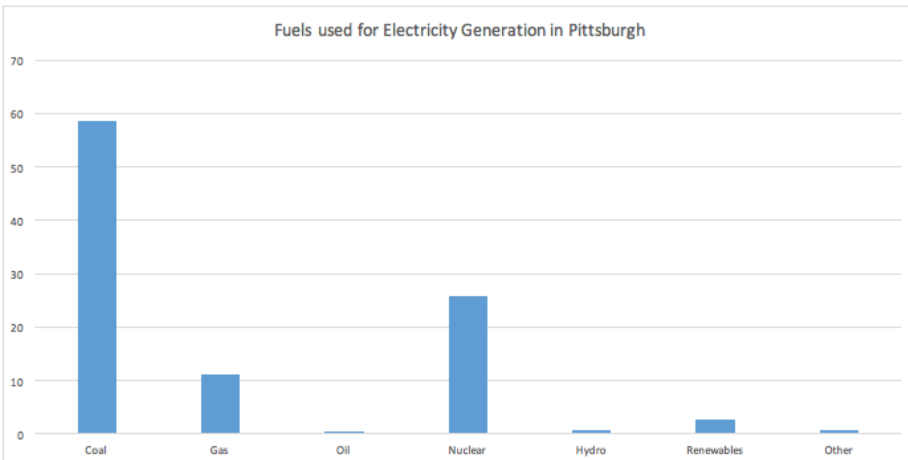


Figure 1: Fuels used for Electricity Generation in Pittsburgh [61]

Pittsburgh Climate Information

Temperature

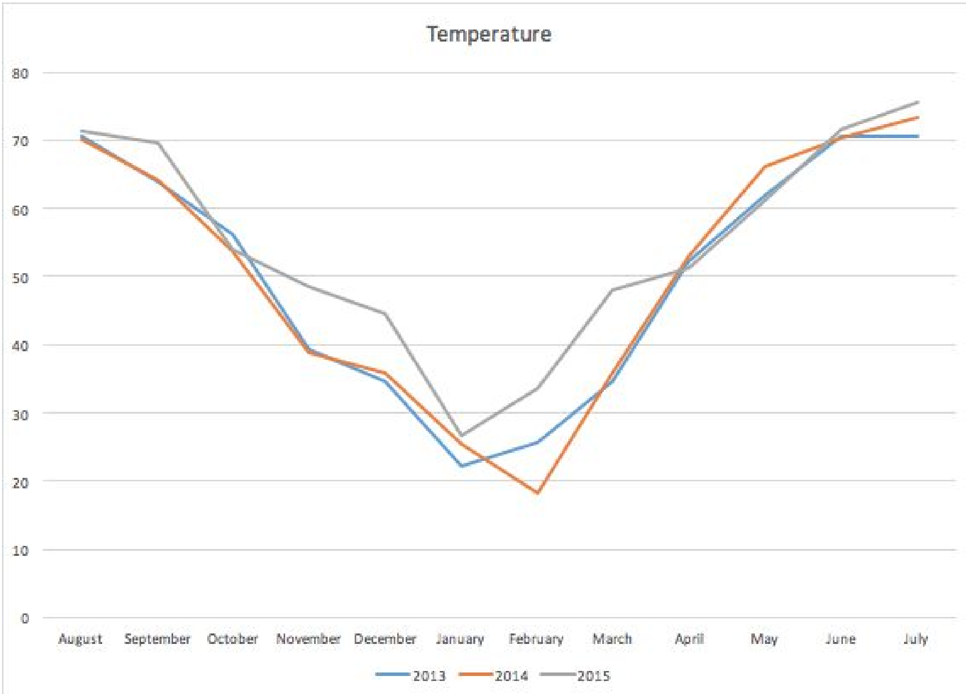


Figure 2: Pittsburgh Temperature for 2013, 2014 and 2015 [62]

Pittsburgh has a temperature of around 80F in summer and around 30F in winters.

Rain Fall

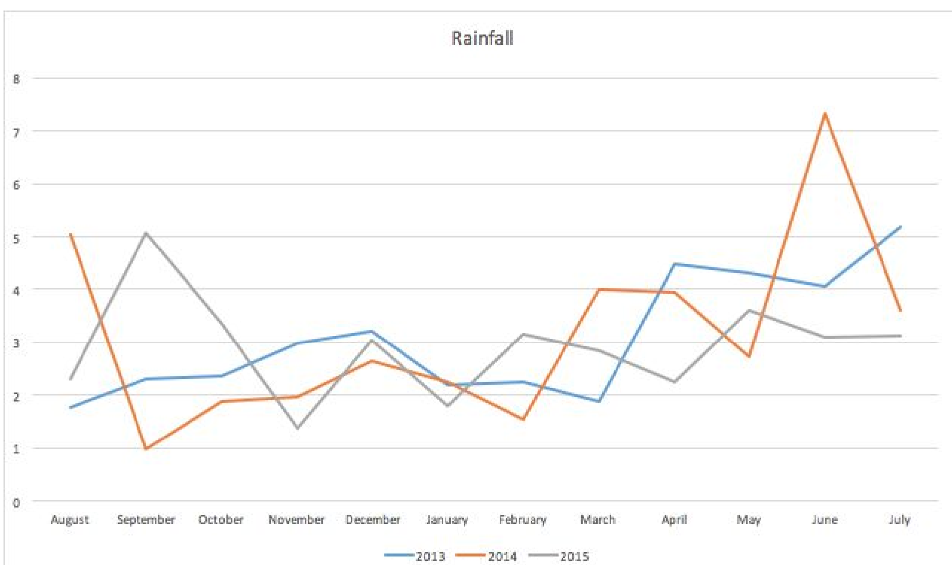


Figure 3: Pittsburgh Rainfall for 2013, 2014 and 2015 [62]

There is a decent amount of rainfall throughout the year and this helps in maintaining green roofs and other green covers without much extra effort.

Heating and Cooling Degree Days

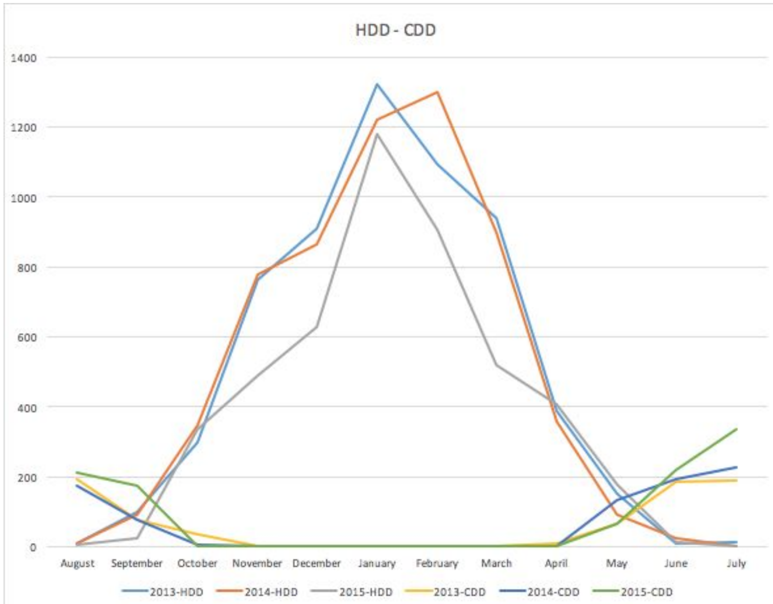


Figure 4: Pittsburgh Heating and Cooling Degree Days for 2013, 2014 and 2015 [62]

The high number of heating degree days during the months November to March indicates that there a large proportion of energy might be used for heating purposes. This can be reduced by using sustainable practices in buildings like windbreaks and further insulation.

Wind Speed

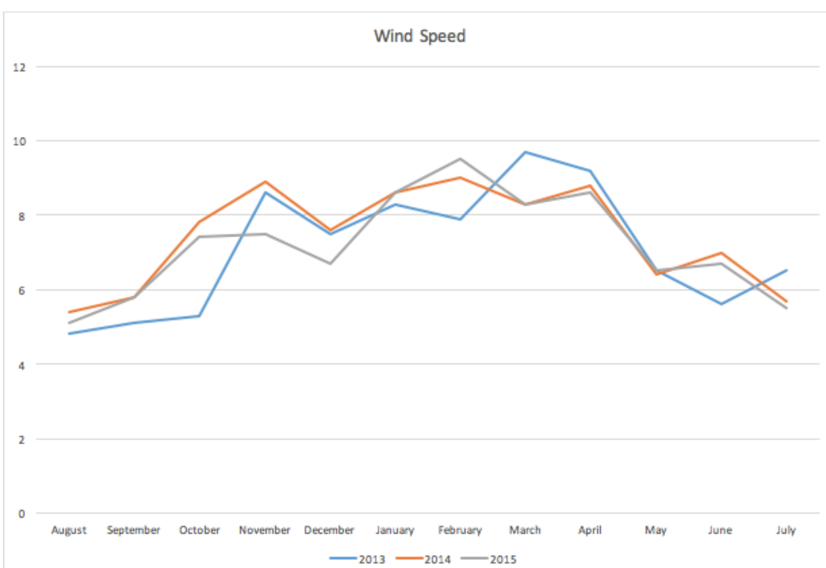
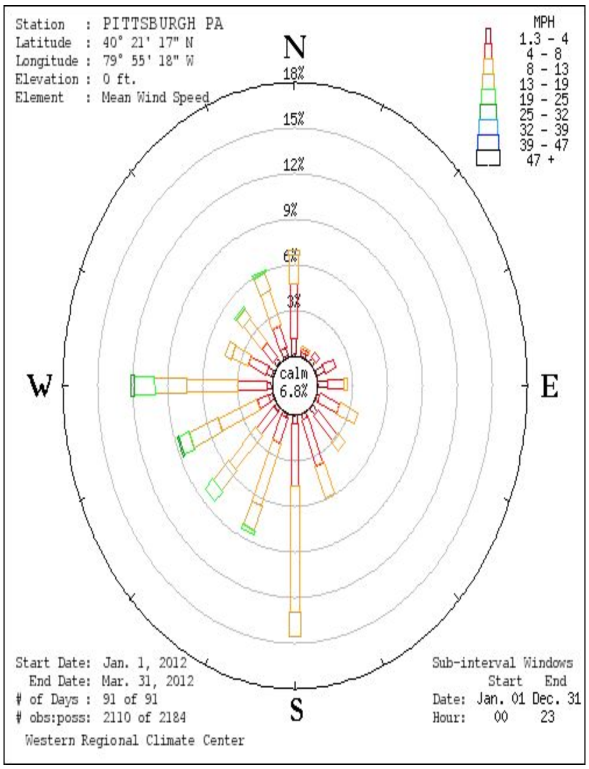


