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# How can occupancy modeling and occupancy sensors reduce energy usage in academic buildings: An application approach to University of San Francisco

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How can occupancy modeling and occupancy sensors reduce energy usage in academic buildings: An application approach to University of San Francisco

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| Paloma R. Duong Date | Allison Luengen, Ph.D. Date |

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## List of Acronyms

| | |
|---|---|
| DOE: | Department of Energy |
| IEA: | International Energy Agency |
| EPBD: | Energy Performance of Building Directive |
| IPCC: | Intergovernmental Panel on Climate Change |
| HVAC: | Heating, ventilation and air conditioning |
| ASHRAE: | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| EIA: | Energy Information Administration |
| CFL: | Compact fluorescent lights |
| LED: | Light emitting diode |
| UMass: | University of Massachusetts, Amherst |
| PIR: | Passive infra-red |
| $CO_2$: | Carbon Dioxide |
| kWh: | kilowatt hour |
| USF: | University of San Francisco |

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## Abstract

Buildings are amongst the highest energy consumers relative to industry and transportation. They account for 40% of the world's energy consumption, due to the need of lighting, equipment, heating, cooling and ventilation. Academic buildings are multi-purpose buildings that create a challenge on energy reduction. Most are old and have fixed occupancy schedules, resulting in high energy consumption because these buildings experience significant occupancy variation throughout the day. Five academic buildings were analyzed; their building information, energy consumption data and methods to project energy savings have been analyzed. The case studies presented different strategies on predicting energy savings, but these have been deduced to their commonalities: the black box, white box and grey box models. The black box is a data driven approach, the white box is a physics based approach and the grey box is a hybrid between the black box and the white box. Control strategies include the usage of occupancy sensors to ensure building energy usage is directly proportional to building occupancy density and that the energy is not wasted on an empty building. An application approach to University of San Francisco was also developed. The active energy retrofits for University of San Francisco have been mentioned and explored by following the black box, white box and grey box model methodology. Findings from the case studies discovered that occupant behavior can be a barrier to energy reduction as occupants are driven by maintaining personal comfort and are usually detached to energy usage consequences. For this matter awareness campaigns such as surveys and educational campaigns need to be implemented to help achieve higher building efficiency and thus lower energy consumption. If all academic buildings in the United States committed to a 5% energy reduction, then over 2 billion kWh could be saved annually.

## Acknowledgements

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## Introduction

The economy in the United States is growing (Pérez-Lombard et al., 2008) and so are the amount of buildings. According to the U.S. Department of Energy (2008) between the years 1980 and 2005, the amount of commercial buildings has doubled; these building and economic development has an impact on energy consumption (Pérez-Lombard et al., 2008). There are multiple categories within the commercial buildings with academic buildings accounting for 11% (Figure 1) of the total floor space and energy usage (DOE, 2008).

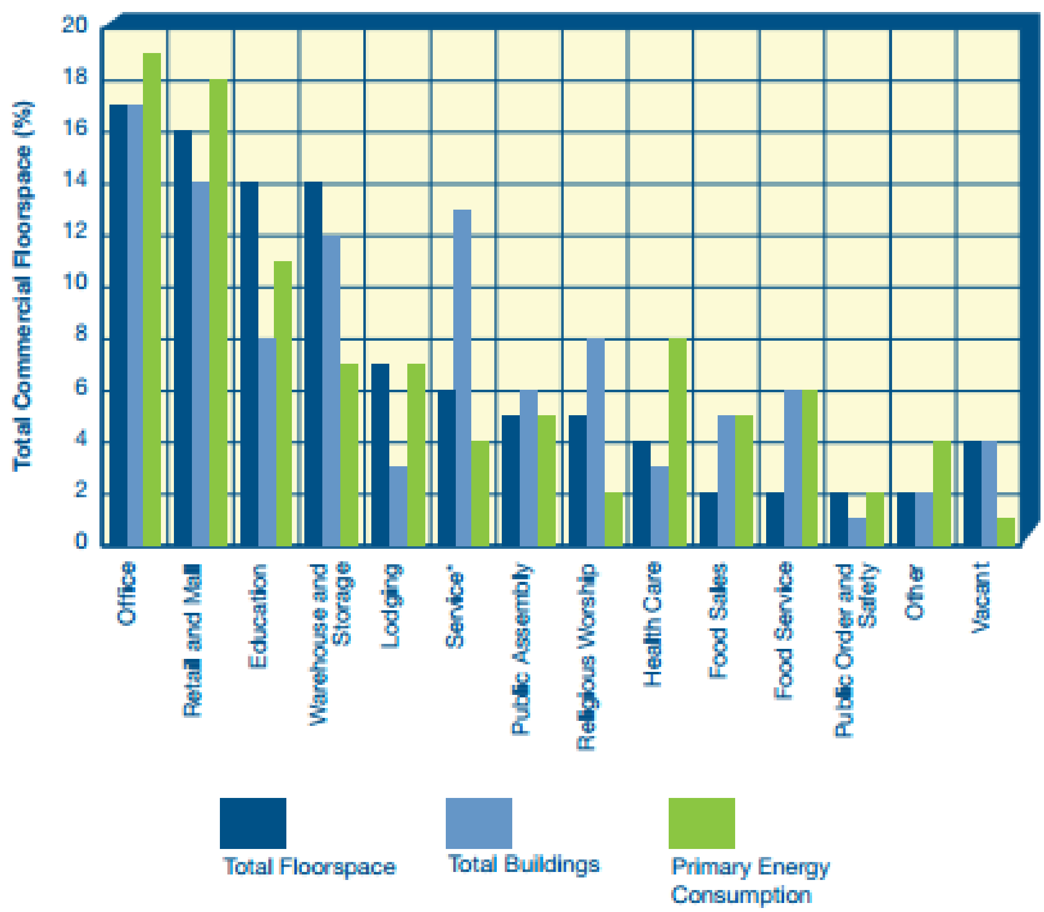


*Figure 1 Commercial building types: Floor space, number and energy consumption. The six largest sectors are the office sector, the mercantile sector, the educational sector, the health care sector and the lodging and warehouse sector (DOE 2008).*

Buildings are responsible for 30-45% of the global energy demand (Gul & Patridar, 2015) with 60% of this energy accounting for lights, heating and cooling use (IEA, 2013). Moreover, commercial and educational buildings consume more than 19% of all energy annually in the United States (DOE, 2011).

Academic buildings are one of the major targets for energy reduction. Because most of these buildings are not a primary residence, occupants do not pay bills, they are not considerate on how to manage their energy usage. The Natural Resources Canada and U.S. Energy Information Administration (2003) states that in a typical academic building, 31% of the energy consumption comes from lighting and 28% from heating and cooling (see Figure 2). According to multiple studies, existing universities have the potential to reduce their energy consumption by 6-29% (Chung & Rhee, 2014).

Building function depends on the different needs of building occupants and how they interact with the building itself (Hillier et al., 1984). Office and residential buildings have a defined purpose, work and living respectively. However, academic buildings are considered multipurpose buildings with variable occupancy profiles due to the multi-function nature of the buildings. An occupancy profile is defined by Rubinstein et al. as the probability that a space will be occupied for every hour of the day. This is why academic buildings are classified amongst the buildings that present the highest energy consumption (Chung & Rhee, 2014). Because of the high energy consumption in academic buildings, the European Energy Performance of Buildings Directive (EPBD) has placed a high demand on building professionals to produce buildings to near-zero energy levels (Gul & Patidar, 2015).

To conserve energy in academic buildings and commercial buildings, it is important to have a dynamic interaction between the occupants and the building itself; this interaction will allow for a more sustainable building design (Yan et al., 2015). Conservation of energy will not only reduce energy cost for the buildings themselves, but will also reduce fossil fuels consumption. The Natural Resources Canada and U.S. Energy Information Administration (2003) suggest that academic buildings spend an average of $1.10 per square foot on electricity and 18 cents per square foot on natural gas annually. The IPCC, Climate Change (2007) states that 1/3 of fossil fuel consumption is derived from buildings. Fossil fuels are a problem because they have been the world's primary energy source and responsible of fueling the United States for decades. These fossil fuels burn to produce electricity producing $CO_2$ which gets trapped in the atmosphere causing global warming and therefore climate change. The Environmental and Energy Study Institute (2016) mentions that the Environmental Protection Agency states that the burning of fossil fuels has been responsible for 79% of the greenhouse gas emissions in 2010.

For this paper, I will evaluate what strategies can be utilized to decrease energy consumption in academic buildings. Amongst these strategies I will discuss occupancy scheduling, which is utilizing occupancy profiles and occupancy sensors to model an energy efficient schedule for academic buildings.   To do so, this paper will first explore how academic buildings consume energy and focus on the areas of high energy usage: lights, heating, ventilation and air conditioning (HVAC). Next the paper will explore how lights and HVAC consume energy and what it is that makes them draw so much power.  Occupancy is important because academic building are multipurpose buildings with high occupancy variability where occupant behavior can contribute to poor usage of buildings increasing energy consumption. Building occupancy and the various occupancy controls available in the market will then be evaluated by analyzing their advantages and disadvantages that are specifically directed to the academic sector.

A case study approach will be used and five case studies will be examined: (1) Daycares and schools in Finland (Sekki et al., 2015); (2) University of California Berkeley (Granderson et al., 2010); (3) A University in Singapore (Yang et al., 2015); (4) University of California Merced (Narayanan et al., 2010) and (5) University of Edinburgh in Scotland (Gul & Patridar, 2014) where the importance of occupancy variability, visualization tools and collection of empirical data has been established.  Yang et al. (2015) developed the black box, white box and grey box model to predict energy consumption, while Granderson et al. (2010) adapted this model to calculate predictive values of energy consumption at University of California Merced and Gul and Patridar (2015), explored the barriers to the predictive model theory.  These case studies have utilized various occupancy sensors application approaches as well as the creation of occupancy schedules for their respective academic buildings which have all resulted in significant energy reduction.

Next, the focus will be an application approach to what University of San Francisco is doing to improve energy efficiency on their campus.  Based on the case studies analyzed, there is a wide variety of effective strategies that show that energy reduction is possible.  I wanted to allow for this application approach to show how energy efficiency works in a university where people are aware of their energy consumption and what other measures they can take to take this energy efficiency and building sustainability to the next level. The case study findings were then compared to the energy improvements already in place and an evaluation of how the black box, white box and grey box predictive model would affect University of San Francisco's campus. Finally, I will give management recommendations on how academic buildings can move forward with a more sustainable building design that incorporates building and user functions.

## Energy consumption in buildings

Academic buildings main source of energy consumption are lights, HVAC and plug load (Figure 2). In this section each source of energy consumption will be discussed and what specifics need to be taken into consideration when designers and managers are designing buildings to provide enough visual and thermal comfort for building occupants.

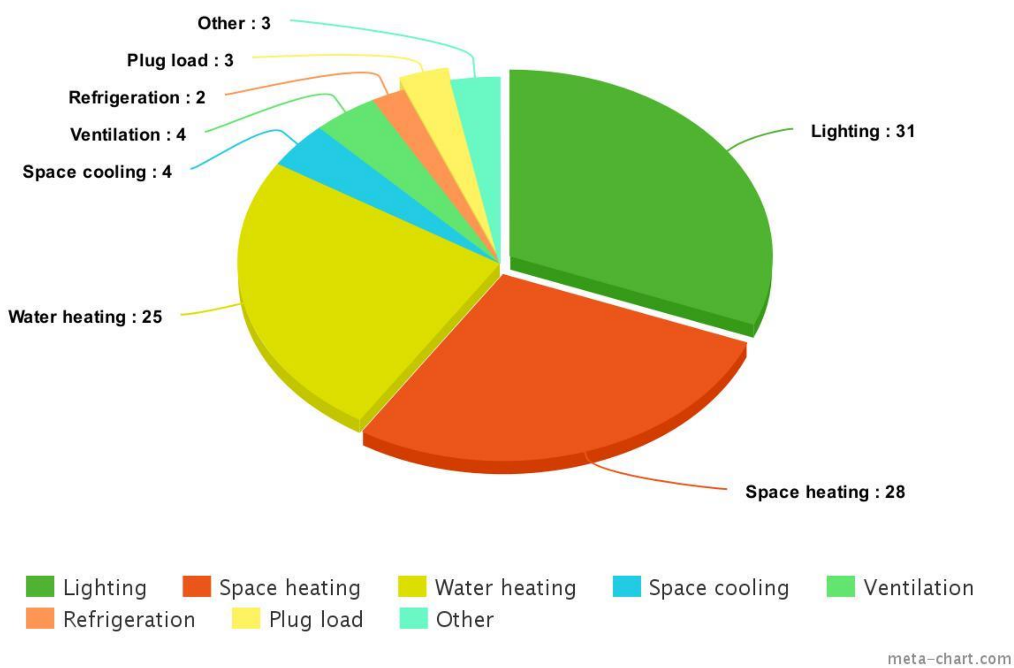


*Figure 2: Information from the Natural Resources Canada and U.S. Energy Information Administration. This pie chart shows the energy consumption in academic buildings. It also emphasizes on the three areas that will be evaluated throughout this paper.*

## Regulations

When academic buildings are built, there are certain standards and regulatory codes that need to be met. These building energy codes are minimum requirements for new or renovated buildings that consist of a baseline of requirements. These requirements apply to the building envelope and the built in equipment used. There are two entities that determine these codes:  the International Energy Conservation Code and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

The International Energy Conservation Code establishes a minimum design, and construction requirement for energy efficiency (Turner, 2004) while the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is in charge of the improvement of indoor environment control technology in the heating, ventilation and air conditioning (HVAC) industry (ASHRAE, 2016).  The ASHRAE guidelines for temperature, indoor air quality and ventilation in academic buildings are the following: 15 cubic feet per minute (CFM) per student (Starr, 1999).  This becomes a complex problem because academic buildings that were built prior to 1981 had a different ASHRAE regulation (5 cfm/student) so when retrofitting an old academic building, following the new ASHRAE regulations is important.  ASHRAE also states that a room that has been designed to be over 100 sq. ft. and has been designed for 8 or more people needs to have demand controlled ventilation.  Demand control ventilation is a method of measurement that approximates the number of people that occupy a space and allows the intake rates to be reset based on the indicated occupancy.  This will allow to optimize the rate of outside air intake to something less than the maximum capacity (Automated buildings, 2001).

Buildings also have to keep the building occupants feeling comfortable and at ease.  To achieve this, it is necessary to feel comfortable with your surroundings.  This includes thermal comfort, visual comfort and safety.  The more comfortable a person feels, the more productive they will be.

