Energy Efficiency Analysis: Portland State University - East Hall

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ABSTRACT

With the increased awareness of the environmental sustainability, Energy Efficiency has been regarded as one of the key factors with respect to the greenness of buildings. PSU has committed to contribute this by joining American College and University Presidents' Climate Commitment community and strive to search for green building or LEEDS certification. However, the old buildings in PSU seems not been received relative attention on improving energy consumption. This led to this project objective of investigating the East Hall, one of the oldest building in PSU on the aspects of energy efficiency and saving.

By conducting site survey, collecting market information, and reviewing relevant literature, three Energy Efficiency Measures including Install Occupancy/Vacancy Sensors, Replace mini Refrigerators, and Improve AC system have been identified. For each measure, several options were proposed and analyzed by using Engineering Economics methods such as Present Worth (PW), Annual Worth (AW), and Sensitivity Analysis, in order to investigate the cost and benefit/saving in more detail.

The analysis of each Energy efficacy Measure are coupled with sensitivity analysis, which identify the key variables influencing the research results and can be served as an aid for utility management decision.

Introduction

Portland State University (PSU) is one of over 600 signatories to the American College and University Presidents' Climate Commitment (ACUPCC). This commitment challenges universities to take a critical role in imposing restraints on greenhouse gas emissions. PSU joined the ACUPCC on May 24th, 2010, and aims at achieving "carbon neutrally" by 2040 [1]. To accomplish this, PSU has developed the Climate Action Plan Implementation Team (CAP-IT) to construct greener buildings or LEED certificated buildings.

LEED, or leadership in Energy and Environmental Design, introduced by the Green Building Certification Institute (GBCI) in 1998, is a green building certification program that recognizes best - in –class building strategies and practices [2]. Before a building can be certificated, it must be evaluated according to the criteria shown in the Figure-1 below. Altogether a total of 100 points could be achieved in the standard categories. Despite the standard points, which are awarded for all types of buildings, it is probable to gain up to ten bonus points for particularly innovation ideas [3]. The following diagram illustrates the different categories for which the 100 standard points are awarded.

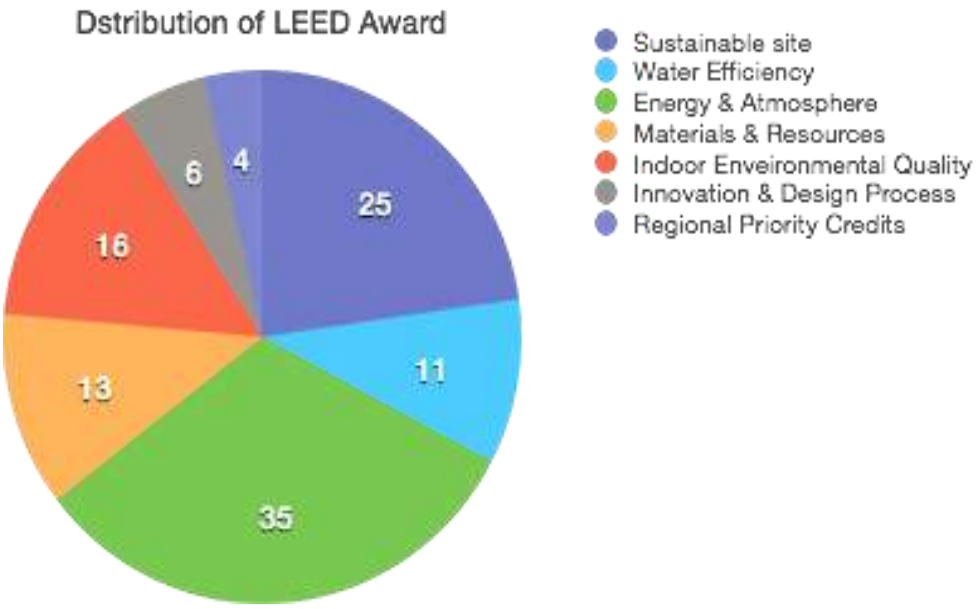

Figure 1: Distribution of LEED Award

Final evaluation is divided into four different rankings:

- LEED platinum: more than 80 points
- LEED Gold: 60~79 points
- LEED Silver: 50~59 points
- LEED certificated: 40~49 points

Figure 2: LEED certificates (source: www.usgbs.org)

Since PSU joined the ACUPCC, nine buildings have been certificated different LEED Certification Level, which is shown in the Table 1.