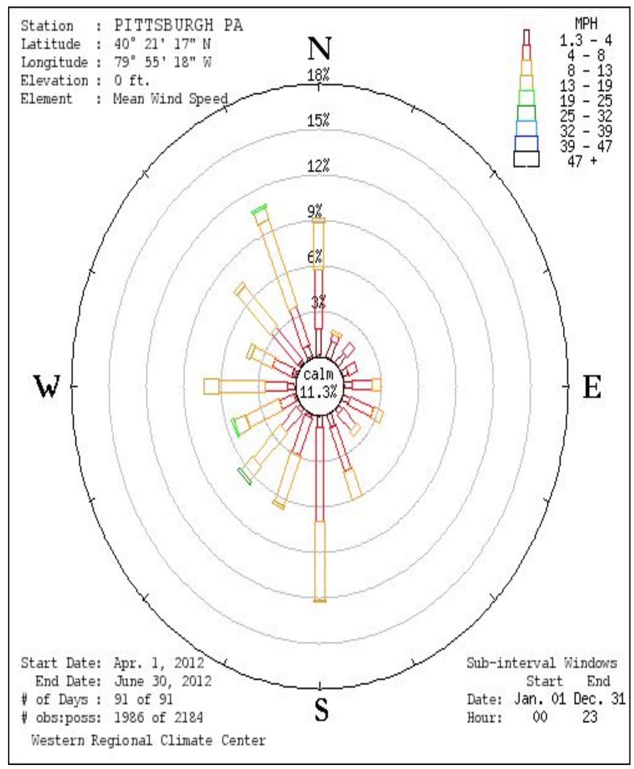
Figure 5: Pittsburgh Winds for 2013, 2014 and 2015 [62]

The wind speed is higher during the winter months and this, along with the low temperatures contribute to the heavy requirement for lot more heating. Windbreaks and constructing a building with properly planned orientations can help in countering the effect of these winds.

Wind Roses [63]

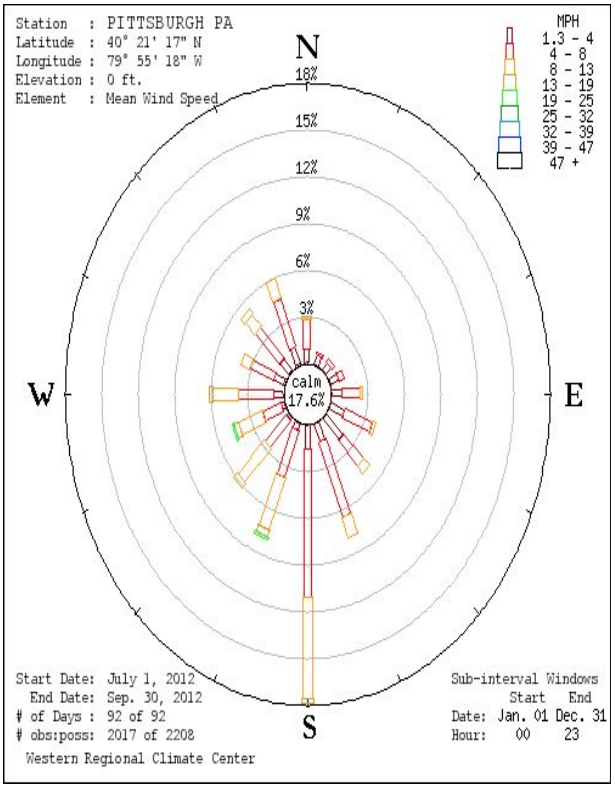
There is wind blowing from the south west direction throughout the year and if the building is rightly oriented to tap this, it would be a good source of natural ventilation. During the colder months, there are stronger winds from the west side.



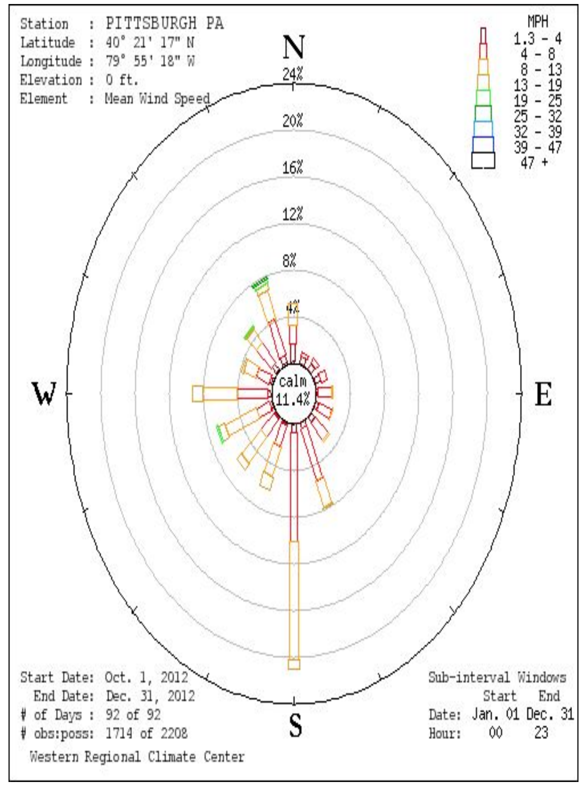


Jan - Mar

Apr-Jun



Jul-Sep



Oct-Dec

Figure 6: Wind roses for January-March, April-June, July-September and October-December

Environmental, Economic, and Social Issues of the Pittsburgh Region

This section will discuss the various environmental, economic, and social issues specific to CMU dorm buildings in the Pittsburgh region. These issues will be addressed throughout the report, as we make sustainable building practice recommendations to alleviate these issues.

One issue that must be considered for CMU dorm buildings is affordability of housing for students. As a university dorm, the dorm building must be cost efficient to lower the economic burden of the student's cost of living. Many students are from a median income household, therefore it is a high priority to have affordable dorms that would be of benefit to many students. Additionally, lowering affordable housing has positive social impacts, as it can affect the supply and demand of housing in the surrounding area. Lack of affordable housing has negative effects on a community's overall health.

Another issue to be considered is environmental sustainability, carbon and particulate emissions, and climate change. Electricity usage and the use of natural gas stoves are the sources of a dorm building's carbon emissions. According to the U.S. Environmental Protection Agency, carbon dioxide makes up over 80 percent of greenhouse gases emitted by the United States, which is largely due to the burning of fossil fuels [64]. These greenhouse gases have a severe impact on global warming and climate change.

Particularly in Pittsburgh, the electric grid mix is powered by more coal compared to the U.S. average grid mix, thus the use of electricity results in higher carbon emissions than most places in the U.S. Additionally, emissions can cause social damage due to worsened air conditions and resulting negative impacts to population health. There are associated economic impacts, due to the cost to treat health problems associated with carbon emissions. EPA and other federal agencies use the social cost of carbon (SC-CO2) metric to estimates the economic damages associated with an increase in CO2 emissions (metric ton per year).

Water usage is another issue to be considered for this report. Heavy water usage will increase the pressure of local water resources. Many of our most important aquifers are being over-pumped, causing widespread declines in groundwater levels [66].

Flash floods and runoff flow due to precipitation is a serious issue in the Pittsburgh area due to the heavy rain of this region. Runoff flow and flash floods challenge the sewage system surrounding the building, and may damage the dorm building facility. Additionally, runoff flow can cause economic damages to property, as well as pose dangers to the population if it is not treated properly.

The following sections will suggest sustainable building practices for a dorm building in the Pittsburgh area, with the above-mentioned issues in mind. The practices we will be recommending are green roofs, water efficient shower heads, building orientation and windows, proper insulation, intelligent HVAC systems, LED lighting, and landscaping.

GREEN ROOFS

What are Green roofs?

Green roofs are roofs of buildings that are partially or completely covered with plants and vegetation, and consists of many layers. These layers allow the roof and building to remain dry, while maintaining enough moisture storage for the plants to survive [1]. Green roofs are commercially available and are sold either by each individual layer, several combined layers, or all layers combined and placed as tiles on the structural roof [1].

Components of a Green Roof

There are 7 layers to a green roof, and are listed below:

- Structural roofing deck
  - This is just the roof structure of the building.
- Waterproofing Membrane
  - This membrane is a durable seal that ensures a dry structural roof, and keeping it isolated from the moisture that penetrates the upper layers. It is commonly composed of layers of asphalt roofing felt placed between asphalt and bitumen. Plants may try to feed on the organic bitumen, so it is essential to use a root barrier with this type of waterproofing membrane [1].
- Root Barriers
  - The root barrier is placed above the waterproofing membrane, and protects and separates the structural roof and waterproofing membrane from the plants above it. It is commonly made of sheets of PVC, since it is long lasting and prevents leakage. Joints of the PVC are chemically welded together, and the root barrier extends up the side of the green roof and around any protrusions in order to completely seal off and protect the structure from vegetation [1].
- Drainage System
  - This purpose of this system is to carry away excess water and is made of two parts – a drainage layer within the roof, and the drains that carry the excess water to the sewer system. The drainage layer is designed to make the excess water enter the drainage system and be carried out through pipes once the substrate is saturated. This layer is typically made of several types of materials with large pore spaces such as gravel, broken rocks, and clinkers [1].
- Filter Fabric
  - This layer prevents soil particles from washing away due to precipitation [1].
- Substrate

    - The substrate provides water retention to support plant life. This also includes the soil mix for the plants to grow in [1].
- Plants and Vegetation
    - The plants and vegetation varies from roof to roof, and depends on how thick the green roof layers are, as well as the climate of the region. For our report, we will be focusing on the Pittsburgh climate and assume that the green roof will be semi-intensive, with a soil mix of thickness 6”-9” [2]. Some plants that will be appropriate for this particular soil thickness and climate include grasses, wildflowers, aromatic herbs, perennials, and small shrubs [4].

Social, Environmental, and Financial Benefits/Impacts of Green Roofs

There are many social, environmental, and financial benefits to having green roofs. Some social impacts of green roofs include improved aesthetics, creation of recreational space for the building residents (which would be students in the case of dorm buildings), and improved market for recycled materials such as compost, soil, and other green roof components.