## Lights

According to the EIA the commercial sector, which includes academic buildings, consumed approximately 262 billion kWh or approximately 19% of energy in the year 2014 (EIA, 2016). There are different types of lights and they all have different effects on energy consumption. These light bulbs have a rated operating life which is affected by how many times they are turned on and off (DOE, 2016). There are various types of light bulbs available in the market: (1) incandescent bulbs; (2) halogen lights; (3) compact fluorescent lamps (CFL) and (4) light emitting diode (LED) lights.

Incandescent lights are the most energy wasteful of all; 90% of the energy they use is given off as heat and therefore only 10% is emitted as light (DOE, 2015). This means that the incandescent bulb is working as a source of heat production in the room, consequently increasing the need for cooling in that room. These types of light bulbs are more common in residential buildings. Halogen bulbs have a similar technology to incandescent lights but are considered to be more efficient. These bulbs have an internal coating that reflects some of the heat produced back into the light bulb itself to recycle the wasted heat (DOE, 2016). These bulbs are more expensive than incandescent bulbs but have a longer life. Compact fluorescent lights are the next most efficient alternative, these bulbs have 2-3 times longer life span than incandescent lightbulbs. These lights are the long tubes that we often see in commercial buildings. The Department of Energy (2016) states that compact fluorescent lights consume 75% less energy than incandescent bulbs. Finally, the light emitting diode lights are the most efficient of the 4 classes of light bulbs presented. They are also the most expensive of all four kinds but provide not only a much longer life span but also a more energy efficient approach. Turning on and off these lights has no significant impact to the life of the bulb itself. This type of bulb will have a full brightness as soon as it is turned on, unlike the other bulbs that need to warm up before they can fully shine. Please refer to table 1 for a summary of each type of lightbulb.

*Table 1: Summary table of different light fixtures with data drawn from the Department of Energy.*

| **Type of light** | **Benefits** | **Disadvantages** |
|---|---|---|
| **Incandescent** | - Light seems natural to the eye<br>- Inexpensive<br>- Intensity, direction and brightness is easy to control | - Life span: 750 – 1,500 hrs<br>- Intensity decreases with life span<br>- Illegal in California new constructions; unless they have a dimmer |
| **Halogen** | - More efficient than incandescent light bulbs<br>- Life span: approx. 3,000 hrs<br>- Stable light output throughout bulb life span | - Somewhat inefficient (20-24 Lm/W)<br>- Special sockets needed |
| **Compact fluorescent light** | - More efficient than halogen lamps<br>- Life span: 6,000 – 20,000 hrs<br>- Available in different color and color temperatures. | - Artificial colored light<br>- More expensive than incandescent<br>- Life span affected by switching lights on and off |
| **Light emitting diode light** | - More efficient than compact fluorescent lights<br>- Life span: 35,000 – 50,000 hrs<br>- Intensity, direction and brightness is easy to control<br>- Different colors available | - New technology<br>- Relatively expensive |

At University of Massachusetts Amherst, a re-lamping campaigned installed 1,100 LED light bulbs across campus. The re-lighting campaign is estimated to have 154,191 annual kWh in savings (UMass website, 2016). Moreover, University of Massachusetts Amherst established a partnership with NSTAR and Phillips Lighting, where LED light bulbs were purchased at a discounted rate so any lamps that students bring to the resident halls can be exchanged for an LED light bulb. The total estimated savings for this resident hall re-lamping campaign is 509,600 annual kWh (UMass website, 2016).

Due to the nature of academic buildings, it is important that the occupants of these buildings meet their visual comfort needs. Visual comfort is related to the quality of light available (i.e., when an occupant can see clearly without feeling tired or having to squint and there is minimal glare present). Visual comfort is dependent on: illumination, luminance and brightness and risk of glare. In academic buildings, most of the tasks are performed during the day so a proper use of daylight is essential to reduce energy consumption in electric lighting as well as maximizing the visual comfort for occupants (Acosta et al., 2015).

**HVAC**

HVAC systems in the summer time transfer heat from the inside of the building to the outside. An air conditioning unit will have a compressor, a condenser, an evaporator, refrigerant lines, blower fan and duct work to distribute the conditioned air to the different rooms. The refrigerant is in charge of transporting the heat from the evaporator inside the building to the condenser outside the building (Figure 3) (Home energy magazine, 2013).

In academic buildings, force heat- air systems are fairly common. In the winter time, heating is more demanding than cooling in the summer time. Supply registers will be found on the floor of the rooms, because warm air rises. Forced-air heating system have a heat source, a fan, a duct system, and openings in every room. A return duct is also needed to return the cold air back to the heat source to re-heat it (Figure 4) (Home energy magazine, 2013).

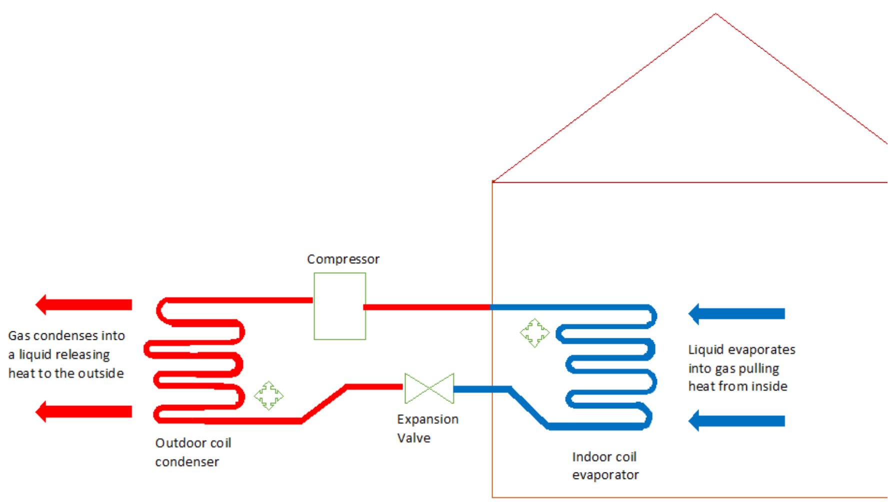


*Figure 3: Cooling system. Data drawn from Home Energy Magazine*

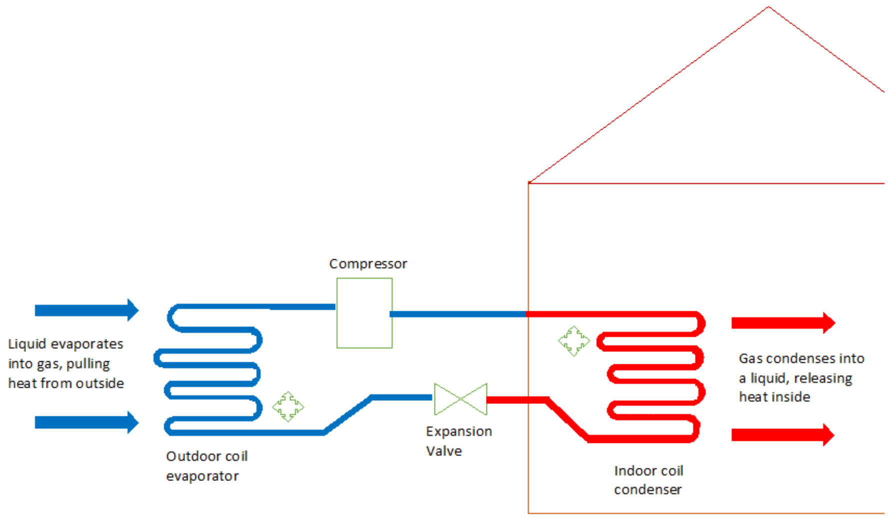


*Figure 4: Heating system. Data drawn from Home Energy Magazine*

Occupants of academic buildings not only have the need for visual comfort but also thermal comfort. Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment (International Standard Organization, 1990). In a study, Nicol (1993) stated the three main reasons why understanding thermal comfort was important: (1) to provide a satisfactory condition for people; (2) to control energy consumption; (3) to suggest and set standards. Standards are set by the American ASHRAE 55-2010 standard or European EN15251 standard (Taleghani et al., 2013). ASHRAE 55's purpose is to specify the combinations of the indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space.

There is a model that is used to determine comfort zone prescriptions: the adaptive model (Kwok, 1998). This model utilizes field surveys and can be adapted to naturally ventilated buildings or mechanically ventilated buildings. Naturally ventilated buildings have no air conditioning unit and depend on cross ventilation through windows and doors that are controlled by the occupants while mechanically ventilated building depend on an HVAC unit for ventilation. Thermal comfort will provide boundary limitations which will allow physicists to estimate how much should a building be heated or cooled (Taleghani et al., 2013).

Brager and De Dear (1998) state that thermal adaptations depend on behavioral, physiological and psychological adaptations. Additionally, Raw and Oseland (1994) suggest six aims for developing knowledge in thermal comfort:

1. Control over indoor environment by people
2. Improving indoor air quality
3. Achieving energy savings
4. Reducing the harm to the environment by reducing $CO_2$ production
5. Affecting the work efficiency of the building occupants
6. Reasonable recommendation for improving and changing standards

In this model, field surveys are an important way to evaluate thermal comfort. ASHRAE will specify certain indoor temperature parameters and personal parameters:

1. Building occupants have an activity level of 1.2 met. A met is the energy expenditure at rest and this includes activities like typing, desk work, reading, writing and walking
2. Clothing: Winter 1.0 clo and summer 0.5 clo. A 1.0 clo is the clothing needed for a person to be comfortable in a 70 degree room (e.g., a person wearing a business suit).

There are other parameters where assumptions will not be allowed to be made. These parameters include age differences, gender differences, air movement and humidity. Each parameter is important in its own way.

The age difference is important from a physiological point of view. Elderly people (>60 years of age) like to keep their environment warmer (Ji et al., 2006). Gender difference is important because females and males perceive comfort differently. Females generally choose a warmer environment due to the morphological differences; surface area to volume ratio, smaller average body, less muscle mass and higher surface area to mass ratio (Young and Lee, 2007). Humidity affects building occupants comfort level but this it's effect is so small and difficult to consider. In areas where the climate is hot, there is an allowance for the comfort temperature depending on how fast the air movement is and how fast can it be provided to the occupants (Nicol, 1993). Wan et al. (2009) discovered that a significant portion of the use of air conditioners is for dehumidification purposes.

**Plug load**

Plug load refers to the electrical energy used by various electronic equipment in a building such as computers, projectors, phone chargers, etc. The International Energy Association (2016) states that 15% of the energy consumption is from consumer electronics and computer equipment. In this section I will perform some plug load calculations for the use of projectors and a computer lab.

Projectors have become a very important aid for teachers and students when they give presentations. Academic buildings have operational hours from 08:00AM to 08:00PM. Imagine this hypothetical scenario (Table 2), a building has 20 classrooms, each classroom is equipped with one projector. For the purpose of these examples I will be using the Sanyo projector which uses 185 Watts. From the 12 hours the building is operating, 11 hours of class require a projector to be used.

The technique I will use to calculate the energy usage was learned in the Energy auditing class taught by Professor Laura Seidman in the Spring of 2015, (1) the kWh of the projector will be found by multiplying the Watts by the hours per day, portion of the year and cycle time. For calculation purposes, the cycle time and portion of the year will be kept at a consistent 100%. (2) After the kWh have been found, I will multiply this number by the number of days in the year to find the annual kWh. (3) Then the annual kWh will be multiplied by \$0.19 to find the annual energy cost for each projector. (4) To calculate the annual energy cost we would multiply the total annual kWh by \$0.19. (5) To calculate the carbon dioxide emission in pounds the total kWh will be multiplied by 1.6lbs $CO_2$/kWh (this number is an assumption).

(1) $$kW = Qty * unit\ watts * hours\ per\ day * portion\ of\ the\ year\ in\ use * cycle\ time$$

(2) $$Total\ annual\ kWh = kW * 365\ days$$

(3) $$Annual\ energy\ cost\ (\$) = \frac{kW}{qty} * 365\ days * \ \$0.19$$

(4) $$Total\ annual\ energy\ cost = total\ annual\ kWh * \$0.19$$

(5) $$Annual\ CO_2\ emmisions\ (lbs) = total\ annual\ kWh * 1.6\frac{lbs\ CO_2}{kWh}$$

*Table 2: Calculations for 20 projectors functioning for 11 hours a day. Utilizing Professor Laura Seidman lecture notes.*

| Equipment | Location | Qty | Unit Watts | Hours per day | Total Annual kWh | Annual Energy Cost each | Total Annual Energy Cost | Annual $CO_2$ Emissions (lbs) |
|---|---|---|---|---|---|---|---|---|
| Projector | classroom | 20 | 185 | 11 | 14,856 | $141.13 | $2,822.55 | 23,768.80 |

Some buildings in academic buildings also have computer labs (Table 3). The following information has been found on the internet and the same previous calculations will be applied for this example, a computer lab.

*Table 3: Power usage of various computer lab equipment (VanHorn, 2005) Data drawn from: https://computing.fs.cornell.edu/sustainable/computingenergyconservation.pdf*

| Device | Off | On-idle | On-Loaded |
|---|---|---|---|
| Desktop - Dell GX 280 | 1 Watt | 85 Watt | 144 Watt |
| Monitor – Dell 17" LCD | 1 Watt | 31 Watt | 31 Watt |
| Laser Printer – HP 4050N | 0 Watt | 19 Watt | 460 Watt |

The academic building has one computer lab, equipped for 30 students. Calculations will be shown for the following scenarios:

- Computer lab with computers on for 24 hours (Table 4)
- Computer lab with computers on only for class and idle the rest of the time (Table 5)
- Computer lab with computers on for class and off the rest of the time (Table 6)

*Table 4: Calculations for computer lab functioning for 24 hours a day. Utilizing Professor Laura Seidman lecture notes.*

| Equipment | Location | Qty | Unit Watts | Hours per day | Total Annual kWh | Annual Energy Cost each | Total Annual Energy Cost | Annual $CO_2$ Emissions (lbs) |
|---|---|---|---|---|---|---|---|---|
| Desktop | computer lab | 30 | 144 | 24 | 37,843 | $239.67 | $7,190.21 | 60,549.12 |
| Monitors | computer lab | 30 | 31 | 24 | 8,147 | $51.60 | $1,547.89 | 13,034.88 |
| Printer | computer lab | 2 | 460 | 24 | 8,059 | $765.62 | $1,531.25 | 12,894.72 |
| | | | | | **54,049** | **$1,056.89** | **$10,269.35** | **86,478.72** |

In reality, this computer lab has 4 classes a day with each class lasting for 1 hour. If in between each class all equipment was set to idle, we can observe 35% energy savings between putting the equipment on idle and leaving the equipment on for 24 hours.