Building	LEED Certification Level	Construction
Academic & Student Recreation Center	GOLD	2009
Biology Research Greenhouse	SILVER	2008
Broadway	SILVER	2004
Collaborative Life Sciences Building	PLATINUM	2014
Engineering Building	GOLD	2004
Lincoln Hall	PLATINUM	2011 Renovation
Science Research & Teaching Center	GOLD	2011 Renovation
Shattuck Hall	GOLD	2010 Renovation
Stephen Epler Residence Hall	SILVER	2003

Table 1: LEED Certified Buildings in PSU

Background

The Portland State University (PSU) East Hall building is one of the oldest facilities built in 1924. East Hall is a Georgian Courtyard style three-story U-shaped brick and timber building located on the corner of SW Hall Street and Broadway, Portland Oregon. It was originally an apartment building acquired by Portland State University in 1966, and since then, it functions as an administrative and academic space for diverse programs such as [4] :

- Center for Japanese Studies
- Institute for Asian Studies
- International Special Programs
- International Studies Program
- Middle Eastern Studies Center
- Office of International Affairs
- Waseda Transnational Program

Building Naming History [4]:

- East Hall (EH) - 1999-present
- College of Urban and Public Affairs (CUPA) -1998-1999
- School of Urban and Public Affairs (UPA) - 1988-1997
- East Hall (EH) - 1966-1987
- Nixon Apartments -1924-1966

East Hall Building Description

Location: Portland, Oregon

Year Built: 1924

Floor Area: 23,390 square foot (Gross floor area)

Type of facility: Mix of offices, classrooms and student lounges.

Operating hours: Monday – Friday (9:00 am – 5:00 pm), Closed on Weekends (Saturday – Sunday).

Number of Floors: 3

	First Floor	Second Floor	Third Floor
Number of Room	23	33	35
Total Floor Size (room)	4,703 square foot	5,194 square foot	6,103 square foot

Table 2: East Hall Floor Data

Historical East Hall building energy use

The Table 3 below presents utility usage historical data for a two-year period 2013-2014. This includes all three floors of the main building - electric and gas meters.

Month	Electric Use (KWh)	Electric Use (KWh)	Electric Use (KWh)	Natural Gas Usage (Therms)	Natural Gas Usage (Therms)	Natural Gas Usage (Therms)
	2014	2013	Average	2014	2013	Average
January	7,965	8,737	8,351	1,504	1,574	1,539
February	8,324	8,469	8,397	1,514	1,378	1,446
March	7,511	8,243	7,877	1,307	1,023	1,165

Month	Electric Use (KWh)	Electric Use (KWh)	Electric Use (KWh)	Natural Gas Usage (Therms)	Natural Gas Usage (Therms)	Natural Gas Usage (Therms)
April	7,611	8,356	7,984	171	908	540
May	7,681	8,003	7,842	537	524	531
June	6,998	8,001	7,500	338	210	274
July	7,569	7,551	7,560	114	109	112
August	8,661	8,129	8,395	98	107	103
September	8,613	7,259	7,936	121	498	310
October	8,748	7,550	8,149	670	849	760
November	9,315	8,642	8,979	1,304	1,351	1,328
December	7,448	7,787	7,618	1,522	1,940	1,731
Total	96,444	96,727	96,586	9,200	10,471	9,836
Cost ($)	$5,557.11	$5,377.75	$5,467.43	$9.723.61	$9,703.88	$9,713.74
Total Energy Use in kBtu				1,313,292.897		
Total Gross SqFt				23,390		
Energy Use Index kBtu/sqft/year				56.15		

Table 3: East Hall Electricity - Natural Gas Usage Historical Data

For the purpose of this project analysis, energy efficiency options are suggested for East Hall's electricity usage only and natural gas energy efficiency alternatives are not suggested or evaluated.

Summary of Proposed Energy Efficiency Measures

Energy Efficiency Measure 1: Install Occupancy/Vacancy Sensors to control HVAC system in Hallways and Stairways on each floor of East Hall.

Energy Efficiency Measure 2: Replace small old refrigerators on each floor to new high capacity common refrigerators.

Energy Efficiency Measure 3: Improve the Air-conditioning measures (AC's) on each floor.

Methodology

Optional/Alternatives Analysis

In practice, there are usually a limited number of feasible alternatives to evaluate for an engineering project. When two or more mutually exclusive alternatives are evaluated, the decision is made easier if following steps are considered:

The alternative that requires the minimum investment of capital and produces satisfactory functional results will be chosen unless the incremental capital associated with an alternative having a larger investment can be justified with respect to its incremental benefits. Namely, if the extra benefits obtained by investing additional capital are better than those that could be obtained from investment of the same capital elsewhere in the company at the MARR, the investment should be made [5].

In optional analysis, there are few key important points. First, the selected study period must be adequate for the decision situation under investigation. So the comparison should be implemented in same equivalent condition. Second, the IRR of mutually exclusive alternatives are not compared against those of other alternatives. Just compare an IRR only against MARR. Thus, the alternative associated with the extra investment should be selected if the rate of return available through the incremental cash flow equals or exceeds the MARR.