Green roofs have significant environmental benefits as well, such as reducing the heat island effect during summers by cooling air with evapotranspiration. As a result, green roofs have a lower average temperature compared to concrete roofs. Green roofs also increase vegetation and wildlife habitat, while adding insulation to the building. This increase in insulation allows for reduced energy consumption, and therefore lowers the carbon footprint of the building. Green roofs also improve the outdoor air quality by reducing smog, which is both a social and environmental benefit.

Green roofs also capture and evaporate 10% to 100% of the precipitation that falls on it, reducing the volume and speed of storm water runoff. This alleviates sewer overflow and flooding which has a positive social impact, and protects rivers and streams which has positive environmental impact. Runoff water temperature is also lowered, which helps to maintain cool stream temperatures needed by fish [3]. Below shows a diagram of the impact of green roof on runoff flow-rate, with time retardation and water flow retardation.

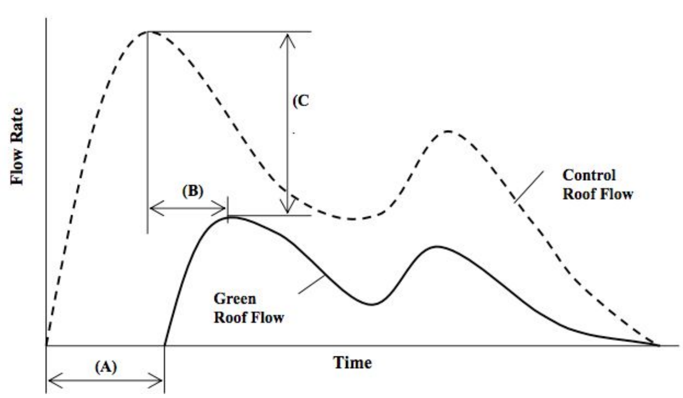


Figure 7: Diagram of Control Roof and Green Roof Runoff Flow-rates [1]

Finally, there are some financial benefits to green roofs. Green roofs double the lifespan of the roof, saving maintenance costs of replacement and materials. Green roofs also lower HVAC operational costs due to added insulation of the roof. Additionally, an accessible green roof could add property value to the building. However, green roofs do have higher installation costs, so the payback period must be determined for feasibility.

Irrigation and Maintenance Consideration

In order to keep the plants of the green roof healthy and alive, significant amounts of water are required. The plants chosen for the green roof should be capable of surviving in the climate of the area. Ideally the natural rainfall that reaches the roof should nearly eliminate the need for watering the plants. However, green roofs generally require installation of light irrigation systems in order to ensure plant survival, since there is always the possibility of extreme drought. An irrigation system for the green roofs adds to the total cost and complexity of the roof design. Often times, vendors of green roofs provide irrigation systems or sprinklers as part of the installation, avoiding desiccation [1]. Additionally, plants require costly and time consuming maintenance such as trimming of trees and shrubs on a regular basis. Maintenance typically is only necessary a few times a year for weeding, replanting, and fertilization [1].

The green roof on Hammerschlag Hall of CMU describes its plant maintenance in the final report [3]. The plants are only watered once after a month without rain, as the plants on the roof are mainly dry-resistant vegetation. Maintenance such as weeding, staking, trimming, and pruning is conducted on an as-need basis to maintain appearance and plant health. The green roof plants are fertilized with organic fertilizer once every three months in the months between March and September.

Green Roof Cost Analysis and Payback Period

In this section, we will consider the installation cost of a green roof, lowered HVAC operational cost, and lowered roof maintenance cost in order to determine the payback period of the green roof. The Residence on Fifth will be used as an example for analyzing the cost of installing a green roof. This residence has a roof square footage of approximately 11,700 ft^2.
A typical installation cost of a green roof can vary, but typically ranges between $15-20 per square foot for all use types [5]. This is in addition to the installation cost of the roof structure itself, which typically costs $450 per square foot [6]. For the Residence on Fifth with a roof area of 11,700 ft^2, the additional installation cost for a green roof is:

$$Green\ Roof\ Installation\ Cost = 11{,}700\ ft^2 \times \frac{\$17.5}{ft^2} = \$204{,}750$$

Lowered HVAC operational cost depends on the increase in R-value due to the green roof. A typical R-value increase of a green roof is about 5 [7]. A typical roof in the Pittsburgh area has an attic R-value of approximately R-40 [8]. This insulation value difference will be used to quantify annual energy savings, and as a result economic savings on electric bills. In Pittsburgh, electricity costs are approximately $0.0912/kWh [9].

We will also assume that the average high and low temperatures, depending on the month, is the constant temperature throughout the whole month. For the months of October through May, we will be using the average low temperature, and for the months of June through September, we will be using the average high temperature. The indoor temperature will remain at 65°F. We will also assume perfect electricity to heat conversion efficiency. The savings on electricity per year due to added insulation is $220.97, as calculated in Table 1 using the following equation:

$$\textit{Heat Savings with Green Roof} = \Delta\left(\frac{\Delta Q}{\Delta t}\right) = \frac{A(T_1 - T_2)}{R_{greenroof}} - \frac{A(T_1 - T_2)}{R_{roof}}$$

$$= \frac{11700\ ft^2 \cdot (65 - T_{outdoor})}{35 + 5} - \frac{11700 ft^2 \cdot (65 - T_{outdoor})}{35}$$

	Average High Temp (F)	Average Low Temp (F)	Heat Savings (BTU/hr)	Electricity Savings ($/month)
January	37	21	1838.571429	35.87720836
February	40	22	1796.785714	35.06181726
March	50	30	1462.5	28.53868847
April	62	39	1086.428571	21.20016858
May	71	51	585	11.41547539
June	79	61	167.1428571	3.261564397
July	83	66	41.78571429	0.815391099
August	82	63	83.57142857	1.630782198
September	75	55	417.8571429	8.153910991
October	64	44	877.5	17.12321308

November	53	34	1295.357143	25.27712407
December	41	25	1671.428571	32.61564397

Total Electricity Savings ($/year) 220.9709879

Table 1: Average High and Low Temperatures of Pittsburgh and Associated Heat and Electricity Savings with Green Roof [10]

A green roof doubles the roof lifespan, and therefore lowers the maintenance cost of the roof. An asphalt roof lifespan can vary from 15 to 30 years [11]. For the purposes of this report, we will assume the roof is made of built-up or modified bitumen and has a lifespan of 16 years [11], and that the green roof lifespan doubles this lifespan to 32 years. The cost to repair a roof will assume to be $2200 on the high end of the average [12]. Therefore, the maintenance cost difference between a standard roof and a green roof is:

$$Maintenance\ Savings = \frac{\$2200}{16\ years} - \frac{\$2200}{32\ years} = \frac{\$68.75}{year}$$

Payback period for adding a green roof is calculated by the following equation:

$$Installation\ cost = \ Payback\ period \times (Maintenance\ Savings + Heat\ Savings)$$

$$Payback\ period = \frac{\$204{,}750}{\left(\frac{\$68.75 + \$220.97}{year}\right)} = 707\ years$$

This payback period of 707 years is much higher than the lifespan of any building. Therefore, despite the various social and environmental benefits of green roofs, it may not make financial sense to install the green roof if there is not enough money in the budget. However, for long-term property owners, green roofs can make financial sense if there are local green roof incentives or storm water policies. These local policies can provide funding for green roofs and reduce the payback period to approximately 0-5 years [13].

For example, 3 Rivers Wet Weather, a non-profit environmental organization supporting 82 Allegheny County municipalities and the City of Pittsburgh, funded various green roof installation and monitoring systems throughout Pittsburgh from 2007 through 2010 [3]. The amount of this funding varied from $25,250 to $240,000, which could cover nearly all of the green roof installation costs.

Run-off Analysis – Before and After Green Roof

In this section, the rational equation will be used to quantify the peak rate of runoff before and after the installation of a green roof. The peak rate of runoff is much lower for a green roof compared to a roof with concrete, asphalt, or gravel. The rational equation is given from Lecture "Energy, Water, Waste 9.12.16" Slide 49:

$$Q = C \times i \times A$$

- Q = peak rate of runoff (cubic feet / second)
- A = drainage area (acres)
- i = average intensity of rainfall (inches/hour)
- C = runoff coefficient (much lower for thick garden roofs compared to asphalt or gravel)

The area of the roof for our example building, the Residence on Fifth, is 11,700 ft^2. The runoff coefficient of various roofs can be found from Lecture "Energy, Water, Waste 9.12.16" Slide 50 (LEED for Existing Buildings: O&M 2008), and is presented in Table 2.

Surface Type	Run of Coefficient	Surface Type	Runoff Coefficient
Pavement, Asphalt	0.95	Turf, Flat (0–1% slope)	0.25
Pavement, Concrete	0.95	Turf, Average (1–3% slope)	0.35
Pavement, Brick	0.85	Turf, Hilly (3–10% slope)	0.40
Pavement, Gravel	0.75	Turf, Steep (> 10% slope)	0.45
Roofs, Conventional	0.95	Vegetation, Flat (0–1% slope)	0.10
Roof, Garden Roof (<4 in)	0.50	Vegetation, Average (1–3% slope)	0.20
Roof, Garden Roof (4-8 in)	0.30	Vegetation, Hilly (3–10% slope)	0.25
Roof, Garden Roof (9-20 in)	0.20	Vegetation, Steep (> 10% slope)	0.30
Roof, Garden Roof (>20 in)	0.10		

Table 2: Runoff Coefficient for Various Roof Surface Types

Average rain event in Pittsburgh is a quarter inch, and over an entire year, precipitation accumulates to an average of 37.5 inches [3]. We will assume the average rain event is a half hour, which gives us:

$$i = \frac{0.25\ inches}{0.5\ hour} = 0.5\ \frac{inches}{hour}$$

Plugging all the values into the equation, varying the runoff coefficient, we get various values of peak rate of runoff, and is shown below in the table below. For a garden roof 9 inches thick, the coefficient is 0.2, which gives us a runoff rate of 0.0269 ft^3/s. The baseline comparison is to the current roof on the Fifth residence dorm building, which consists of concrete pavement roof with a runoff coefficient of 0.95, corresponding to a runoff rate of 0.1276 ft^3/s. Therefore, the installation of the green roof was able to reduce the runoff rate by (0.1276 ft^3/s)¸(0.0269 ft^3/s) = 4.74 times in terms of volumetric flow rate.