*Table 5: Calculations for computer lab functioning for class hours only and then turning equipment to idle. Utilizing Professor Laura Seidman lecture notes.*

| Equipment | Location | Qty | Unit Watts | Hours per day | Total Annual kWh | Annual Energy Cost each | Total Annual Energy Cost | Annual $CO_2$ Emissions (lbs) |
|---|---|---|---|---|---|---|---|---|
| Desktop | computer lab | 30 | 144 | 4 | 6,307 | $39.95 | $1,198.37 | 10,091.52 |
| Monitors | computer lab | 30 | 31 | 4 | 1,358 | $8.60 | $257.98 | 2,172.48 |
| Printer | computer lab | 2 | 460 | 4 | 1,343 | $127.60 | $255.21 | 2,149.12 |
| Desktop (idle) | computer lab | 30 | 85 | 20 | 18,615 | $117.90 | $3,536.85 | 29,784.00 |
| Monitors (idle) | computer lab | 30 | 31 | 20 | 6,789 | $43.00 | $1,289.91 | 10,862.40 |
| Printer (idle) | computer lab | 2 | 19 | 20 | 277 | $26.35 | $52.71 | 443.84 |
| | | | | | **34,690** | **$363.39** | **$6,591.02** | **55,503.36** |

Computer lab has 4 classes a day with each class lasting for 1 hour. If in between each class all equipment was turned off. We can observe 82% energy savings when all the equipment is turned off in between class periods.

*Table 6: Calculations for computer lab functioning for class hours only and then turning equipment off. Utilizing Professor Laura Seidman lecture notes.*

| Equipment | Location | Qty | Unit Watts | Hours per day | Total Annual kWh | Annual Energy Cost each | Total Annual Energy Cost | Annual $CO_2$ Emissions (lbs) |
|---|---|---|---|---|---|---|---|---|
| Desktop | computer lab | 30 | 144 | 4 | 6,307 | $39.95 | $1,198.37 | 10,091.52 |
| Monitors | computer lab | 30 | 31 | 4 | 1,358 | $8.60 | $257.98 | 2,172.48 |
| Printer | computer lab | 2 | 460 | 4 | 1,343 | $127.60 | $255.21 | 2,149.12 |
| Desktop (off) | computer lab | 30 | 1 | 20 | 219 | $1.39 | $41.61 | 350.40 |
| Monitors (off) | computer lab | 30 | 1 | 20 | 219 | $1.39 | $41.61 | 350.40 |
| Printer (off) | computer lab | 2 | 0 | 20 | 0 | $0.00 | $0.00 | 0.00 |
| | | | | | **9,446** | **$178.92** | **$1,794.78** | **15,113.92** |

## Occupancy

Building occupancy is defined by the Merriam-Webster dictionary (2016) as the number of people who are in a particular building or room at one time. The more people in a place, the more ventilation needed and lighting used. The difference between the need and the use is that ASHRAE requires more ventilation by code (15 cfm/person) while with lights, the more people in a room, the higher the chances that someone will have the need to turn the lights on.

Buildings are designed to perform specific functions, for example a residential building's purpose is for people to live in them while an office building's main purpose is for people to go and work. These two types of buildings are similar in terms of how their occupants have a daily pattern or routine. Academic buildings, on the other hand, are multipurpose buildings, where the occupant density is constantly varying and often have low but non-zero occupancy (Sekki et al., 2015). According to Gul and Patridar's study (2014) at University of Edinburgh, the post-graduate center showed that 92% of the building's users were visitors. This means that only 8% of the buildings occupants have a daily routine in that building. In an academic building, a non-visitor is referred to the teachers and administrative staff who have an office in that building. A visitor is defined as a student, someone attending a conference and even a teacher who does not have an office in that building and is only there for one lecture.

Occupancy not only affects energy usage but occupant behavior affects it as well. It has become extremely important to increase awareness in academic buildings in regards to the relationship between indoor environment comfort and productivity (Yang et al., 2015).

Occupants release both sensible and latent heat to indoor space (Yang et al., 2015). Sensible heat is the heat that plants, animals or objects produce. This heat is produced by the body and released into the room causing changes in temperature which can be detected by the thermostat. Latent heat is energy released by the change in physical state without changing temperature (i.e. melting a solid, freezing a liquid). Latent heat is usually expressed as the amount of heat per unit of mass of the substance undergoing a change of state (Encyclopedia Britannica, 2016).

In this section, I will show the effects of occupancy diversity and how their behaviors affect energy consumption as well as why is occupancy modeling important and what information is needed to create a successful occupancy schedule. An occupancy schedule is the schedule for HVAC equipment that reflects back to occupancy density at any given time.

**Occupant diversity in buildings**

As stated earlier, academic buildings have a large occupancy variability while office buildings occupant variability is less. Occupant variability creates a barrier for energy modeling predictions in academic buildings.

When designing for a residential building, occupants of these buildings are more aware of their purpose and schedules; if they leave the room where they are at they are more likely to turn the lights and equipment off. This is mainly due to the fact that residents are able to modify and adapt their behavior through energy bill feedback. Office buildings occupancy is not as stable as residential building occupancy, but the permanent user to visitor ratio is fairly constant. In addition, office buildings have a consistent use of their space; they are not multipurpose buildings. Finally academic buildings are considered multipurpose buildings where the permanent user to visitor ratio is low. The building occupants do not associate their behavior with the energy usage impact. To them, they are only temporarily utilizing the building and are not responsible for the energy consumption.

Building energy consumption has shown that occupancy variability and building energy consumption are closely related. Occupancy variability is also closely related to occupancy behavior. A building can have the top of the line energy efficiency equipment in place and based on calculations it should consume minimum amounts of energy. However, if the occupants of that building are careless and not conscious of their decisions, the full potential of these technologies will not be observed, unless behavioral changes are also implemented (Earhardt-Martinez & Laitner, 2010).

**Occupancy behavior**

The Annex 66 organization, a division of the International Energy Agency, defines occupant behavior as the key issue for building design optimization, energy diagnosis, performance evaluation and building energy simulation contributing to building energy consumption. To achieve energy efficiency, it is necessary to combine energy conservation awareness into occupant’s daily routines.

Occupant behavior is also closely related to comfort. An occupant will act in a certain way because they need to achieve comfort in the space and time where they are interacting. As stated in section 2, the two main areas affecting occupant behavior are visual comfort and thermal comfort, mainly lighting and HVAC usage (Dounis & Caraiscos, 2009).

Yang & Wang (2012) mention that the interaction of users and the environment always has a direct effect on the system’s performance. For example, lighting, users may turn the lights on and off or may set the electrical lighting level to control the interior light. For HVAC, users may change the temperature set point to star the heating or cooling of their space. These are all observations of bad occupancy behaviors.

In academic buildings, occupants have a tendency of turning classrooms lights on. Sometimes for morning classes, it is not necessary to turn the lights on, and instead of taking advantage of the daylight, occupants will choose to turn on the artificial lights instead. Moreover, once the class is over, occupants will not turn the lights off. Sometimes classrooms will not be utilized right away, so if the last person to leave would turn the light off, energy consumption can be reduced.

Just like occupants leave equipment on when this is not needed, in academic buildings, when occupants are hot or cold, they immediately try to change the thermostat settings. But why would they need to change the thermostat settings if most academic buildings have operable windows to allow for cross ventilation? This should only be done if the building does not have a cooling system and the only ventilation strategy is opening windows and this would only be available in certain classrooms as this is not possible in a science laboratory. Occupants can also wear more layers to increase their clothing factor instead of increasing the thermostat temperature in the winter time. People seem to not want to inconvenience themselves to dress up accordingly to the weather; instead, they want to change the buildings settings to adapt to their comfort. Another problem is that this comfort only applies to one person. So in a class of 30 students, one of them is hot, another student is cold and the other 28 feel alright. It will be one of these 2 outlier students who will change the settings to make themselves feel comfortable without taking into consideration how this affects not only the other occupants in the classroom but also the occupants of the surrounding classrooms as sometimes there is only one thermostat per 3- 4 classrooms.

As we can see, occupant behavior can play a big role in energy consumption and if this behavior is made a priority, it is possible for buildings to achieve maximum energy efficiency and, therefore, experience significant savings in energy consumption.

**Occupancy Scheduling**

Due to occupancy behavior being so closely related to energy consumption in buildings, it is important to develop an occupancy schedule that not only takes into account weather information but also occupancy schedules and possible bad behavior to minimize energy consumption. Occupancy modeling is especially important for appropriate conditioning in rooms and increases HVAC system efficiency. Having the ability to adjust an HVAC system based on real-time occupancy is an important step towards greater efficiency, perhaps just as important is the ability to anticipate room usage based on current room usage (Erickson et al., 2012).

Buildings, more specifically academic buildings, are in need of establishing and creating a successful occupancy model. This is because the difference between real and predicted energy use depends on both the final realization of the construction, the technical installations and the real use of the built systems operated by occupants (Hoes, 2009). To establish a successful occupancy schedule, it is necessary to have the following criteria: (1) surveys; (2) data collection; (3) visualization mechanism; (4) comparison; and (5) evaluation.

To establish occupancy schedules, the occupants of the buildings need to be interviewed or fill out surveys where their usage of the building and time spent will be asked. The data collection stage is where all the various controls in the building will collect empirical data that will be later utilized to evaluate the building performance. After this data is collected by the controls, this data is uploaded into a building automation system where data trends can be observed through graphs. These patterns will then be compared to historical baseline data if it is available and amongst itself to determine regular occupancy patterns or abnormal patterns which could be the cause of energy consumption. Finally in the evaluation stage, the results from the interviews and surveys will be evaluated against the visual patterns that have been observed in the building to attempt to find how the predicted and real energy consumption is taking place.

## Controls

Achieving overall building comfort and efficiency can be quite challenging with the absence of controls to monitor lights and temperatures. Controls are more commonly used to represent the presence or absence of occupants in a building (Yang et al., 2015). Just like it has been mentioned in section 3, these controls will assist in the data collection stage. Occupancy based controls are used in the field of air conditioning, ventilation and lighting in buildings (Yang et al., 2015). There are many types of controls out in the field but for the purpose of this paper, I will focus on occupancy sensor controls and how they can help determine occupancy schedules for academic buildings and how these controls work in conjunction with a building automation system, a computer based program that allows for energy management in a building.

### Types of sensors

There are two popular types of sensors in the HVAC industry: pneumatic and digital controls. Prior to direct digital controls, all HVAC units would have pneumatic controls. The Merriam-Webster dictionary (2016) defines pneumatic as moved or worked by air pressure meaning that the reading on these controls were based on an air pressure. A direct digital control is composed of wired and wireless communication devices that allow for monitoring to occur on a real-time based scenario (Ruys, 1990).

Direct digital controls became more popular in 1990s mainly based on their accuracy and how easy it is to read the controls. In reality, replacing all the controls in a building to direct digital controls would be ideal in a building retrofit. For example, a building in the county of Santa Clara, California replaced all their pneumatic thermostats for direct digital control ones. A 300,000 sq. ft. facility spent $175,000 (before incentives). The retrofit lasted less than 20 minutes and there was minimal disturbance to the work place. The energy savings experienced within a year by only replacing the controls was $42,000 per year (Cypress Envirosystems). However, replacing all the pneumatic controls to direct digital control can become expensive, especially if they are still functioning. This is why it is still common to find pneumatic controls in some buildings especially in older academic buildings, such as the case at the University of California Berkeley. Starr (1999) suggests that direct digital controls appear to be a more reliable control system than pneumatic controls. These controls will have digital readings and through their wireless networks they can send the recordings to a computer.

**Direct digital controls**

Modern buildings condition their rooms assuming maximum occupancy rather than their actual usage and as a result, these rooms are over conditioned (ref). Occupancy sensors are needed to regulate this over conditioning capacity and help save energy. Yan et al. (2015) states there are multiple types of occupancy sensors that can be utilized in a building. In literature, occupancy detection sensors include: (1) motion detectors; (2) carbon dioxide sensors; (3) video cameras and (4) wearable sensors.

For lights, the most popular controls are timers and motion sensor controls. Light timers allow building managers to allow certain lights to be turned on and off automatically at certain hours of the day while motion sensors allow for the lights to “sense” movement and turn the lights on or off as well. Timers as well as motion sensor controls can work together; for example, the building operation times in a building are from 8:00AM to 6:00PM, so the timer will allow the building lights to be on between those hours while the motion sensor controls will help determine if a room is occupied or not and turn the lights on or off.

Motion detectors include passive infrared (PIR) sensors, which are commonly used to control lighting. The downside of this control is that it cannot provide any information on how many people are in the building (Erickson et al., 2012). A passive infrared sensor has two different slots that can see past a certain distance. When a sensor is idle, both slots will detect the same amount of infrared but when a person moves, one of the sensors will have a positive differential change (Figure 5). When the person moves away, the opposite will happen and a negative differential change will occur. The inside of the passive infrared sensor is sealed to improve any disturbance created by temperature, noise or humidity.

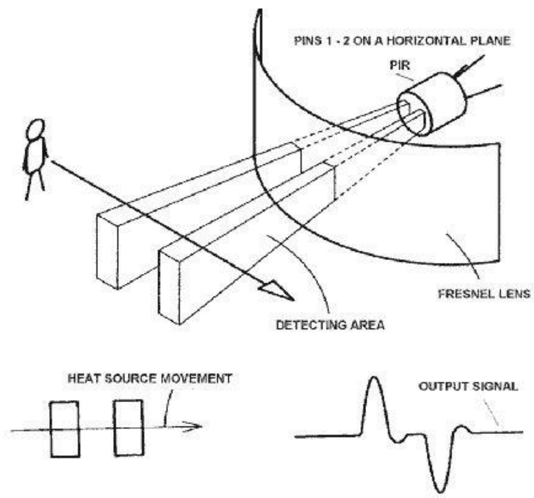


*Figure 5: Picture of a passive infrared sensor. (https://www.adafruit.com website)*

Passive infrared sensors seem to be a good alternative for occupancy sensors because they help detect the presence or absence of people in a room. However, they have their own limitations; (1) they can only handle certain temperatures and (2) they have poor tolerance to ambient light and bright color objects, possibly interfering with the infrared detection (Saracoglu, Michigan State University). In an academic settings where computers, projectors and bright clothing objects are common, passive infrared sensors might not be as effective. Imagine a professor or student accidentally leaves a projector on, this would shine on the wall and reflect on the sensor giving the wrong impression that the room is occupied. In this example, not only would the projector waste energy by being left on, but the occupancy sensor would think the room is occupied leaving lights on as well.

Direct digital controls are important because they allow building managers to schedule the HVAC operating schedule. These operating schedules allow for different areas of the building to have different set points. A set point is the temperature you want to maintain for the zone the thermostat is serving. For this example, a typical room temperature set point would be a temperature set point of 74 degrees. Direct digital controls also allow for precooling or preheating of a building or space; this allows the building manager to set up various start and stop times depending on the various building schedules. For example, if a buildings regular operating hours are 8:00AM to 6:00PM and the zone's set point has not been reached by 7:00AM then the HVAC will turn on to preheat the building before the building starts operating. And the case is the same in the summer time, but instead of heating the space, the HVAC will precool the area.

Direct digital controls allow to stop the usage of the HVAC system a few hours before the building is set to be unoccupied. Just like preheating and cooling, the HVAC system can stop an hour prior to the building being fully unoccupied. If the HVAC system is stopped half-hour earlier, it can reduce the operating times by 130 hours per year. It is also possible to have different set points for unoccupied times. Buildings can be kept at 74 degrees while occupied. The set point during the summer time can be 80 degrees to minimize the usage of the HVAC system and in the winter time the set point can be 68 degrees. Different schedules for different days of the week and holidays can also be set with the help of direct digital controls. If a buildings operating schedule is Monday through Friday, then the direct digital control can be set to either shut down the system completely for the weekend or to keep the weekend at a higher set point like the unoccupied hours set point. The same goes for holidays like Christmas, New Year's Day, etc. It is also possible to adjust to daylight savings time; this adjustment is important because with this time change twice a year. Having the possibility of changing this digitally would save lots of hours of human power to change the schedule manually.

Carbon dioxide sensors are mainly used for HVAC purposes. They not only help regulate ventilation in specific rooms when occupancy levels vary but they also contribute to a better indoor air quality. An average adult's breathe contains 35,000 – 50,000 parts per million (ppm) of $CO_2$, this is equivalent to 10 times more the amount of $CO_2$ found in outside air. ASHRAE recommends that indoor $CO_2$ levels do not exceed local outdoors concentrations of 650ppm and in good practice, $CO_2$ levels in indoor air should not exceed 1,030ppm (WSU, 2013). Even though these sensors do not give us an exact number of occupants, they measure the amount of $CO_2$ produced by the occupants of a room and send a signal to the building automation system to increase the ventilation needed in a specific room if the $CO_2$ levels are above the equilibrium point. This is important because if a room has high levels of $CO_2$, occupants may become sleepy and drowsy (WSU, 2013).

These sensors are mostly utilized in the field because of their low cost making it more affordable for a retrofit. However, $CO_2$ buildup occurs slowly and by the time the sensors have detected high levels of $CO_2$ in a specific room, the occupants in that room might be already feeling uncomfortable (Fisk et al., 2006).

Video cameras are a different type of sensor that might help to count how many occupants are in a building and in specific rooms. Knowing the number of occupants is important because the more occupants are present the more occupant behavior will impact energy consumption (Haldi & Robinson, 2010). If high resolution cameras are utilized, finding the number of occupants in buildings can be achieved (Triverdi et al., 2000). The downside of utilizing cameras is that not only are they expensive to purchase and install but there are some privacy factors to take into account. Think about the following scenario, how would you feel if you knew that when entering a building you were being monitored? Banks for example, not so creepy, because of the security reasons and the possibility that someone might go in and try to rob the bank. But academic buildings? That is not a place where you expect to be monitored 24 hours a day. Parents might have an issue with it and even students. Privacy documents would have to be signed with you application. A reason why cameras might be a good idea, and a justifiable excuse could be that teachers need to ensure there is no cheating in classrooms. Cameras might also add a sense of security to parents; with all the school shootings that have been happening lately, having cameras in all rooms and constant monitoring for suspicious activity might be a good thing.

Finally, wearable sensors, which on the other hand seem like a much better idea. Li et al. (2012) proposed an occupancy detection system based on tags. This system would report real-time occupancy and their occupancy zones within a building. The problem with this sensors was that not everybody would wear them. But with technology these days, what if these tags were integrated into cellular devices, computers or even shoes? Nike makes shoes that have a sensor that communicates back to your cell phone to track your distance run and number of steps. So why could not these sensors be in all shoes? Then all academic and commercial buildings could benefit from it. The problem with this technology is that people would either have to purchase specific shoes with these sensors or get one sensor that can be transferred from one shoe to another. This would create the problem of people forgetting to change the sensor from shoe to another shoe. Or what if you are wearing sandals? How would we be putting a sensor on a flip flop or sandal? These are all barrier that would need to be investigated on how to make it easier for the consumer.

Since almost all students and teachers own a cellular device, how about linking the GPS technology in cell phones with occupancy sensors? This method might eliminate the privacy issues that cameras have, while helping the occupancy count. If there was a detector at the entrance of every building and classroom that counts how many different GPS or cellular devices are in each room that could be the solution to how to determine occupancy in academic buildings or even commercial buildings in general. The topic of privacy is still an issue because if GPS technology used everyone's coordinates, this will create an invasion of privacy. But what if instead relying on GPS technology, occupancy could be counted as how many devices are currently connected to the Wi-Fi? The problem with this would be that every different building on campus might need their own wireless password, considering the example of University of San Francisco, there is only one wireless network for the whole campus.

All these various types of sensors have potential, Yan et al. (2015) believes that coupling motion detectors and carbon dioxide could improve occupancy detection accuracy. And with new technology emerging, maybe coupling wearable detectors and $CO_2$ sensors might be the answer to the problem, but ever academic building will have its own limitations and individually they need to explore what methods will be more effective for their current situation.

## Building Automation Systems

As stated earlier, direct digital controls appear to be a more reliable control system than pneumatic controls (Starr, 1999). However, direct digital controls cannot work on their own. They need a building automation system in place. A building automation system is a computer based control system that gathers information from multiple digital controls into one interphase allowing for management of a whole building performance. The way this automation system works is that all the individual controls will send information to a building automation system that is controlled by the building manager that records and stores data. This automation system allows for the HVAC and lights scheduling to be set. Nguyen and Aiello (2013) state that recent research focuses on developing energy intelligent buildings by integrating occupant activity and behavior as the key element of a building automation system which can automatically turn off unused lights, computer, HVAC, etc.

In a case study Kamali et al. (2014), state that in an office building in San Francisco, a building automation system had been set to automatically shut off the lights at a certain time and if anybody remained in the building they would be allowed to call a specific phone number to override the shut off. The implementation of this system resulted in 50% annual energy savings for that building.

Moreover, this automation system will allow for building manager to visualize all the energy consumption data and patterns and make the necessary adjustments for a more efficient building performance. Au-Young et al (2014) stated that having a centralized and graphically viewable software can improve the maintenance and operation of buildings by allowing the building manager/engineer or technician to diagnose equipment that might need maintenance by looking at data trends and equipment sensors not only increasing productivity but also reducing labor costs. A well maintained HVAC equipment will result in fewer failures or wasted HVAC cycling consequently reducing energy usage.

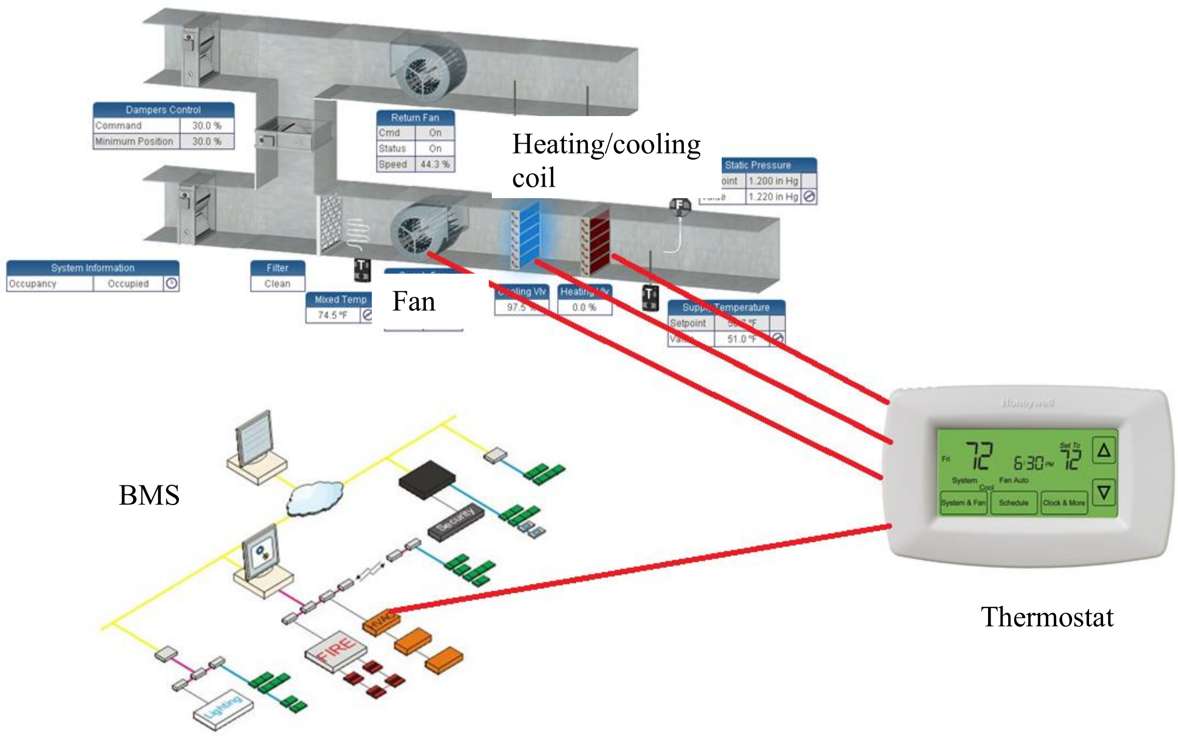


*Figure 6: Pictures taken from multiple websites (Distech control, Honeywell and University of Strathclyde) to explain the connection between direct digital controls and a building automation system when conditioning a space. The way this system works is the thermostat tries to satisfy a set point that is coming from the building automation system, specifically the HVAC area. The thermostat sends a digital signal to the fan, cooling coil or heating coil to attempt to satisfy the temperature set point. Once the set point is met, then the thermostat will send another digital signal to the fan, cooling coil or heating coil to stop.*

## Case Studies

Due to large occupancy variability in academic buildings, it is important for these institutions to have an adaptive schedule that deals with occupancy to achieve maximum energy savings (Al-Daraiseh et al., 2015). In 2012, the United States had 4,726 academic buildings (National Center for Educational Statistics, 2012) so what if all these institutions decided to commit to at least 5% energy consumption reduction? For example, University of San Francisco uses 750,500 kWh per month (personal communication, Craig Peterson, Director of Operations, University of San Francisco). If this was used as a baseline for the other academic buildings in the United States, a 5% energy consumption reduction would yield a total energy savings of over 173 million kWh per month. In this section, I will describe the different methodologies that five different academic institutions around the world have analyzed to achieve global energy reduction techniques.

**Finland**

In this case study Sekki et al. (2015) acknowledges that energy consumption is relevant in schools where there is high occupancy variability within small time intervals and sometimes low but non-zero occupancy. The focus of this study was set mainly due to the rise in primary energy consumption which is believed to be due to the increase in the use of the school and daycare premises. The efficiency of building usage is affected by the space efficiency or occupant density ($m^2$/person) and building occupancy. Buildings are designed with a fixed schedule and fixed occupancy times. In other words, two different size buildings can consume the exact same amount of energy even though one building is smaller than the other. If building A is 1000 sq. ft. and has 500 occupants while building B is 500 sq. ft. and has 500 occupants, building A should consume more energy than building B because it is more dense. Occupant density correlates almost directly with energy consumption when buildings are refurbished (Hietanen, 2009). It is believed that the more effectively the buildings is occupied, the less space needed for a given number of people, therefore lowering the space heating energy consumption per person (Sekki et al., 2015). However, when space efficiency is increased, measures to guarantee appropriate indoor air quality need to be considered. Remember back in section 2.1, ASHRAE recommend 15cfm/person. This is important to avoid respiratory diseases (Milton et al., 2000).

Dooley (2011) provided energy simulators to compare energy efficiency in terms of three indicators: (1) specific energy consumption; (2) energy intensity of usage; and (3) specific energy consumption adjusted for person hours. The indicators were compared with different space efficiencies and daily operating times. Under the specific energy consumption indicator, energy efficiency was found to decrease as the floor plan layout in the building increased. The purpose of this was to evaluate different control strategies to indicate energy efficiency and how each indicator can be used to make the right choices.

To evaluate these indicators, data were collected from various monitor systems, via direct digital controls, specifically heating and electricity data. The results for the daycares and school can be seen in table 7. This shows that the more space a child has, the more the building consumes energy.

*Table 7: Showing results from Sekki et al. (2015) study.*

| | Daycares | Schools |
|---|---|---|
| **Building usage range ($m^2$/child )** | 6.8 - 22.1 | 4.7 - 59.5 |
| **Heating consumption(kWh/ $m^2$ )** | 551 - 61 | 383 – 45 |
| **Electricity consumption (kWh/ $m^2$ )** | 372 - 37 | 125 – 10 |

For the daycares, the results show that there is a rising trend between occupant densities in function of age (Figure 7) since the year 1970. This means that because buildings are growing in size, they are becoming less dense. This could mean that there is a relationship between newer buildings consuming more energy. In this specific case, newer buildings have more space per child and similar operating times, which yields a higher energy consumption.