Runoff Coefficient	Peak Runoff Rate (ft^3/s)
0.95	0.127582644
0.9	0.120867768
0.85	0.114152892
0.8	0.107438016
0.75	0.10072314
0.7	0.094008264
0.65	0.087293388
0.6	0.080578512
0.55	0.073863636
0.5	0.06714876
0.45	0.060433884
0.4	0.053719008
0.35	0.047004132
0.3	0.040289256
0.25	0.03357438
0.2	0.026859504
0.15	0.020144628
0.1	0.013429752

Table 3: Runoff Rate vs. Runoff Coefficient

WATER EFFICIENT SHOWERHEADS

Introduction

Although energy efficiency is key in ensuring a building's sustainability and maintenance of low utility bills, water efficiency must also be carefully considered. All buildings are billed based on the volume of water that they consume (e.g. in thousands of gallons per month). Using water more efficiently can lower utility bills, and especially for water-stressed geographic regions, can reduce the often-intensive environmental impacts of buildings. Therefore, there are financial and environmental motivations behind water conservation and efficiency.

Water conservation and efficiency in the built environment can occur through multiple pathways, including encouragement of building residents to change their water usage behaviors (e.g. operate dishwashers only when full, minimize water use in sinks, etc.), or even introducing novel sources of water, like re-circulated "greywater". However, one of the most easily implementable tools for water efficiency is to actually limit water flow from different fixtures like sink faucets, toilets, and showerheads. This report section recommends the installation of low-flow showerheads to definitively reduce water usage during showering.

Showerheads

Bathing and sanitation are often regarded as key components of a modern, healthy society, causing showering to be a cornerstone of the average American's life. However, with that sanitation comes large water consumption costs. Showering composes approximately 15% of all Americans' water usage annually, demanding over 1 trillion gallons of water nationwide [14]. This translates into nearly 40 gallons of water per day spent showering, for an average American family. In states with water shortages including California and Texas, this is an especially huge environmental demand.

EPA WaterSense

To better address water efficiency, the United States Environmental Protection Agency (EPA) established federally standardized recommendations for efficient sink faucet and showerhead water flow: WaterSense. Rather than being a regulatory program, it is voluntary, meaning that faucet, showerhead, and toilet manufacturers may have their devices verified by a third party to comply with WaterSense standards, easily identifiable by a certified sticker [14]. These WaterSense-certified items release less water per unit of time, effectively forcing someone to use less water while washing their hands or showering.

Specifically, WaterSense-certified showerheads use no more than 2.0 gallons per minute (gpm), in comparison to standard showerheads that consume water at 2.5 gpm [15], the federal standard mandated by the Energy Policy Act of 1992 [16]. This amounts to a 20% decrease in maximum water flow per showerhead, and has been quantified to still ensure comfort and effectiveness during a standard shower [17]. Before issuing the official WaterSense standard for showerheads, physical laboratory tests were conducted to ensure that pressure and spray coverage would not be compromised [18].

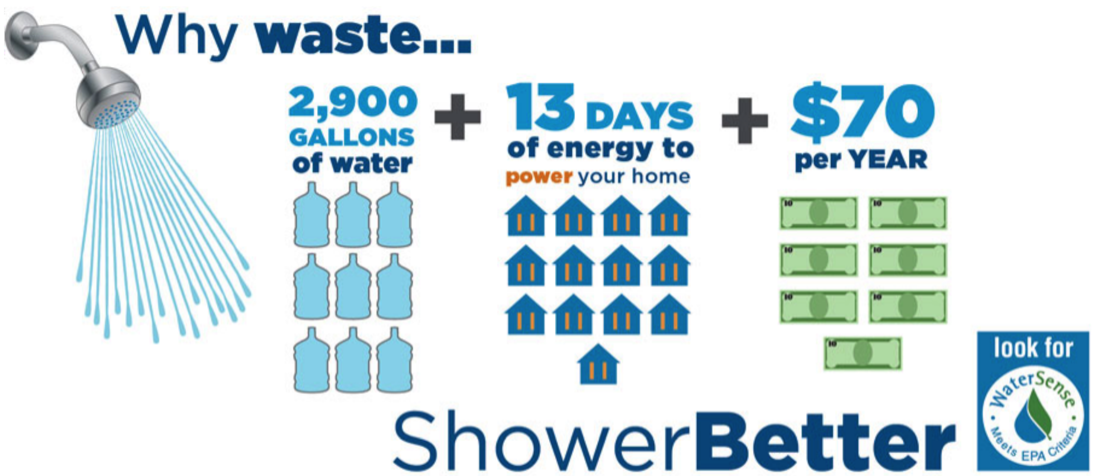


Figure 8: Estimated annual water savings due to 1 WaterSense compliant showerhead used in an average American household [16]

With WaterSense showerheads, the EPA estimates that an average American family can save almost 3,000 gallons per water, conserve enough electricity to power a household for 13 days, and avoid $70 in utility bills annually, shown in Figure x [15]. Nationally, if every home in the United States were to install WaterSense showerheads, more than 260 billion gallons of water and $2.2 billion in water utility bills could be abated per year as well [15].

WaterSense-certified showerheads are recommended over sink faucets and toilets due to relative ease of installation. Whereas sink faucets may require tools to dismantle for re-installing new aerators and toilets would require complete overhaul, showerheads are comparatively simple to retrofit. One can simply unscrew an inefficient showerhead and replace it by screwing in a new WaterSense-certified showerhead. Nevertheless, EPA-approved sink faucets and toilets may be pursued in addition to showerheads for maximum water efficiency.

Figure 9: Standard water flow bag used to quantify fixture efficiency

Additionally, such showerheads can be easily assessed for water efficiency by using a water flow bag: a usually plastic, fillable bag with markings to measure water levels, as shown in Figure xx. After 5 seconds of full capacity flow enters the bag, if it records more than 2.0 gpm, a WaterSense showerhead can be pursued. This can be done to ensure that all current showerheads in the dormitory are operating efficiently. While the EPA itself does not provide rebates, many water utilities do. Although the Pittsburgh Water and Sewer Authority (PWSA), the water utility that would serve the new dormitory building, does not currently provide rebates for WaterSense showerheads, it does refer website viewers to the WaterSense website in an effort to raise awareness about the program [19].

Potential water savings in new dormitory

Low-flow showerheads would serve to establish water efficiency in the new dormitory building, since dozens of residents would be taking multiple showers in total per day. A simple analysis shown in Table 4 makes these benefits apparent when the following assumptions are made:

- The average American shower duration is 8.0 minutes [21]
- Each building resident takes 5 showers per week on average
- The average undergraduate school year lasts for 10 months, which includes an average of 43.45 weeks
- 150 residents live in the new dormitory building (equal to the number of residents in the Residence on Fifth at CMU) [22]

Water savings		
Measure	**Quantity**	**Unit**
Average length of shower	8	minutes
Water used per shower with 2.5 gpm showerhead	20	gallons
Water used per shower with 2.0 gpm showerhead (EPA WaterSense)	16	gallons
Water saved per shower from change to 2.0 gpm showerhead	4	gallons
Number of showers taken per student per week	5	showers

Amount of water saved per student per week	20	gallons
Number of showers taken per student per school year (10 months)	217.25	showers
Amount of water saved per student per school year (10 months)	869	gallons
Number of residents	150	residents
Total water saved per school year	130,350	gallons

Table 4: Water savings for 1 school year induced by EPA WaterSense 2.0 gpm showerheads

As shown in Table 4, if the new dormitory building were to provide enough showerheads for all 150 residents, more than 130,000 gallons of water used would be avoided per school year.

Potential financial savings in new dormitory

In terms of financing, there is a timely payback of 1.32 years if WaterSense-certified 2.0 gpm showerheads are used as opposed to 2.5 gpm showerheads. This is shown in Table xxx, and is contingent on the following assumptions:

- 150 residents live in the new dormitory building (equal to the number of residents in the Residence on Fifth at CMU) [22]
- Double and triple occupant units are equally distributed (30 each)
- There is one showerhead per unit
- The average cost to purchase a WaterSense-certified 2.0 gpm showerhead is $20 [17]
- The average showerhead installation cost in a college dormitory is $20 [23]
- The price of water provided by PWSA is $13.94 per 1000 gallons of water for educational institutions [24]
- Showerhead maintenance costs are not included

Financial Savings		
Measure	**Quantity**	**Unit**
Number of residents	150	residents
Number of two-occupant units	30	units

Number of three-occupant units	30	units
Number of total units	60	units
Number of showerheads per unit	1	showerheads
Capital cost of each showerhead	20	USD
Installation cost of each showerhead	20	USD
Total cost of each showerhead	40	USD
Total number of showerheads in building	60	showerheads
Total cost of all showerheads	2,400	USD
Water utility price of water	0.0139	USD/gallon
Total water saved per school year	130,350	gallons
Money saved per year from change to 2.0 gpm showerhead	1,817.08	USD
Payback period for total cost of all showerheads	1.32	years

Table 5: Financial savings for 1 school year induced by 2.0 gpm showerheads

BUILDING ORIENTATIONS AND WINDOWS

Introduction

Positioning and structure can have huge influences on general sustainability in buildings: depending on the orientation, windows, doors, roofs, and other fenestrations (openings in the structure), heating and cooling loads can be affected. Building orientation and windows in particular are key interfaces with weather and other building surroundings. They can optimize the structure for interaction with incoming sunlight and wind and vegetation.

Building Orientation

The actual situation and positioning of a building, or “building orientation”, at a site can influence its solar and wind gains, and therefore, its energy consumption and indoor occupant satisfaction [25]. For example, depending on how much sunlight enters the building through openings, different heating and cooling loads may be demanded which would affect the general well-being of building residents. Natural sunlight provides heat for free in comparison to artificial light, which consumes nearly 20% of the world’s electricity, and 1.2 billion tonnes of carbon dioxide emissions in total every year [26]. Additionally, more natural sunlight in buildings adds benefits like natural aesthetics, and has been tied to increased productivity of students and employees, reduction of fatigue, and general improvements in mental and physical health [26]. Usually, orienting the building so that the most commonly-occupied spaces face the northern and southern exposures can maximize incoming daylight and natural ventilation. This can help the building use natural sunlight for heating needs, and winds for ventilation and cooling needs [25].