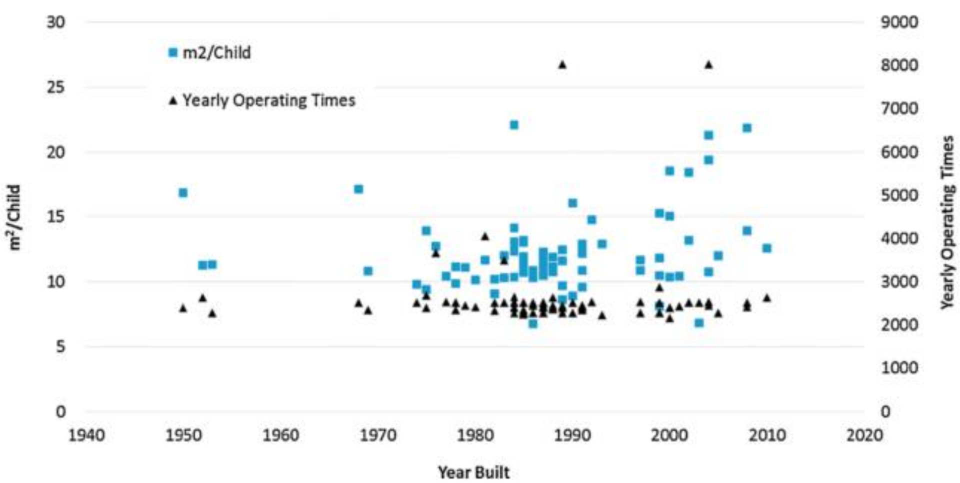


*Figure 7: Building occupancy as a function of age efficiency of building usage ($m^2$/child and yearly operating times) (source: Sekki et al. 2015) The X axis represents the year the buildings were built. The first Y axis represents the occupant density and the second Y axis represents the yearly operating times. In this graph we can see that most building operate for 2500 hours.*

For the schools, the results from table 7 show that there is a trend (Figure 8 ) between building age and occupant density but no correlation between building usage as a function of age and operating times as well and no relationship between energy consumption and occupant density.

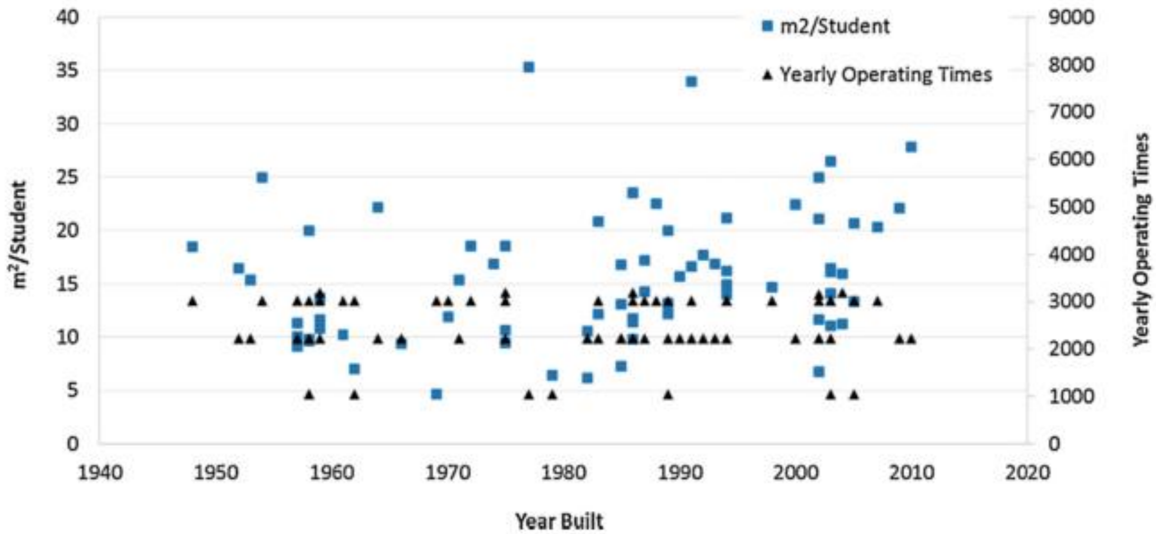


*Figure 8: Building usage as a function of age and occupant density (m²/student) and yearly operating times (source: Sekki et al. 2015) The X axis represents the year the buildings were built. The first Y axis represents the occupant density and the second Y axis represents the yearly operating times. In this graph we can see that most building operate between 2000 and 3000 hours.*

The energy consumption has also been adjusted based on occupancy density and in both cases, daycares and schools (Figures 9 and 10), there was a connection found. This means that the difference between occupancy densities has a connection with the energy consumed by the building. Energy consumption has also been adjusted for usage and occupant density, and again in both scenarios, there has been a connection. In this case, the energy consumption based on space value in design guidelines is higher than when the energy consumption is calculated based on the actual size of the buildings themselves (Sekki et al., 20015). Energy consumption measurements had to be adopted and combined with the occupancy per building and the yearly operating times throughout the whole year. With this approach, the difference between the most effective and least effective school/daycare has shown a significant variation.

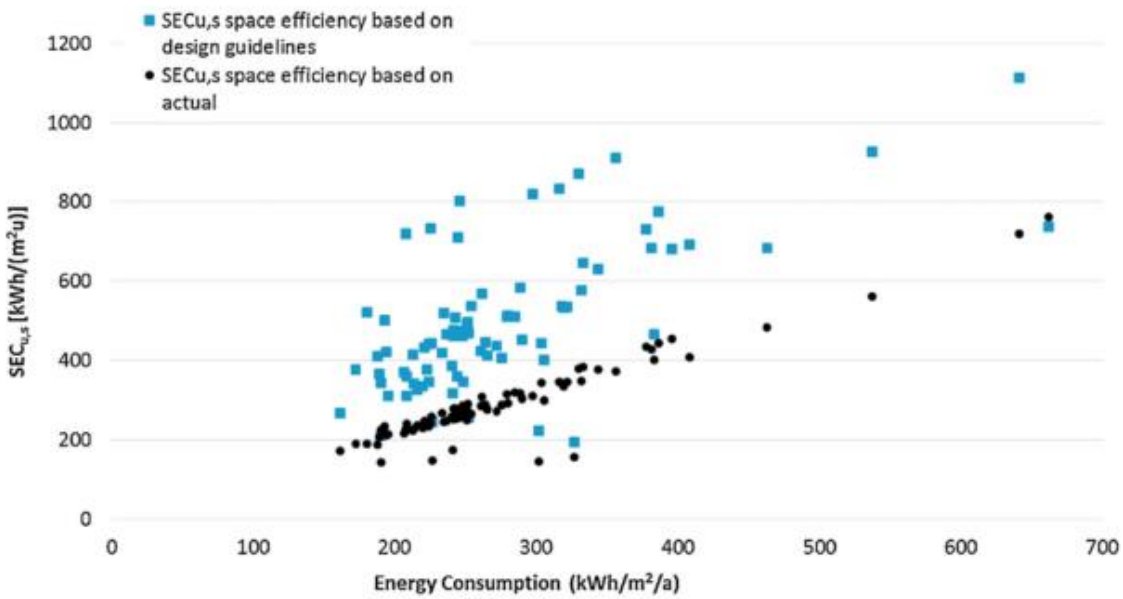


*Figure 9: Energy consumption (kWh/m²/a) in comparison with energy consumption adjusted for usage [kWh/(m²u)] in studied daycare centers. (Source: Sekki et al. 2015). This graph shows that the predicted value based on design guidelines value is higher than the actual value of energy consumption.*

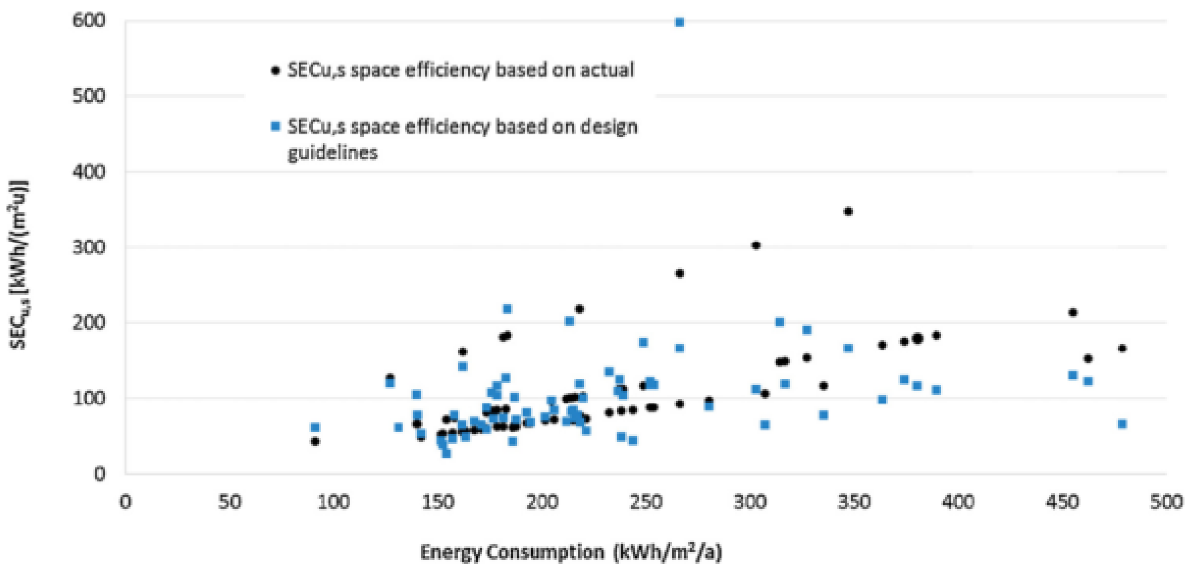


*Figure 10: Energy consumption (kWh/m²/a) in comparison with energy consumption adjusted for usage [kWh/(m²u)] in studied schools. (Source: Sekki et al. 2015). This graph shows that the predicted value based on design guidelines value is similar to the actual value of energy consumption*

This case study shows that there is a close relationship between occupancy and energy consumption (Sekki et al., 2015). When a building is occupied it will consume energy, but there will be variations between different buildings. In the case of the Finnish daycares and schools, newer buildings have longer operating times and are used more efficiently. The older buildings have operation times from 07:00AM to 05:00PM while the newer buildings operating times are from 06:00AM to 06:00PM. In newer building the occupancy density grew but with it, the building floor space also grew meaning that newer buildings have more space per user.

**University of California Berkeley**

In this case study, Granderson et al. (2010) focused on finding out if energy information systems can improve the overall building performance at University of California Berkeley. Data from meters, sensors and external data streams were used to collect data and perform a baseline, load profile and benchmarking analysis with the hope of determining any building anomalies (Granderson et al., 2010). An energy information system provides hourly whole-building electric data that is web accessible with analytical and graphic capabilities (Motegi & Piette, 2003). Energy information systems are very well known; however, there is still a gap that needs more attention, and this is investigating how a building functions between occupied and unoccupied hours.

The University of California Berkeley was analyzed because the university consumed large amounts of energy due to the potential wasted energy. This campus is a large campus; 15.9 million sq. ft. and it is 140 years old. The campus is located in Berkeley, CA and it has a Mediterranean climate with dry summers and wet winters. This campus does not have a building automation system in place but they use an online website where all the data is uploaded. This case study shows what information is needed and what kind of energy savings are desired when an old campus is trying to reduce their energy consumption.

Utility bills were combined and manually uploaded into these systems. Eight people had to go to each of the sixty-one Berkeley buildings to check how the HVAC and light equipment was running and if there were any problems. They usually checked for on/off status and temperature set points were confirmed. After all this data was uploaded into the system, energy performance was evaluated in 15 minute intervals. Figure 11 shows the detailed building plot for Wurster Hall, the architecture hall at University of California Berkeley, and two different week's energy consumptions were plotted against each other. These plots include the minimum, average and maximum energy demand in the hall. These plots revealed that there has been an excessive use of the ventilation system and over illumination in the architecture building. To fix this problem, the ventilation scheduled was reduced by 6 hours per day and a lighting retrofit was put in place. Once all this was done, a 30% energy reduction was achieved (Granderson et al., 2010). The University of California Berkeley energy manager stated that a limiting factor to achieving energy reduction was the lack of remote access interval metering and sub-metering beyond the whole-building level. Overall the common findings of this study were the incorrect implementation of scheduled HVAC and lighting loads in buildings.

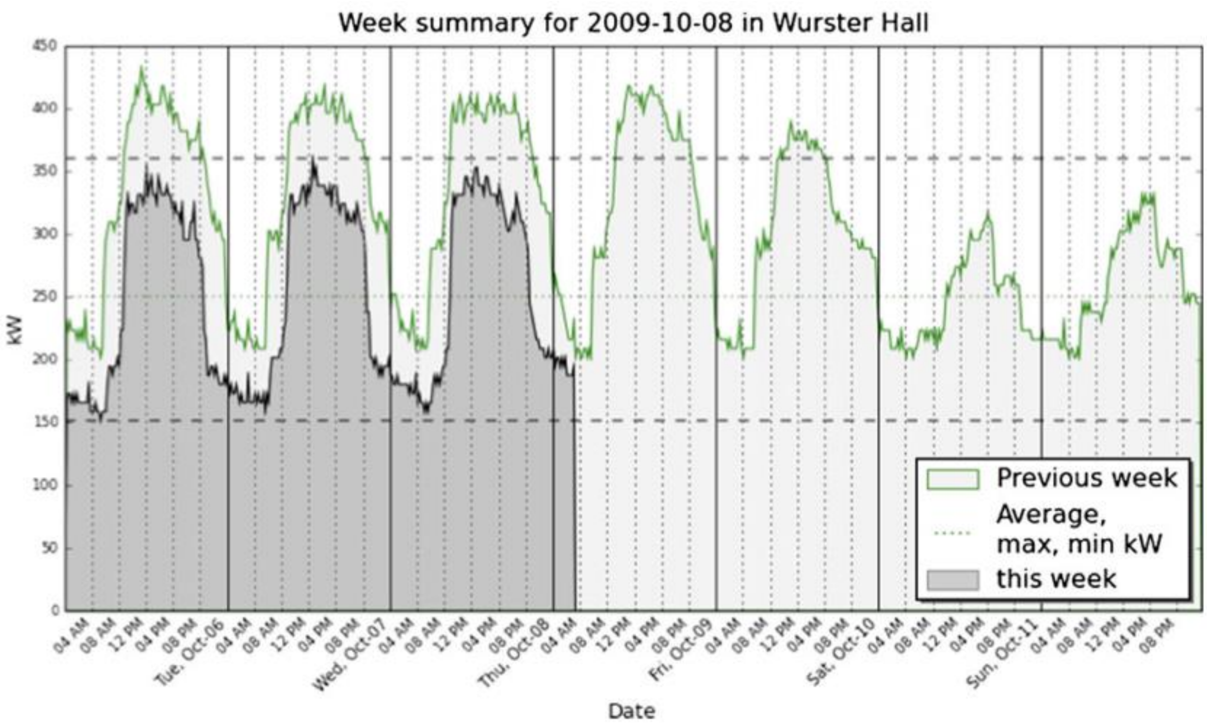


*Figure 11: University of California Berkeley Energy Dashboard "detailed building plot" (Source: Granderson et al., 2010) The Y axis shows the energy consumption in kW and the X axis shows the dates and times there has been data inputs in the system. "Previous week" data is the data observed prior to the lamping campaign and ventilation schedule change. "This week" shows the data observed after the schedule change and lamping campaign were successfully executed.*

## Singapore

In this case study, Yang et al. (2015) focus on the daily energy consumption variation and developed identification tools which can calculate the variability of the building occupants. The black box, white box and grey box approach were taken (Li& Wen, 2014). The black box is a data driven approach, the white box is a physics based approach and the grey box is a hybrid between the black box and the white box.

The black box approach is a data driven approach; it has an empirical value. This model needs a lot of data collection, but this is difficult since the data needed is limited to specific buildings. The purpose of this model is to develop a model with limited data without losing its accuracy. However, if there is a lack of input data that might allow for generalizations and these generalizations need to be taken cautiously due to the lack of input quantity (Lu et al., 2015). Because most buildings have access to their energy consumption data, it is possible for other institutional buildings to use this model. For the Singapore institutions, data was collected for a whole year, and that is the data that will be used for the black box approach.

The white box approach is more of a physics based approach; it is a calculated value. It relies on the ENERGY PLUS software to predict energy consumption. ENERGY PLUS is a whole building simulation program that building designers use to model energy consumption in buildings (DOE, 2011). This approach also requires a lot of information like; the building materials, the door and windows insulation factor, local weather data, etc. Outdoor temperatures are important because they have an impact on HVAC systems (Dong et al., 2001). The software requires having occupancy information, which is probably the hardest piece of information to acquire in institutional buildings. The more occupants there are in a building the more heat they generate, therefore affecting the HVAC load (Kwok, 2011). Occupancy density and energy consumption are directly related and knowing the occupancy information is crucial for designers to provide the best thermal comfort for the occupants.

The grey box approach is a hybrid approach from the black and white box. This approach uses the black box data to identify the variability of occupant density in buildings and inputs this data into the white box and ENERGY PLUS to achieve a higher building simulation accuracy. The purpose of this model is to find a model that will reduce errors between predicted values and real time measurements. The final result of this model is to quantify the real effect of a specific energy solution in a specific building allowing the possibility to compare two different scenarios such as before and after building retrofits. This would allow identifying the best energy renovation practices to define optimal long term strategies.

Energy consumption is highly dependent on building space and function of the building. For example, an office building has a consistent number of permanent user which decrease occupancy variability, the same 80% of people come to work every day and usually perform the same function daily. Academic institutions are more complex and have a high occupancy variation. Questionnaire studies have demonstrated that 92% of the institutional building users were visitors with only 8% of the users claiming to have a permanent office (Gul & Patridar, 2015). Previous studies in Ireland, Slovenia, UK and Serbia have shown that occupancy is an important factor regarding energy consumption so it is critical to track occupancy data. This includes occupancy detection, occupancy tracking and energy consumption estimation.

**University of California Merced**

In this case study Narayanan et al. (2010) created two projects that are related to building occupancy at University of California Merced. These two projects are: (1) metering the energy usage to aid facility operations; and (2) demand control ventilation per occupant density.

When metering the energy usage of a facility, having a visualization tool that allows the user to not only look at the actual energy trends but also monitors constantly and integrate data is important and very useful. The building automation system allows this visualization to be possible. Using the building automation system to plot the data into standardized quantities allows for a quicker understanding of how the building as a whole is functioning and how the end-use energy is affecting the overall operational energy trends. Being able to compare data trends to historical baselines can allow the user to look at the building operation requirements as well as the areas for possible energy savings potential. This is a representation of the black box model discussed in the previous case study.

Having a demand control ventilation approach allows for the building automation system to integrate data into actionable items. The $CO_2$ sensors utilized will allow determining the correct ventilation required instead of using fixed scheduling which limits the possibilities for energy usage reduction. Moreover, occupancy data will be needed. As mentioned in the previous case study, occupancy data is important for the white box model in order to come up with a predicted energy savings. To measure occupancy, low power and low-resolution cameras (Figure 12) were used and whenever a building occupant crossed the camera, this was detected and the information was sent back to the monitoring hardware for an occupancy count (Erickson et al., 2009). Along with cameras, class schedules were collected that will also be an input in the white box predictive model. Once all this occupancy information was collected, this data was uploaded to the eQUEST software. The eQUEST software is a similar tool to ENERGY PLUS, which predicts building energy consumption based on weather, building materials and equipment information. This predictive model has estimated potential energy reduction of 10-20%.

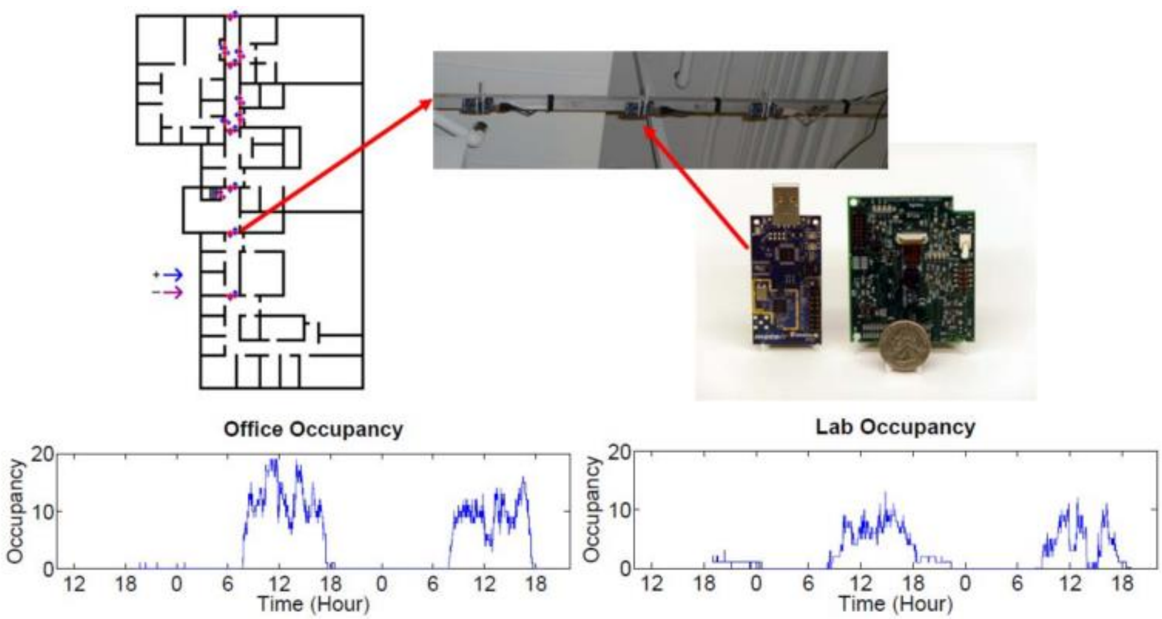


*Figure 12: (top) Wireless camera sensor network (bottom) observed occupancy patterns in lab and office space (Source: Narayanan et al., 2010). When an occupant crosses the transition point, the cameras capture the image to determine occupancy count.*

Once the black box and white box applications at the University of California Merced have been combined to simulate the grey box model, this allows the building manager to find if there is any faulty equipment in the building that is consuming unnecessary energy. This grey box model has predicted a 10-20% energy consumption reduction based on historical baseline data and a 4% energy consumption reduction based on $CO_2$ sensor data.

**University of Edinburgh**

In this case study Gul and Patridar (2014) evaluated how to use occupancy patterns to redesign different control strategies for optimum building performance. Throughout this study barriers like human behavior were discovered and discussed.

The study takes place at the University of Edinburgh in Scotland where electrical consumption (kWh) was studied in undergraduate and graduate buildings. Electrical data between the years 2012 and 2013 was collected. The results are shown in Figure 13 where there is a higher energy consumption trend in January and February than in May. This could be attributed to the climate, as January and February are the colder months while in May temperatures are also higher as well as possibly the end of the school year. Based on the energy analysis, the peak in energy consumption is probably recognized to be the on/off of the HVAC system (Kilpatrick & Banfill, 2011). This consumption could also be credited to the use of active and standby appliances in the building. An active appliance is one that is in constant use like lights, printers, etc. while a standby appliance is one that is not actively working like a computer, projector, etc.

To determine occupancy, a bi-directional infrared beam was used to count how many people entered and left the building. Classrooms were also monitored to determine how many people were in each classroom throughout the day. Because this is an academic building, not all classes have the same student capacity. For example one class can have 30 students while the next class will only have 10. Determining the amount of students per classroom is important for the ventilation standards set by ASHRAE.

Surveys were also conducted to determine the different types of energy usage. Figure 14 shows the maximum number of occupancy at approximately 200 with some slight variation, and the various energy consumption activities performed. Three main activities that contribute to energy consumption were determined; more than half of the occupants in the building do not switch the lights off when a room or area is not in use; over 50% of the occupants do not switch the projector off when they are done using it; and more than half of the occupants use the electric hand dryer in the bathrooms.

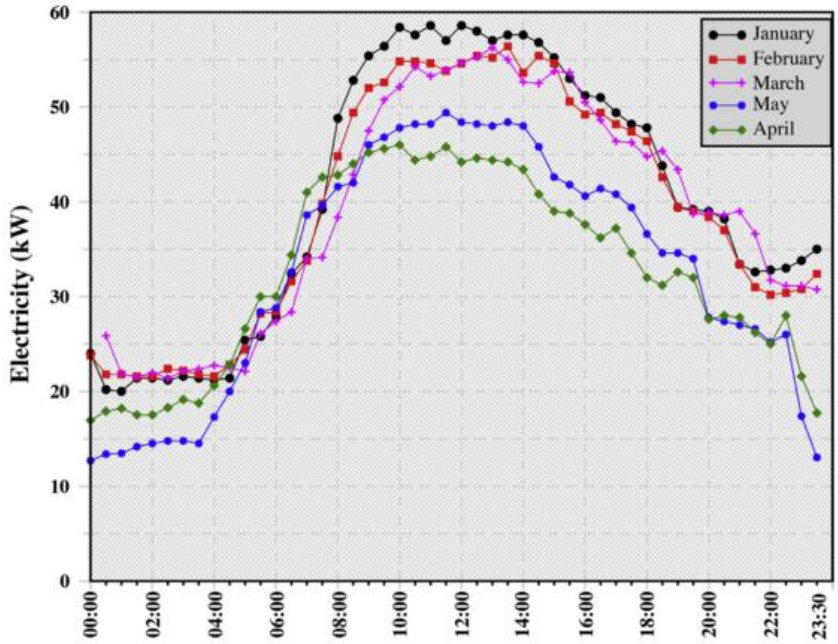


*Figure 13: Electrical demand at the post graduate center in Edinburgh for the months of January – May 2013. The X axis shows the operating hours of the building and the Y axis shows the electrical consumption in kW. This figure shows that the maximum electrical consumption occurs between the months of January and February indicating the need for heating in the winter time. This also shows the demand profile rising from 04.30AM to opening hours at 07:00AM and a semi consistent value until 12:00PM. The profile then starts slowly decreasing until 07:00PM and onwards until 09:30PM.*

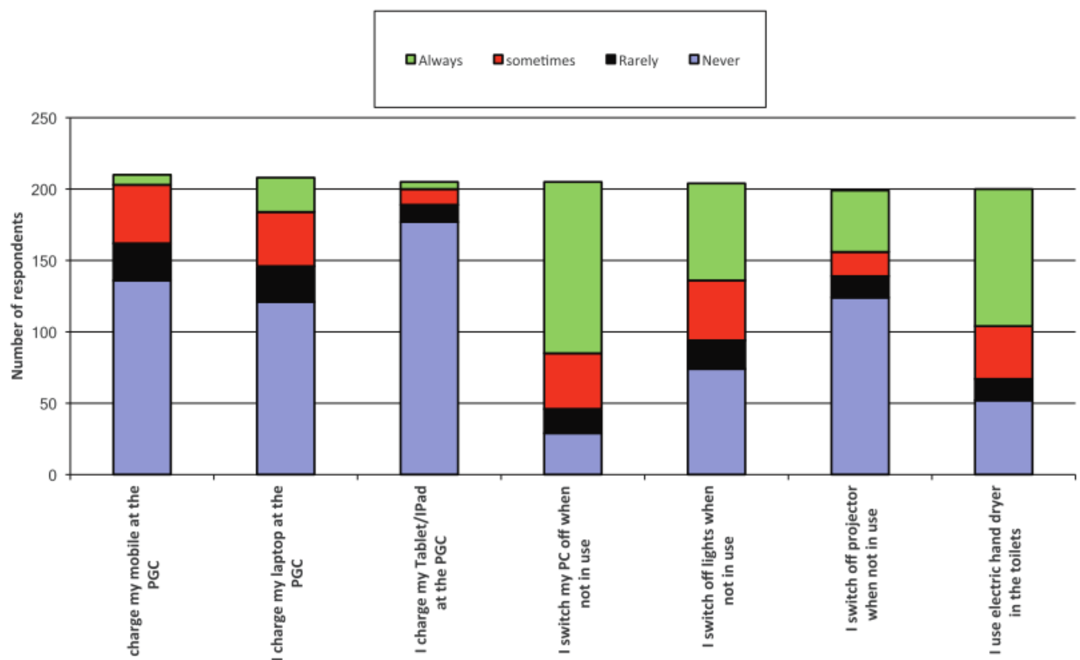


*Figure 14: Occupant activity while in the post-graduate center (PGC). The X axis shows the different activities building occupants partake while in the post graduate center and the Y axis shows the number of responses. Each color s representative of a different answer. (i.e., green: always; red: sometimes; black: rarely and blue: never). These are the*

*results of a survey where 208 responses were received; 81 from post-graduate students, 116 from undergraduate student, 2 from academic staff and 11 from administrative staff.*

This study shows that human behavior is closely related to energy consumption. For this matter, awareness campaigns are needed in academic buildings to educate building occupants that their careless behavior is affecting the energy consumption in the building as well as the effect of this energy consumption in the world.