Solar radiation

Specific tools can be used to maximize experience of solar radiation and wind flow for a building, including solar radiation tables and wind roses. A solar radiation table displays average annual data of sunlight strength for different building façades orientations, based on differences in radiation due to the Earth’s revolution around the Sun. Using that data, a building can be positioned to have windows and doors facing certain directions that can balance both daylighting and unwanted solar heat gain [25]. The solar radiation table for Pittsburgh at 40 degrees Fahrenheit is shown in Figure 10.

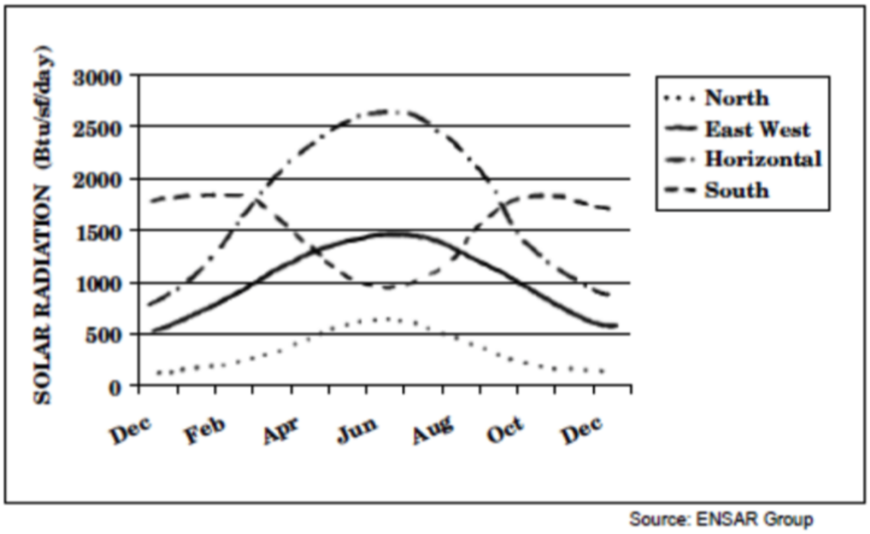


Figure 10: Monthly solar radiation in Pittsburgh, 40° F [1]

As seen in Figure 10, the highest magnitude of measured solar radiation in the colder winter months (taken as December-February) occurs in the northern direction. A building like the new dormitory described in this report would do well to maximize facades in the north and south directions, in an effort to reduce winter heating loads.

Natural ventilation

Similarly, building orientation can be optimized to experience greater natural ventilation from wind. Incoming wind provides natural breezes that reduce heating loads, potentially provide enough power for utilizing renewable wind turbines, and can provide outdoor air to circulate often stagnant and (possibly unhealthy) indoor air [25]. These possible outcomes can also provide added aesthetics and productivity benefits to building residents [27].

A wind rose quantifies overall wind impact on a specific site, and is created by amassing historical data on wind direction, strength, and frequency [25]. The wind rose for average wind in Pittsburgh in 2012 is shown in the Wind Roses section of this report. As shown in the wind roses, the greatest magnitude of wind historically comes in from the generally southward direction [63]. Coincidentally, this is the same direction with the lowest amount of sunlight in winter months. Therefore, the new CMU dormitory could position long façades facing south in order to enhance the cooling effects of natural ventilation during all months of the year.

Financial savings

A broadly conducted calculation based on assumptions specified below shows the financial impact of totally artificial heating and cooling. Depending on the amount of consideration directed toward effective building orientation, a sizeable portion of these costs can be avoided by using more natural heating and ventilation, as shown by previous efficiency studies of dormitories [26]. Table 6 below depicts this, based on several assumptions:

- Colleges and universities in the United States spend an average of approximately $1.10 per square foot on electricity and 18¢ per square foot on natural gas every year [30]
- There 60 total units in the new dormitory (similar to assumptions previously made for water efficiency calculations), and the average dormitory unit size is 351.5 square feet [31]

Financial Impact		
Measure	**Quantity**	**Unit**
Number of two-occupant units	30	units
Number of three-occupant units	30	units
Number of total units	60	units
Average size of two-occupant unit	220	square feet
Average size of three-occupant unit	483	showerhead
Average size of unit	351.5	USD
Dormitory cost of electricity	1.1	USD/square feet
Dormitory cost of natural gas	0.18	USD/square feet
Electricity cost for one average unit	386.65	USD
Natural gas cost for one average unit	63	USD
Electricity cost for all units	23,199	USD
Natural gas costs for all units	3,796	USD
Total annual utility costs for all units	26,995.20	USD

Table 6: Average dormitory electricity and natural gas cost estimates

Windows

When designing or retrofitting a building for maximizing sustainability, windows are a key component to pair with building orientation. They make up a primary interface with the building's surroundings, since they can provide daylight and outdoor views, solar gain, and opportunities for natural ventilation when opened. However, they simultaneously can act as source of heat loss during colder periods of the year. Windows with operation capabilities, added panes, and different material compositions can help address the issue of heat loss, albeit at generally higher costs [25]. The larger the difference between the indoor and outdoor sides of a window, the faster heat will move through it, and air leakage is more likely to occur [32].

A commonly used metric for measuring window efficiency (heat conduction through it) is the "r-value", also taken as the inverse of the "u-factor", a measure of thermal conductivity. More efficient windows have higher r-values and lower u-factors. The following equation is used to quantify heat flow through a window

$$\Delta Q/\Delta t = A*(T_1 - T_2) / R \text{ [25]}$$

where: $\Delta Q/\Delta t$ = heat/time in Btu/hr

A = cross sectional area of the window in square feet

T_1, T_2 = indoor and outdoor temperatures in degrees Fahrenheit

R = r-value on a simple numeric scale

As shown in the equation, the greater the r-value, the lesser $\Delta Q/\Delta t$ will become, signifying a smaller value of heat transfer. Popular methods to attain high r-value windows are to select specific materials or to add multiple "panes" (similar to layers) to the window.

Windows in the dormitory setting

Windows are actively being pursued in the campus sustainability space – with many new dormitory and instructional facilities using high r-value materials [33]. For dormitories in colder climate, more efficient windows are especially sought after. In Pittsburgh, specifically, there is an appreciable number of heating degree days per year as shown in Figure xvi, which would benefit from less heat loss via windows.

Heating degree days (HDD) represent the number of degrees that a single day's average temperature is greater than 65 degrees Fahrenheit, the point at which a building is expected to use artificial heating.

Pittsburgh Heating and Cooling	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Heating Degree Days	1206	1016	794	462	214	36.0	6.0	14.0	100	400	681	1039	5968
Cooling Degree Days	0.0	0.0	0.0	0.0	44.0	123	227	184	67.0	9.0	0.0	0.0	654

Figure 11: Heating and cooling degree days for Pittsburgh, PA [34]

For the new CMU dormitory in Pittsburgh, windows should not only be positioned in directions of maximizing passive sunlight and natural daylight, but chosen to have high r-values to minimize outgoing heat conduction during colder periods of the year. These actions would both would help warm the building, add to internal aesthetics, and reduce operation costs. Surveys of installing higher r-value windows have occurred for educational institutions as proof of potential for electricity, natural gas, and financial savings [35].

INSULATION

What is insulation?

Insulation is the addition of materials typically to the roof, walls, and floor (sometimes) of a building to reduce the unwanted flow of heat. It is typically installed on exterior surfaces, but can be installed between interior spaces if one is unconditioned and the other is not. During summer, insulation prevents heat from outside from entering and during winters, it prevents the insulated space to lose heat to the outside.

How to insulate?

In existing homes, cellulose or other loose-fill materials can be installed in building cavities through holes drilled (usually) on the exterior of the house. After the installation, the holes are plugged and finish materials replaced.

Different forms of insulation

There are a lot of different forms of insulation.

- Loose Fill [36]

Recommended Specifications by Loose-Fill Insulation Type			
	Cellulose	Fiberglass	Rock Wool
R-value/inch	3.2–3.8	2.2–2.7	3.0–3.3

Table 7: R-values for different types of Loose Fill Insulations

- Blanket,Batt & Rolls [36]

Table 1. Fiberglass Batt Insulation Characteristics*		
Thickness (inches)	R-Value	Cost (cents/sq. ft.)
3 1/2	11	12-16
3 5/8	13	15-20
3 1/2 (high density)	15	34-40
6 to 6 1/4	19	27-34
5 1/4 (high density)	21	33-39
8 to 8 1/2	25	37-45
8 (high density)	30	45-49
9 1/2 (standard)	30	39-43
12	38	55-60

Table 8: R-values and cost for different Fiberglass Batt Insulations

- Rigid Foam Board
- Spray Foam Insulation
- Mineral Wool (R-value of 3.7/inch)
- Polyurethane (R-value of 7/inch)
- Blue Jeans (R-value of 3-4/inch)
- Many others listed in Table 9

Material	R/ Inch
Insulation Materials	
Fiberglass Batt	3.14-4.30
Fiberglass Blown (attic)	2.20-4.30
Fiberglass Blown (wall)	3.70-4.30
Rock Wool Batt	3.14-4.00
Rock Wool Blown (attic)	3.10-4.00
Rock Wool Blown (wall)	3.10-4.00
Cellulose Blown (attic)	3.60-3.70
Cellulose Blown (wall)	3.80-3.90
Vermiculite	2.13
Urea Terpolymer Foam	4.48
Rigid Fiberglass (> 4lb/ft3)	4
Expanded Polystyrene (beadboard)	4
Extruded Polystyrene	5
Polyurethane (foamed-in-place)	6.25
Polyisocyanurate (foil-faced)	7.2

Table 9: Insulation Materials and their R values [37]

Homeowners can install some types of insulation -- notably blankets and materials that can be poured in place. Other types require professional installation. To choose the best type of insulation, following should be determined first:

- Where you want or need to install/add insulation
- The recommended R-values for areas you want to insulate.

R-value Associated Calculation, Cost and Payback Period

The cost and payback period will be calculated based on the total insulation cost and lowered HVAC operational cost. The area will assume to be 20000 ft^2 for the sample calculation. We will also assume that the average high and low temperatures, depending on the month, is the constant temperature throughout the whole month. For the months of October through May, we will be using the average low temperature, and for the months of June through September, we will be using the average high temperature. Specific temperature data are listed Table 1 [10].