*Table 8: Case study summary*

| Case study | Problem presented | Method used | Results | Recommendation |
|---|---|---|---|---|
| Schools and daycares in Espoo, Finland | Studied the effects of occupant density on building energy usage | Collected building energy usage data for one year and the number of occupants in each building. | Occupant density is directly proportional to energy consumption Newer buildings are less dense due to larger floor plans, but still utilize the same amount of energy or more | To implement control strategies that are based on occupant density. (e.g. occupancy sensors to operate as needed, on a demand basis) |
| University of California Berkeley | An old university campus wants to improve their building efficiency | Collected data from 61 different buildings at various times | Visualization patterns allowed to determine a building was consuming more energy than it should<br>Once this was fixed, 30% energy savings was achieved | Implementing a remote data collection system is necessary |
| Singapore | Discovered that multipurpose buildings are at higher risk of energy waste due to large variability of occupancy density | Collected building energy usage data for one year | Created a method of "black box", "white box" and "grey box" to help analyze building energy usage and potential savings through occupancy driven schedules | Utilize the new method to identify best energy renovation practices and strategies. This method can be implemented to other universities as well |
| University of California Merced | Buildings had fixed equipment schedules that ran independently and not based on occupancy density | Collected occupancy data by installing wireless network of low-power, low-resolution cameras | Based on empirical data from cameras and predictive models, 10-20% energy consumption reduction can be found | Install $CO_2$ sensors and tie-in to BMS to allow equipment to vary capacity per occupancy density |
| University of Edinburgh | Human behavior influences a buildings energy consumption. | Collected data via surveys and interviews on occupant's use of a building.<br>Occupancy data was collected through the use of cameras | Energy consumption and occupant behavior are closely related | Behavior awareness campaigns are needed |

**Discussion of case studies**

Looking at the previous case studies, occupancy diversity has a big impact on energy consumption. The problem with academic buildings is that most of them have been designed to have a fixed schedule for operations. But because of the diversity of these buildings there can be wasted energy when there is low but non-zero occupancy. Findings have been consistent throughout the case studies showing that the path to fixing this problem includes gathering data, the use of metering devices, interviews and surveys, the utilization of sensors and the need for an occupancy schedule. The creation of this occupancy schedule will allow the possibility of creating variable schedules that work in academic buildings. The creation of these variable schedules is not the only answer. We have to take into account that the occupants of these buildings have habits that contribute to increased energy consumption. To overcome these barriers, awareness and education to academic building occupants are extremely important. Once the occupancy schedules and the awareness have been implemented is when academic buildings can perform more efficiently.

In Finland daycares and schools, the importance of variable occupant density was established. Within the schools and daycares themselves, buildings that serve the same purpose were found to have a relationship between building occupancy and energy consumption. The electrical usage had a more steady variation. However, the heating load has a much larger variation. This variation in energy usage is related to the space available per person or occupant density. The more children there are in a smaller space, the less heating a room will require. There is a smaller area that needs to be heated, as well as humans releasing latent and sensible heat, reducing the mechanical load needed. The case study produces the relation between occupant density and heat load (energy usage). Thus a fixed equipment schedule would not suffice for a building that has variable occupant density if energy consumption is to be reduced.

Occupancy scheduling needs to work in conjunction with a visualization tool, which is why building automation systems are important. At the University of California Berkeley, there was an absence of a building automation system, but the students had created an automation system where the data was manually uploaded. The uploading of this data took time because the temperature set points and light information needed to be collected manually. This could increase room for error due to human error, the people in charge of collecting the data could write down numbers wrong or could input the number wrong in the computer program. If direct digital controls were installed, the data collection process would have been a lot easier and possible problems would have been detected much earlier. Either way, this automation system allowed the building managers to find a relation between occupancy profiles and energy consumption (Figure 5). These plots allow for the building managers to observe recurring or unusual patterns in the energy consumption and make the correct adjustments. By analyzing these graphs, a retrofit to the lights in the building as well as a ventilation schedule adjustment was performed, and 36% of the energy consumed by the architecture building was saved. It seems like with the visualization tools available to us, we are able to identify energy consumption trends and fix any problem that arises at the time it occurs.

Through the process of occupancy profiles and visualization tools Yang et al., (2015) created the black box, white box and grey box methods to analyze building energy usage and potential savings based on occupancy driven schedules. The black box model can simulate the energy performance of academic buildings; the white box model is a predictive model which requires a lot of data to achieve high accuracy; and the grey box model will utilize the information acquired from the black box and white box models to determine a much higher accuracy at simulating the energy consumption in academic buildings. The purpose of a more elaborate grey box model is to quantify the real effect of a specific energy solution in a specific building. This model will allow building managers to analyze different scenarios and even a before and after retrofit energy savings. For example, the University of California Berkeley is manually imputing all their data collection manually and achieving a certain percentage of energy savings. If the University decided to take a further step and upgrade their controls to digital controls and change their building automation system to a building automation system then the digital controls would be able to upload the information automatically giving a more accurate real-time energy management tool. If the grey box model is applied here, then the University of California Berkeley will be able to show their before and after control retrofit and the predicted as well as actual energy savings comparison. After this analysis is performed, the grey box calculation will be able to determine if investing in digital controls is a safe way to get a jump start at energy savings and increasing building efficiency.

The case of University of California Merced by Narayanan et al. (2010) can be considered an application model to the black, white and grey box methodology created by Yang et al. (2015). The University of California Merced refers to the black box model as the performance metrics. During this analysis, the building automation system, in conjunction with the digital controls around the campus buildings gathered a large amount of data; total electrical consumption, electricity demand, total gas consumption and the gas demand throughout a whole year. A building automation system usually determines how to run the equipment based on operational requirements, it is the building manager's job to tailor this information in terms of energy performance. This building automation system does not have a brain of its own, it needs to be told what to do. This why the building manager becomes the energy analyst and evaluates the data that has been obtained from this system.

The white box model in this study is referred to as the performance benchmark analysis. In this section, the historic baseline is evaluated as well as the climate, temperature, and code regulations. Information like wall insulation, overhangs, glazing and weather files for that year were also collected (Narayanan et al., 2010). All this information was then uploaded into the ENERGY PLUS software to generate predictive calculations. In section 5.3 I mentioned that occupancy information was probably the hardest piece of information to find. In the study of the University of California Merced, occupancy sensors already available on campus were used to gather this information. Some of these sensors included low power and low-resolution cameras to track the number of occupants entering and leaving the building.

The grey box model in this study is referred to as the occupancy-based energy automation system where an existing eQUEST model of the classroom and office building, developed during building design was analyzed to evaluate the energy savings potential (Narayanan et al. 2010). This model would combine the data gathered from the black box model such as the occupancy information as well as the predictive model from the white box to determine that by adjusting the air flow of the HVAC in classrooms, auditoriums and conference rooms, the potential energy savings on HVAC itself are of 10-20% (Emmerich & Persily, 2001).

If the black, white and grey box model approach is adapted to individual schools, significant energy reductions can occur based on building specific information as well as weather information. This is important because weather information varies between various academic buildings. If this model is successful at predicting the potential energy savings and can prove it after building retrofits have taken place, then the academic sector can find itself being successful at reducing their total annual energy consumption.

In theory, the prediction models are a great concept, but we all know that occupants have a tendency to deviate from theory to make themselves comfortable allowing behavior that contributes to energy waste. This causes a barrier on any building efficiency model that can be implemented. This is the case in the University of Edinburgh where occupant behavior was the main cause of energy consumption. Through the surveys and interview answers, occupants admitted to not turning projectors off when they were done using them, as well as not switching lights off when leaving classrooms. However turning the lights completely off can be a safety risk, people can trip and fall. These lights can be set to motion sensor detection or, at least, limit to hallway lights stay on while on a dimmer light. Awareness campaigns would also be needed to inform and educate the occupants on how their actions are affecting energy consumption. If occupants saw the numbers of how much energy is being wasted by leaving a projector on all the time, I believe they would think twice before forgetting to turn it off next time they use a projector. The use of hand dryer is another use of energy at the University of Edinburgh. The given choices are electric hand dryers or paper towels. To make a decision, what is best hand dryers or paper towels depends entirely on what type of hand dryer is in place. If an energy efficient hand dryer is in place, it might be worth it to use that dryer instead of the 2 or 3 paper towels that you would use to dry your hands. Most paper towels these days are compostable but these still require to be transported to the composting facility using energy in transportation and the composting process. But educating building occupants on reducing the amount of paper towels used to dry your hands, if that is your preference, will become useful at the end of the day.

Overall, if academic buildings monitor energy consumption, occupancy patterns are established and inputted into the predictive model then this will allow building managers to detect any unusual consumption peaks reducing energy consumption. As long as wasteful occupancy behavior is kept in mind and awareness is raised, then academic building can increase their overall efficiency.

## University of San Francisco

### Background

The University of San Francisco's facilities automation mission statement is the commitment to responsibly steward the USF campus with integrity, while conserving USF campus heritage and improving the campus to meet the challenges of today and the future (University of San Francisco, 2015). This caused me to think, what is USF doing on campus to increase building energy efficiency? Especially since it is located in California where energy reduction is such an important goal.

In 2014, USF created a Climate Action Plan and these are the energy savings strategies that were agreed to (Brooks et al., 2014). Implementing an energy auditing and metering system to identify opportunities for energy demand reduction in water heating, space heating and electrical appliance usage as well as the implementation of an energy management system. USF will also require that all new construction and upgrades have an extensive use of passive energy systems (solar gain, shading, daylight, ventilation). Moreover, working with the city of San Francisco towards net-zero energy in all new construction and major retrofits will be a major focus. Additional energy efficiency upgrades will be analyzed; these upgrades include examining the potential for efficiency gains in refrigeration, lighting, cooling of computer clusters and other commonly used appliances.

I decided to reach out to Michael London, the Associate Vice President of the Facilities Management, at USF to learn more about what they were doing towards academic building energy efficiency. I was directed to get in contact with Craig Petersen the Director of Operations at the University of San Francisco. After a few email exchanges, I finally learned what USF has implemented thus far (Appendix A).

Craig Petersen stated that to date:

USF's main source of energy consumption is the co-generation plant, which produces 1.5mW of electricity. Co-generation is the simultaneous production of electricity with the recovery and utilization heat. It is highly efficient form of energy conversions and it can achieve energy savings of approximately 40% when compared to the separate purchasing of electricity from the national electricity grid and a gas boiler for onsite heating (Clarke Energy, 2016). The way a co-generation plant works is that fuel goes into the generator, this generator produces electricity for the university campus. While generating this electricity, waste heat is produced.  This wasted heat is then captured and used to create steam that will then be used to provide heat to the lower campus buildings as well as for domestic water needs for all resident hall rooms, showers, and the heating of the Olympic sized swimming pool (Brooks et al., 2014). Even though, originally the heat generator is using energy to supply to campus, the "waste heat" is then being recycled to be utilized in other areas of the university campus which is considered the production of energy (Figure 15).

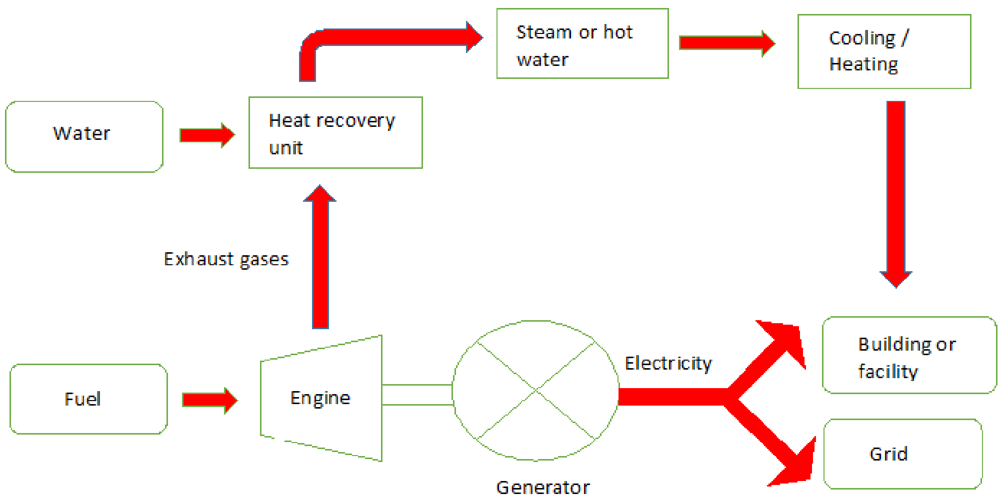


*Figure 15: Made by compiling data from Madison Gas and Electric website.  Diagram explaining how a co-generation plant, engine uses fuel to provide electricity, the exhaust gases from the engine are then sent to a heat recovery unit which will use this waste heat for hot water used for cooling or heating of the facility.*

The average energy consumption at USF is of 750,500 kWh per month.  However, 42% of this energy demand is produced by the co-generation plant and the solar farms around campus.  Solar farms are located on the roof tops of the Gleeson Library, Geschke Learning Center, Kalmanovitz, Cowell Hall, University Center and Koret Health and Recreation Center.  These solar farms have a total capacity of approximately 590 kW and have generated over 2.5 gigawatt-hours.  These panels have contributed to 4.5% of the Universities electrical output (753,000 kWh per year) (Brooks et al., 2014).  USF building automation system has been updated to be accessible in every building on campus and can also be monitored by the co-generation plant. USF is working on the upgrade of their controls to be fully digital to allow for web-accessing monitoring. As of right now, they have a mixture of the three kinds of controls; pneumatic controls, fully digital controls and the hybrid of pneumatic/digital controls.

A comprehensive energy auditing was performed and it was suggested to implement a detailed monitoring system. The primary goal is to be able to monitor individual campus buildings and the secondary goal is to monitor energy consumption in individual offices, resident hall floors and individual rooms in the resident halls. USF has started their re-lamping campaign, replacing over 8,000 ballasts and 16,000 lamps for LED fixtures specifically in buildings and garages. Looking back at the re-lamping campaigned at University of Massachusetts Amherst, that campus is 1,463 acres big which is equivalent to 26 times larger than University of San Francisco's campus which is 55 acres big. If University of Massachusetts Amherst observed 154,191 annual kWh savings, that number divided by 26 could show a relative energy savings of 5,930 annual kWh savings. If this is compared to the previously establishes California kWh rate of $0.19, then the monetary savings in light fixtures could be equivalent to $1,126.70. And for the resident hall re-lamping campaigned, the observed 509,600 annual kWh divided by 26 could show a relative energy savings of 19,600 annual kWh savings which could be equivalent to $3,724 in California.