Heat transfer = Q/t = A(T1-T2)/R. Based on Pittsburgh region and climate, R5 to R6 insulative wall sheathing should be installed. We will use $\Delta R = 5$ for the calculation. The original R-value is assumed to be 30 [38].

In Pittsburgh, electricity costs are approximately $0.0912/kWh [9].

$$Heat\ Saving\ = 20000\,ft^2 * \Delta T\ /\ 30 - \ 20000\,ft^2 * \Delta T\ /\ (30 + 5)$$

$$1\ BTU\ =\ 0.000293071\ kWh$$

Table 10 lists the savings in HVAC operational cost.

	Average High Temp (F)	Average Low Temp (F)	Heat Savings (BTU/hr)	Electricity Savings ($/month)
January	37	21	4190.47619	83.3305
February	40	22	4095.238095	73.55566
March	50	30	3333.333333	66.28563
April	62	39	2476.190476	47.65234
May	71	51	1333.333333	26.51425
June	79	61	1333.333333	25.65895
July	83	66	1714.285714	34.08975
August	82	63	1619.047619	32.19588
September	75	55	952.3809524	18.32782
October	64	44	2000	39.77138
November	53	34	2952.380952	56.81625
December	41	25	3809.52381	75.755
		Total Electricity Savings ($/year)		579.9534

Table 10: Electricity savings due to insulation

The cost of insulation will be calculated roughly by the material price for reaching the additional R-value of 5. As there are a lot of different kinds of insulation, we will chose the lowest unit price one specific on R-value. Table 11 [39] shows the price for each insulation type.

Material type	Rvalue	Cost per square foot	Cost per square foot per R-value
Fiberglass batt (3.5 inches thick)	13	\$0.20 to \$0.40	\$0.02
Loose fill such as fiberglass, cellulose, and mineral wool (8 - 23 inches thick)	30	\$0.45 to \$1.35	\$0.03
Open cell polyurethane spray foam (3.5 inches thick)	12.6	\$1.70 to \$2.50	\$0.17
Closed cell polyurethane spray foam (1 inch thick)	6.5	\$1.30 to \$2.00	\$0.25
Expanded polystyrene foam board (1 inch thick)	3.8 – 4.4	\$0.20 to \$0.35	\$0.07
Extruded polystyrene foam board (1 inch thick)	5	\$0.40 to \$0.55	\$0.10
Polyisocyanurate foam board (1 inch thick)	6.5	\$0.60 to \$0.70	\$0.10

Table 11: Cost of insulation [39]

As shown in this table, fiberglass batt has the lowest R-value unit price. So we will use fiberglass batt as a sample for the calculation. For R5, the unit price associate with area for fiberglass batt is 5 x $\$0.02/ft^2 = \$0.1/ft^2$.

$$Total\ cost = \$0.1/ft^2 * 20000\ ft^2 = \$2000$$

So the payback period is easy to find out:

$$Payback\ period = \$2000/(\$579.95/year) = 3.45\ years$$

The payback period is not so long so it is worth to get the insulation in the wall for the buildings as there are so many benefits with it.

Social, Environmental, and Financial Benefits/Impacts of insulation

Insulation can make some benefits to the social such as comfort the residents, reduce in-home noise. This can benefit the residents' health. Insulation has significant influence on financial as well. It will higher installation costs, so it is necessary to determine optimal R-value for minimum payback period and maximum insulation. It will also lower cost for HVAC operation, reduces energy consumption. Environmental effect for insulation is that it will lower energy use, that is equal to lower CO_2 emissions.

HEATING, VENTILATION AND AIR CONDITIONING

The Heating, Ventilation and Air Conditioning (HVAC) systems consumes about 50% of the total building's power consumption on an average [40]. It is responsible for maintaining the working and living environment of a building space, making the occupants comfortable by controlling the temperature, humidity and ventilating the space.

Intelligent HVAC

Automating the operation of HVAC systems result in huge energy savings while maintaining the occupant comfort. Machine learning and data analysis performed on sensor data provides accurate thresholds for HVAC operation. There have been many comfort control indices that have been used to quantify user comfort. Few examples are Standard Effective Temperature [41], Predicted Mean Vote [42] which has now been included as an ISO standard. There are Thermal Comfort Controllers which use these control indices and operate the HVAC systems efficiently. As the heating/cooling preference changes from person to person, this paper [43] talks about operating different zones of a building differently to achieve maximum energy savings while maintaining occupant comfort in each of these zones.

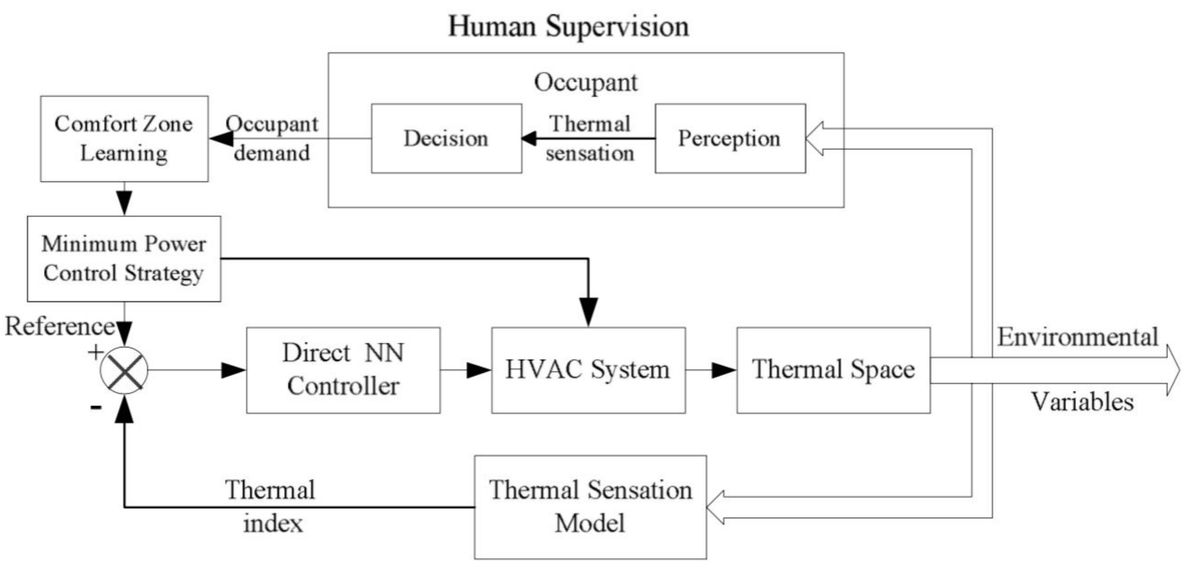


Figure 12: Block diagram of the Thermal Comfort Controller in [43]

The desired comfort level for each zone is determined by the average Predicted Mean Vote of all the occupants of that particular zone. The PMV for each user is determined by his input to how comfortable he is in the current environment on a scale from (-3 to 3) with each having the following implication:

- +3 = hot
- +2 = warm
- +1 = slightly warm
- 0 = neutral
- -1 = slightly cool
- -2 = cool
- -3 = cold

Most modern systems like [43] have the following components:

1. Comfort Zone (a comfortable temperature range, comfortable humidity range etc.) for each zone - which can be set by learning user's preferences over time or by user setting it.
2. A learning algorithm (Neural Network is shown in Figure 12) that quantifies and calculates the comfort level of the zone based on the user inputs.
3. A power control strategy based on energy savings and user control that actuates the Variable Air Volume or any other type of modern HVAC system.

So while user gives his/her input it wouldn't directly affect the environment as it does not directly affect the system. The systems does some analysis on the inputs of all users and chooses the best strategy. This allows every user to have his/her vote on the working or living environment while still not giving them enough control to change the system directly that might not be the least power consuming setting.

Demand Controlled HVAC

More popularly available and implemented systems would be the Demand controlled systems that work on particular thresholds. Demand Controlled Ventilation Based on CO_2 [44] or Occupancy controlled HVAC Systems [45] turn on/off or control the parameters of the HVAC systems based on CO_2 levels or number of occupants (eg: if the amount of CO_2 is greater than a particular threshold, turn on the ventilation system). This is useful as always turning on the HVAC system might not be required or might have limited benefits. For example, 1000 ppm of CO_2 [46] is permitted to be present in an ideal working environment without affecting the productivity or comfort of occupants. So keeping the ventilation running even below this amount of CO_2 gives marginal improvements in comfort level while lot of energy is being spent. There are many algorithms that sensor data as inputs and take necessary actions. One such demand controlled ventilation algorithm from a previous work [47] is shown in Figure 13.

Financial Benefits

There have been few studies that showed the financial and energy benefits of a sensor based demand controlled HVAC algorithm. Results from one such study [48] have been stated below:

- Assembly rooms like auditoriums, lecture halls, theaters have reported savings from 11% (cinema) to over 50% (auditoriums) with 1-3 years of payback period.
- A large university restaurant space with CO_2 ventilation control was very efficient and cost effective with a payback of a few months.
- Office Buildings had rather less cost effectiveness due to the relatively less amount of energy required to ventilate small conference rooms.

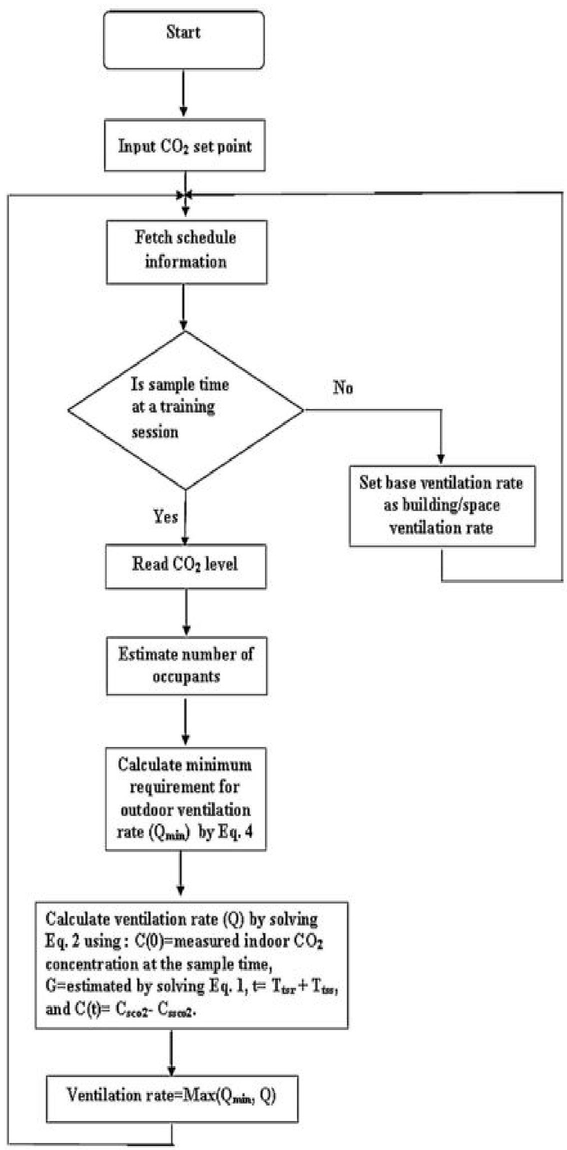


Figure 13: Demand Controlled Ventilation in [47]

Financial Benefits for the student dormitory (in Pittsburgh) in consideration:

[48] states that sensor based demand controlled HVAC systems can produce up to 40%-60% of energy savings. Going ahead with the minimum factor of 40% savings and with data from Table 6 (*Average dormitory electricity and natural gas cost estimates),* Table 12 below shows the overall annual savings in energy.

Assumption: There is a 40% savings in natural gas consumption as Natural gas is used for Heating purposes in this building.
There is a 40% savings in the electricity used for cooling and ventilation - which is a total of 40% of 50% of electricity consumed by the building (50% of the electricity is for HVAC [1]) = 24% savings.

Number of units in dormitory	60
Annual electricity cost per unit	$386.65
Annual natural gas cost per unit	$63
Annual electricity savings per unit	0.24 x $386.65 = $92.80
Annual natural gas savings per unit	0.40 x $63 = $25.2
Annual electricity cost for whole dormitory	$23199
Annual natural gas cost for whole dormitory	$3780
Annual electricity savings for whole dormitory	$5568
Annual natural gas savings for whole dormitory	$1512
Annual energy costs before savings	$26979
Annual energy savings	**$7080**
Total Annual utility costs	$19899

Table 12: Energy Savings through Demand Controlled HVAC

LED LIGHT

The light-emitting diode (LED) is one of today's most energy-efficient and rapidly-developing lighting technologies. Quality LED light bulbs last longer, are more durable, and offer comparable or better light quality than other types of lighting.

LED advantages [49]

Solid-state lighting technology uses semiconductor light-emitting diodes (LED), organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) rather than electrical filaments, plasma, or gas to create light. When it comes to street lighting, LEDs have several distinct advantages over traditional lighting technologies:

1. Directional light
   Traditional lights emit light in all directions while LEDs emit light in a specific direction. This reduces the need for reflectors and diffusers, resulting in less wasted light and more efficiency.

2. Energy efficiency
   LEDs use 50 to 90 percent less energy than other light sources while maintaining the same light output, which results in lower operating costs.

Life Cycle Phase	Incandescent			CFL			LED(2011)			LED(2015)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Material Manufacturing	10.2	42.2	106	11.3	170	521	38	87.3	154	25.4	58.5	103
Package Manufacturing	N/A	N/A	N/A	N/A	N/A	N/A	1.88	256	1340	0.54	73	381
Total Manufacturing	10.1	42.2	106	11.3	170	521	39.9	343	1490	26	131	484
Transport	0.26	0.27	0.27	1.42	1.57	1.71	1.23	2.71	4.19	0.77	1.69	2.62
Use	15100	15100	15100	3780	3780	3780	3540	3540	3540	1630	1630	630
Total	**15100**	**15100**	**15200**	**3790**	**3950**	**4300**	**3580**	**3890**	**5030**	**1550**	**1760**	**2120**

Table 13: Life Cycle Primary Energy (Lecture Note)

3. Longer life

LEDs have two to three times' longer life than conventional light sources (except induction). LEDs can last 20 to 30 years depending on the quality of the product, power usage, and other factors. The reduced re-lamping costs of long-lived LEDs are a contributing factor to the lower maintenance cost of LEDs. A longer life also means less landfill waste.

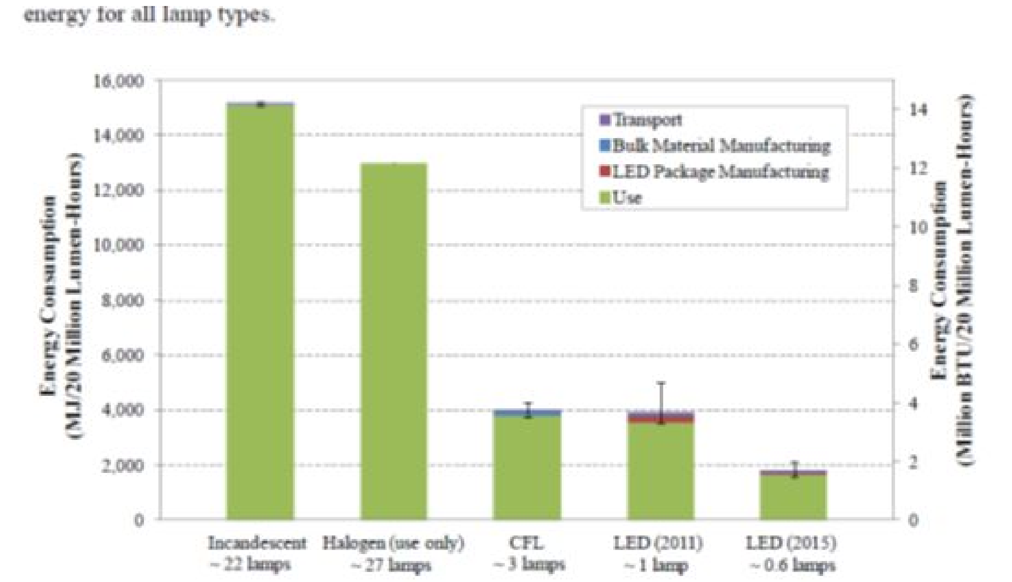


Figure 14: Life Cycle Energy of Lamps (Lecture note)

4. Wide color temperature range

White LED light sources are available with a fixed color temperature (CT) and color rendering index (CRI), typically from 3,000 to 6,500 Kelvin (K). A further option are white light LEDs arrays that can be continuously controlled to offer warm (2,700 - 3,000 K) to cool white light (5,000 K+).

5. Dimming

Rather than burning out, LEDs gradually dim over time. LEDs are measured on the L70 standard, which indicates the average hours of operation until the light output (lumens) deteriorates to 70 percent of it original quantity.

6. No toxic metals or chemicals

LEDs do not contain hazardous waste, they can be completely recycled.

7. Instant-on and rapid cycling

LED lights achieve 100 percent brightness nearly instantly when activated. They are also unaffected by repeatedly being turned on and off, unlike traditional lighting technologies which have a shorter lifespan and higher energy needs.

Drawbacks of LED

1. Relatively high purchase cost

The current purchase cost of LED lighting products is higher than standard options and varies widely, with good quality products at a cost premium.

2. Incompletely developed technology

LEDs have been used in outdoor lighting applications for less than 10 years. As such, they have a short history over which to benchmark their performance

3. Energy intensive production process

LED production process is energy intensive and includes dangerous chemicals in the manufacture of its semiconductors. Moreover, the majority of LEDs are produced in countries with significantly lower standards regarding labor rights and environmental standards.

Case study [50]

1. LED Use in Pittsburgh

   The City of Pittsburgh began retrofitting all traffic signals and accompanying crosswalk signals with LED light fixtures in 2006. To date, the City has updated 3,668 traffic lights at nearly 800 intersections with LED fixtures, resulting in 958,945 kWh of annual energy savings and a CO2 reduction of over 1,000 tons.

   Since 2008, the City's Office for Sustainability has been investigating the use of LED technology for street lighting in two pilot projects, one permanent LED installation, and plans for the LED retrofit of 3,000 cobra head fixtures in 30 business districts by early 2012.

   Walnut Street Pilot Project, Shadyside

   Grandview Avenue Permanent Installation, Mount Washington

2. Pittsburgh's LED project: Second phase shines light on neighborhoods [51]

   Carnegie Mellon's Remaking Cities Institute (RCI) is literally casting a new light on Pittsburgh. The institute led the effort to relight more than 30 business districts, replacing 3,300 sodium and mercury vapor streetlights with long-lasting, energy-efficient, light-emitting diode (LED) bulbs. And now it has its sights set on Pittsburgh's 90 residential neighborhoods.

With backing from the city and funding from the Heinz Endowments and CMU's Metro 21 Initiative, the RCI will use this second phase of the project to develop and propose recommendations and technical specifications for replacing more than 37,000 neighborhood streetlights with LEDs.

Figure 15: The image on the left shows a neighborhood street lit with sodium vapor streetlights. On the right is the same street under LED lighting.

Types of LED lamps [52]

Important characteristics needed to consider when choosing the type of LED lamps:
Cost, Life cycle, Light Output, Efficacy, Warranty, Certification, Voltage, Wattage, Color Temp, CRI, Application, etc.

1. HID Replacement Bulb

   Suitable for closed fixtures and features an isolated driver for superior quality and long life performance.

2. Vertical LED Plug-in Lamp

   This LED Plug-in Lamp is damp listed and designed for vertical mounting. It is lightweight and easy to install and features a simple ballast bypass to ensure maintenance-free energy savings and performance. The lamp holder rotates 270 degrees.

3. Horizontal LED Plug-in Lamp
   This LED Plug-in Lamp is damp listed and designed for horizontal mounting. It is lightweight and easy to install and features a simple ballast bypass to ensure maintenance-free energy savings and performance. The lamp holder rotates 270 degrees.

4. LED Dimming Lamp
   These LED lamps are suited for damp locations are compatible with most Triac dimming systems and universal dimmers. Not for use in enclosed fixtures.

5. LED Bulb
   These LED bulbs look like a standard incandescent light bulb, offers the same degree of beam spread and can be used in all of the same applications.

Automatically Modifiable control via sensing technology

Control systems can manipulate LED color temperature, color hue and light intensity. Using light sensors, it is possible to control shutdown and resume operation, detect lumen depreciation and sense occupancy and save energy waste via sensing technology.