**Recommendations to University of San Francisco**

If the black, white and grey method approach were to be followed by USF, just like in the University of California Merced study, the first step would be to implement metering devices to evaluate energy usage. This is important because monitoring energy usage of a building is critical to adapt control strategies that will reduce energy consumption. From my experience, when I go to class on some weekday nights as well as Saturdays, I have noticed that in Kalmanovitz Hall and the University Center, all the classrooms lights are turned on, but not all the classes are in use. This results in energy waste in terms of providing light and ventilation in a room that is unoccupied. If these classrooms, were equipped with light motion sensors as well as $CO_2$ sensors, USF just like University of California Merced could expect at least 10-20% energy savings.

Following the sensors, if infra-red low- resolution cameras were set at all entrances of campus buildings, occupancy numbers can be calculated and entered into a white box model which along with climate information and building material information would have a predictive model. If USF and University of California Merced were compared, I would say that USF has a higher value of energy savings mainly because of the different climates between the two cities aiding a possible higher percentage of energy savings. University of California Merced is located in the Central Valley between Fresno and Modesto where the weather is dry and hot with summer temperatures above 100 degrees experiencing the need of mechanical ventilation to stay cool in the buildings while USF is located in San Francisco where there is usually fog and lower temperatures that allow free cooling. Free cooling is when the outdoor air temperature is at or below the set point temperature at which the HVAC equipment does not have to work as hard to cool down the space.

Finally, if the occupancy data has been set and the metering devices have collected enough data, occupancy schedules can be created for each academic building and even individual classrooms within the building, just as Mr. Peterson stated is their secondary goal. The grey box model would be able to combine all this information and allow for building managers to create live buildings that react to real-time occupancy density instead of working with fixed schedules consuming energy that is not necessary.

Currently, USF buildings appear to have occupancy schedules from 8:00 AM to 8:00/9:00 PM. Buildings remain open with student ID card access until midnight. What if USF implemented a system where occupancy past operating times was controlled by the swipe of an ID card when entering a building? That could grant you access to allow motion sensors to start working because they are aware someone is in the building, especially after hours. Moreover, if lights are left on, the person who left the lights on will be able to be identified since the card reader can record the student ID that was swiped to enter the building. This might bring up some privacy concerns that users might not be very happy about. Looking back to the Kamali et al. (2014) case study, where the lights were automatically shut off at a certain time, might have been more convenient for an office building due to the consistent occupancy schedule. Doing something along those lines in an academic building would be complicated as students tend to stay after class for group meetings or to talk to the professors.

Overall, USF has started to make significant progress towards building efficiency but there is still some more room for improvement. More control strategies could be implemented as well as occupancy sensors to work with the new building automation system implemented on campus. Setting accurate occupancy profiles will maximize energy savings in buildings and rooms that are not being utilized. More solar panels could be installed on other buildings on campus allowing for the increased production of more green energy. If the university can generate more green energy, then the co-generation plant could utilize it and be a self-sustainable mechanism. If they do so, this will aid in the energy reduction efforts in their buildings and help achieve a great feat, net-zero energy, ay USF.

## Recommendations

Just like in the case of University of San Francisco, managerial recommendations are necessary for academic buildings to take into consideration when attempting to reduce their energy consumption and becoming more sustainable. The following recommendations are more of a general managerial recommendation on what to consider when thinking of energy reduction specifically to academic buildings but not limited to commercial buildings in general (Figure 16).

Lighting is one of the largest areas of energy consumption, therefore a re-lamping campaign is necessary. This is an easy, inexpensive and immediate solution that will generate instant energy reduction. If an academic building utilizes T12 fluorescent lamps, a common fluorescent type of light, re-lamping the buildings with T8 lamps, a more energy efficient fluorescent type of light, energy consumption can be reduced by 35% (Natural Resources of Canada and U.S. Energy Information Administration, 2003). The resident hall re-lamping campaign at University of Massachusetts is also a good idea. It would probably be more economic for academic buildings to partner up with a company that sells LED lamps and offer students to replace their lamp bulbs for free than to have to pay for the different lamps student bring from home.

The HVAC can have multiple phases of improvement. Primarily, a control retrofit, to update the universities controls from pneumatic to digital direct controls. Just like the office building in the county of Santa Clara, California performed. This is a minimal invasion process that will not even disturb the building function.

The second phase of an HVAC energy consumption reduction plan would be to implement a building automation system. Having performed a control retrofit will also allow for a smooth transition during the implementation of the building automation system. This building automation system will allow building managers to have a platform to gather all the data from the direct digital controls. Moreover, this platform will allow the data to be turned into graphs to visualize energy trends.

Once the data collection platform has been generated, then the black box model can be implemented. An energy consultant firm or energy analyst will then need to be hired. The analyst's purpose is to create a white box model and find predictive values of energy conservation and consumption in academic buildings. Following the black box and white box model implementation, then together they will create the grey box model where it will be determined what control strategy will yield the highest energy savings in academic buildings. Control strategies like installing $CO_2$ sensors and passive infra-red cameras to work in conjunction with occupancy profiles will be evaluated.

To overcome the barriers caused by occupant behavior and wasteful energy behaviors, awareness campaigns will need to be promoted. These campaigns will be done via flyers, internet and word of mouth. Students and professors should all be distributed surveys that have a self-evaluation. Some of the questions to be answered in the survey could be: Do I forget to shut the lights off when I leave? Do I forget to close my windows? Do I leave my computer on when I will not be using it for more than 15 minutes? Do I turn my printer off when I am not using it? Do I keep my TV on even if I am not watching it? Etc. Once these questions have been answered, students and professor can tally their scores and they can find out if they are being energy conscious or not. Some energy conservation facts can be added to the survey as well as facts about how their energy consumption is affected in dollars (e.g. If 75% of the students leave their computers on for 12 hours straight it will cost this amount of dollars per day).

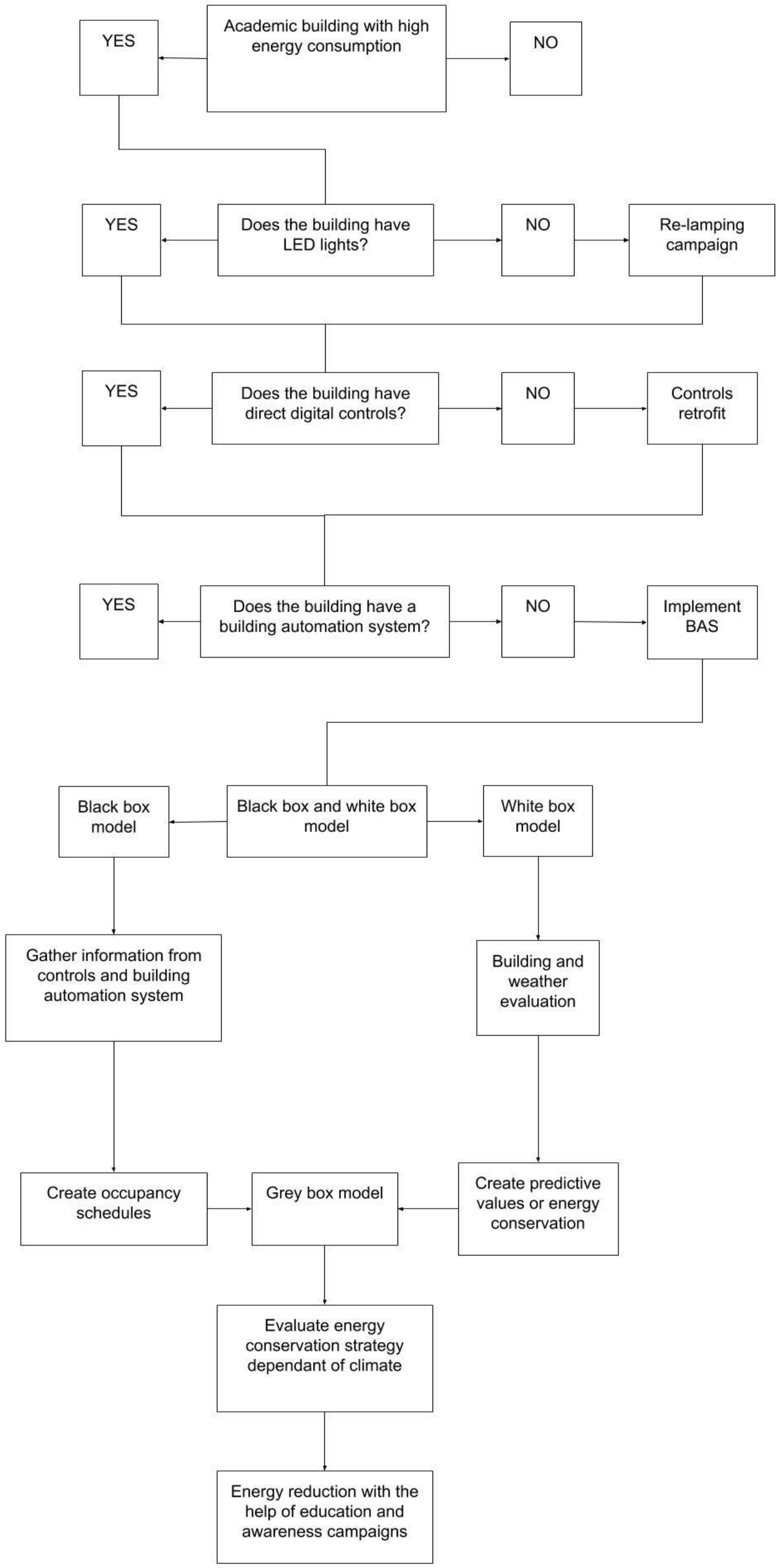


*Figure 16: Flow chart explaining the standard procedure to reduce energy consumption in buildings. Applying these various techniques should work on all commercial buildings but specifically in academic buildings.*

## Conclusions

Through the analysis of the five case studies, occupancy scheduling techniques and occupancy sensors have been analyzed based on how can they reduce energy consumption in academic buildings. The case studies show that energy reduction is possible but challenging.

Energy reduction is a challenge in academic buildings because of occupancy diversity. In the Gul and Patridar's study (2014) 92% of the people in the post graduate center at University of Edinburgh were visitors. This variation shows a large percentage of occupancy diversity but that is not the only problem. Another problem is that academic buildings are multipurpose buildings, meaning that multiple activities are happening in the same building, sometimes even at the same time. Just take a look at the University Center at University of San Francisco. That building has, the student bookstore, cafeteria, classrooms and administrative offices. It is a challenge to please every occupant, especially due to occupancy variability. Especially when the occupancy variability can be so drastic, comparing occupancy during lunch time and dinner time against occupancy between 03:00PM and 05:00PM.

It is not impossible to achieve building sustainability but it takes time and major building retrofits. A re-lamping campaign is necessary, just like at University of Massachusetts Amherst where the re-lamping campaign yielded over 150,000 annual kWh savings. A direct digital control retrofit is also necessary, and like the office building in Santa Clara, where over $40,000 savings were experienced in the first year. A building automation systems would also allow academic buildings to increase energy savings. This system will gather information from the digital controls and allow the building manager to visualize trends on energy consumption, like in the University of California Berkeley where the architecture building was utilizing energy in non-operational hours, and after the fix was made 36% energy savings were observed. When all these tools are available, the black box model will already be in progress, this is because the black box model is the data collection stage.

Following that, the white box model will need a weather evaluation as well as building evaluation to come up with predictive values for energy conservation. Finally together the grey box model will allow energy conservation strategies to be analyzed individually.  Each individual climate will be able to evaluate independently the various occupancy sensors and occupancy schedules react to each specific climate to find what control strategy works best for their own situation.  An academic institution in Arizona will not behave the same as an academic institution in California. However, the steps that need to be taken towards energy efficiency can be generalized, it is at the grey box model stage where each academic building will need to analyze and decide what the best strategy is for them depending on their geographic location and climate variation.

And finally, campus awareness will be absolutely necessary.  If academic building occupants are not aware of how their behavior and actions affect building performance and therefore energy consumption, building sustainability will not be able to go to the next level. Surveys and self-evaluations will be required to narrow down what behaviors and actions are affecting energy consumption to later focus on the main issues individually.  Education and awareness are necessary to work in conjunction with building retrofits and energy analysis to reduce energy consumption and achieve building sustainability.

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## Appendix A

Email to Craig Peterson, Director of Operations, University of San Francisco:

Q: Does USF have DDC or a BMS?

A: USF is in the process of upgrading its buildings to a building A: automation system that is accessible in each building as well as provides the ability to be centrally monitored in our Co-generation Plant workstation. Are thermostats fully pneumatic, pneumatic/DDC or fully digital? We use a combination of all three thermostat systems, since each of our buildings and HVAC systems are one of a kind and unique. Over time we will be transitioning to fully digital and web-accessible monitoring.

Q: How does USF monitor their energy consumption?

A: Unfortunately we have not yet invested in energy monitoring for the campus. We recently conducted a comprehensive energy audit that identified the need to provide detailed monitoring. Our first goal is to monitor individual buildings, but ultimately we will want to monitor individual offices and resident hall floors and even individual rooms.

Q: What is your average monthly energy consumption?

A: On average, we use 750,500 kWh per month. Of this total, we produce approximately 42% of our demand through our cogeneration power plant and our solar farms atop several of our buildings.

Q: What do you think is the main source of energy consumption?

A: Our main source of energy consumption is the cogeneration plant, which produces 1.5 mW of electricity, while simultaneously providing much of our domestic water heating needs in the resident halls for steam heat, showers, and heating the swimming pool.

Q: Has there been any energy/building retrofits? Specifically towards lighting, HVAC and controls? If so, do you have any energy data before and after the retrofit?

A: There have been several energy retrofits, to include upgraded LED lighting in several buildings, garages, and other locations. Unfortunately, since we did not have precise metering, we could not accurately gauge before and after energy usage. But it was decided to install these upgrades quickly, rather than spend the money to meter, then assess, and finally make retrofits. In some cases this caused us to lose out on rebates and other incentives, but the decision was made when we were needing to perform large renovations anyway.

Q: What is USF approach to energy efficiency and building efficiency?

A: USF fully supports energy efficiencies through building automation, improved technology, and behavior modification. No one option solves the problem; it is a holistic effort across the entire spectrum.

Q: What is the typical occupancy schedule for campus buildings? And how has this been determined? Are there any other additional steps that can be taken to improve the occupancy schedule?

A: The occupancy rate for USF buildings is quite high. In fact most campus classrooms start at 8am and run until 8 or 9pm. This makes it a challenge to perform preventive maintenance and when a classroom goes out of service for mechanical issues, it is difficult to provide alternate locations for teaching, especially in the laboratories and other low density, high demand locations. Dormitory rooms typically run in excess of 95% capacity, although that may change throughout the academic year due to attrition (drop outs, transfers, etc).