Selected sensor: PDV-P9003

Description: [53]
The PDV-P9003 are (CdS), Photoconductive photocells designed to sense light from 400 to 700 nm. These light dependent resistors are available in a wide range of resistance values. They are packaged in a two leaded plastic-coated ceramic header.

Features:
Visible light response
Sintered construction
Low cost

Applications:
1. Light sensors can be installed above the doors of any rooms, and detect whether there is people get in or leave the room(also detect the number of people get in or leave this room). If the room is occupied, the LED lamps will turn on automatically and vice versa.

2. Light sensors can be used to automatically control the brightness of a room in situations where the natural light intensity is high or low. Light sensors can detect the amount of light in a room and raise or lower the brightness to a more comfortable level.

3. Light sensors can be used to automatically turn on the LED lamps outside and inside the building at night.

Savings Calculator for ENERGY STAR Qualified Light Bulbs [54]

Residential use in Pennsylvania:
Electric Rate = 0.134 $/kWh
The assumed LED bulbs used and parameters are showed in Table 14, Table 15 and Table 16.

	Comparable incandescent or halogen bulb	Qty	Bulb	Average daily use	Additional cost	Rated lifetime
bulb 1	40W incandescent	30	7.0W LED	11hrs	$7.60	25000 hrs
bulb 2	43W halogen(60 equivalent)	40	9.0W LED	9hrs	$8.00	30000 hrs

Table 14: Average bulb use/cost in residential scenarios

Resulted Detail:

General Purpose CFL/LED (Omnidirectional)	Qty	Annual Total				
		Electricity cost savings	Electricity savings (kWh)	Electricity cost	Electricity consumption (kWh)	Emissions reduction (pounds of CO2)
Bulb 1 (7.0 W LED replacing 40 W)	30	$532	3,975	$113	843	6,121
Bulb 2 (9.0 W LED replacing 43 W)	40	$598	4,468	$158	1,183	6,880
Total	70	$1,130	8,442	$271	2,026	13,001

Table 15: Average LED use/cost in residential scenarios

General Purpose CFL/LED (Omnidirectional)	Life Cycle Total			Total additional purchase price	Simple payback period for additional initial cost (years)	Assumed equipment lifetime (years)
	Electricity cost savings	Electricity savings (kWh)	% Electricity Savings			
Bulb 1 (7.0 W LED replacing 40 W)	$2,883	24,750	83%	$228.00	0.4	6.2
Bulb 2 (9.0 W LED replacing 43 W)	$4,502	40,800	79%	$320.00	more than 9	9.1
Total	$7,385	65,550	81%	$548		-

Table 16: Average LED use/cost in residential scenarios

LANDSCAPING

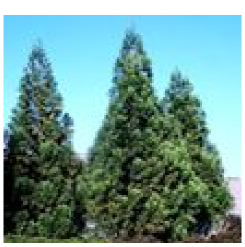
It may sound too simple, but the landscaping can have a major impact on energy costs. Just as humans tend to seek shade on a hot day, the facility also can benefit from natural shade. Research shows that strategically placed trees can be an effective means of combating "heat islands" in urban areas and can have a beneficial impact on cooling costs for large facilities via shading.

Plant selection [55]
When selecting plants, local environmental aspects should be considered. For Pittsburgh, climate changes dramatically in a whole year. Plants are required to be tolerant to tough climate and snow. Large shade is also needed to block the intense sunlight in summer for social concerns. Plants should also accommodate to local environment (soil, water, wind, etc). Proper plant selection can also help reducing energy use and improve ventilation and indoor light intensity.

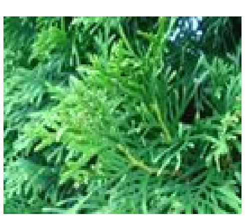
1. Evergreen
   1) Characteristics of evergreen trees
      Can block the wind flowing into the building in winter, which can help prevent heating energy loss.
      Should not be planted on the wind orientation of summer to improve wind ventilation and reduce the cooling energy use.
      Evergreen leaves bring contrast in the winter.

   2) Categories and features

American Arborvitae
Mature height: 14~40 ft; Mature width: 10~15ft
Features: Easy to maintain; Tolerant to most soil conditions and climates; Well shape-maintaining



Cryptomeria Randicans
Mature height: 30~40 ft; Mature width: 15~20ft
Features: Grow at an amazing rate of 3~4 feet per year; Tolerant to most soil conditions and climates; Disease resistant; Backdrop for lower shrubs

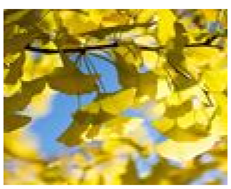


Emerald Green Arborvitae

Mature height: 8~12 ft; Mature width: 3~4ft
Features: Easy-to-grow hedge trees; Ice and snow damage resistant; Medium-sized privacy screen.

2. Deciduous
   1) Characteristics of deciduous trees
      Provide shadow in summer
      Fall off in winter to obtain more sunlight, which can help reducing heating energy
   2) Categories and features

Sawtooth Oak Tree
Mature height: 40~60 ft Mature width: 40~60ft
Features: Majestic presence and shade coverage; Wide canopy of cooling shade; Strong and adaptable



Ginkgo Tree
Mature height: 40~70ft Mature width: 30~40ft
Features: Colorful, unique foliage; Pest and drought resistant

American sycamore
Mature height: 70ft Mature width: 50ft
Features: Fast growth; dense leaves; Adaptable

3. Shrubs

Double Knock Out Rose
Mature height: 3~4ft Mature width: 3~4ft
Features: Long blooming period; Disease and insects resistant; Improved cold hardiness

Wax Myrtle
Mature height: 15~20 ft Mature width: 10~15ft

Features: Heat and drought resistant; Grow fast; Easily be planted in multiples and shaped into privacy hedge; Blooms in spring; Trouble-free

Planting position

According to wind rose:
West is the dominant wind orientation from January to March (winter);
South is the dominant wind orientation during the whole year.

Evergreen trees planted on the west side of the building to block the wind in winter, which can help reduce heating energy cost;
Deciduous trees planted on the south side of the building to provide shadow in summer and guarantee the ventilation and sunlight in winter, which can also help save energy use.

Plant spacing [56]

Trees
Large shade trees need at least 35 feet of space between trees for proper growth and root formation. Less space between planting sites means the trees shade each other and have to grow taller to reach the sun. The bottom limbs are higher on the trees, which results in more open space under the trees. Ornamental trees do well when planted closer together. A grouping of small trees, spaced about 8 to 10 feet apart, adds interest to the landscape. Large trees should be at least 20 feet from building so the root system does not grow into the walls. Smaller trees need to be at least 8 feet from any structures.

Shrubs
Shrubs grow well when spaced about one half the spread of a mature plant. Keep shrubs at least 2 to 4 feet from the house or other buildings. Naturally, shrubs that have a wide growth habit need more space to appear natural in the landscape. Space the shrubs closer together to create a dense refuge for birds and other wildlife.

Planting concerns [57]

- Adapted to soils
- Use approved species determined by NRCS or State Forestry Agency

- At least one species provides optimal height for the site
- Favorable for wildlife food and cover
- Diverse mix of species
- Consider seasonal variation of foliage
- Adjacent species should have similar growth form
- Choose within/between-row spacing suited to species growth and vigor
- Row spacing needs to accommodate maintenance equipment

Operation and maintenance concerns

- Weed control
- Watering/irrigation
- Protection from pests
- Maintain required fencing
- Replacement of dead plants

Irrigation system [58]

There are four major types of landscape irrigation. the size of the area, the type of grass or plants need irrigating, and the drawbacks of each system should be taken into consideration. Table 17 reviews and summarizes the advantages and disadvantages of each system type.

Type	Description	Pros	Cons
Micro-irrigation	Gives water directly to plants' root systems, using only as much water as needed.	Best for dwarf fruit trees, shrubs, groundcover; it's not a good option for lawns or turf.	Tubing can be damaged easily by dirt, freezing or vandalism because it remains above the ground.
Flood System	Floods the ground rather than spraying plants. Comes as jet system, bed sprayer, or bubbler.	Some plants -- ground covers, fruit trees, and roses, for example -- are prone to mold and disease from overwatering, which can result	Often requires abundant water, and land must be flat so that water flows evenly and does not run off, wasting

		from other systems. Ideal for adobe or clay soil.	water and causing erosion.
Rotary Sprinkler	Spray head that rotates in a circle.	Can cover as many as 100 feet (30.5 m) from sprayer, which is ideal for turf or landscape.	Needs higher water pressure to function best. Rotating head may stick; requires checking as part of regular maintenance.
Spray Irrigation System	Traditional sprinkler head is most common form. Pop-up heads come up only when in use, which helps to prevent accidents.	Adjustable, covering from one to 15 feet (4.6 m). Works best in smaller areas that are regularly shaped. Performs well even with low pressure.	Sprinkler heads need to be replaced if water is full of minerals. Not precise, so can waste a lot of water

Table 17: Types of Landscape Irrigation

The plants need to be irrigated are grass, trees and shrubs, so micro-irrigation is not proper. The landscape of Pittsburgh is not flat so flood system cannot be used. Considering the covered area and environmental aspects (to save more water), rotary sprinkler is the best choice of irrigation system.

Water usage estimation [59]

Formula to calculate the gallons of irrigation water needed per day:
(Eto x PF x SF x 0.62) / IE = Gallons of Water per day
Eto: For zip code 15217, Eto=0.15 [60]

Historic ET Data for 15217											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	0	0.08	0.12	0.14	0.15	0.15	0.13	0.11	0.08	0.05	0.04
Suggested Reference Value: 0.15											

Table 18: Evapotranspiration data for zip code 15213 [60]

PF: The plant factor. Different plants need different amounts of water. Use a value of 1.0 for lawn. For average water use shrubs use 0.5.
SF: The area to be irrigated in square feet.
0.62: A constant value used for conversion
IE: Irrigation efficiency. Very well designed sprinkler systems with little runoff that using efficient sprinklers can have efficiencies of 80%.

Assume it is a 500 square foot grass lawn:
The calculated monthly water usage is changed according to different Eto each month.

Water usage reaches the maximum on June and July because it is the best time period for plant growth and high evaporation rate due to the relatively high temperature. In January and February the Eto value is 0 for no irrigation at that time period.

Average water usage in one year
=（0.08+0.12+0.14+0.15+0.15+0.13+0.11+0.08+0.05+0.04）*（1.0*500*0.62）/0.8
=581.25 gallons per year

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