Sensitivity Analysis

The traditional means to evaluate risk is through sensitivity. In a normal sensitivity analysis, the value of an input variable identified as a significant potential source of uncertainty is changed while all other input values are constants, and the amount of change in analysis results is indicated. This sensitivity process is repeated for other input variables for risk analysis. The input variables may be ranked according to the effect of their variability based on analysis.

Sensitivity analysis provides the impact of the variability of individual inputs on overall economic results. In general, if sensitivity analysis reveals that reasonable changes in an uncertain input variable will not change the relative economic ranking of project alternatives or undermine the project's economic justification, then the analyst can have reasonable comfort from the results. Alternatively, a reasonable change in an uncertain input value could severely diminish the project's economic justification. If so, the analyst would investigate method to reduce the risk of a change and minimize consequences when the adverse event occurs. If the risk cannot be mitigated, the analyst may recommend another project design [6].

Sensitivity Analysis methods can be classified in a variety of ways. They are classified as mathematical, statistical and graphical. In this report, mainly mathematical and graphical methods were applied for sensitivity analysis of the alternatives [7].

Assumptions

General Common Assumptions

1. The average electricity cost considered is $0.06 per kWh, based on the information or data provided by Facilities department at Portland State University.
2. MARR – 11%: information provided by Finance department at PSU.
3. For calculation purpose of all three energy efficiency measures, useful life is considered 7 years.

Lighting

1. For the other office space lights – such as offices, classrooms, and conference rooms – it is assumed that the staff will turn the lights off when they leave after working hours on weekdays.

2. It is assumed that facilities department at Portland State University will be able to install the occupancy sensors at East Hall and cost of installation is not considered in the initial investment of each option.

3. The electricity cost of operating occupancy/vacancy sensors is negligible due to very low wattage value, therefore it is not considered in operation/maintenance cost of evaluating each lighting alternative.

Refrigerator

1. According to the site survey, the old mini refrigerators in East Hall are all of different brands and no information of the brand or model is available, therefore it is more difficult to calculate the electricity cost of each one. So assumption is made that all the mini refrigerators have the same wattage- 0.45 kWh since the capacity of each mini refrigerator is nearly same.

2. Through the online literature review of the average usage of old mini refrigerators, it was found that the average working hours are around 10 hours per day. While for new energy-efficient full-sized refrigerators, the mean working hours are assumed as 6 hours per day.

Air-conditioning

1. For calculating the AC working period, it is assumed that the AC will turn on 10 hours a day from 8:00 am to 6:00 pm. In views of the temperature change in different seasons, it is assumed that AC will need to operate from May to October, which is equivalent to 6 months or 132 working days.

2. According to the MACRS table, the AC may be considered in the "office furniture and equipment class" [5]. Therefore, it is assumed that the GDS (Recovery period) is 7 years. The SV in the end of the 7 years will be assumed to be zero.

Analysis of the Proposed Energy Efficiency Measures

Lighting: Occupancy/Vacancy Sensors

Based on the observations and survey information, lights in the hallways and stairways of East Hall are 'ON" 24/7 including the closed business hours of operation from 5:00 pm to 8:00 am on weekdays

in addition to 24 hours on weekends. Lights must be kept ON for the security reasons, but some scope of energy savings is possible if occupancy/vacancy sensors are installed only for hallways and stairway lights. This will not only serve the purpose of security but also save some electricity by turning the lights ON only when it detects any motion or activity. Appendix A: Table 1 provides information about the total number of light fixtures in hallway and stairway for all three floors (right, left and central lobby area). To check for the feasibility of investing in occupancy/vacancy sensor, it is important to know how much electricity is consumed now and how much will be saved if the occupancy/vacancy sensors are installed.

For Hallways and Stairway lights turned on 24/7:

Annual Total Energy Cost = Number of days in a year (days) * Hours of operations (hours)* Cost of Electricity ($/kWh) * Wattage value (kWh)

= 365 days * 24hours * $0.06 * 0.828kW = **$ 435.196** per year

In case if occupancy/vacancy sensors are installed, the lights in hallways and stairways will be ON only during the working hours of operation 8:00 am – 6:00 pm on weekdays (assuming 10 hours) and will be turned OFF during closed hours i.e. 6:00 pm – 8:00 am on weekdays and 24 hours on weekends.

Assuming that the lights in hallways/stairways are on for 10 hours during working days:

Cost of Electricity = 260days * 10hours * $0.06 * 0.828 kW = **$129.68** per year

Therefore, Annual Savings (Hallway and Stairway lights) = $ 435.196/year - $129.68 /year

= $ 306.028 per year

So, it is worth looking for occupancy/vacancy sensor options further as the annual savings is $306.028 per year.

OPTION ANALYSIS:

A large variety of occupancy and vacancy sensors are available in market with variable price options, brands, technology such as passive infrared (PIR), Ultrasonic, dual technology (PIR plus Ultrasonic) depending on the method it detects activity, mounting options such as wall-switch/ ceiling mount – 360 degree or 180 degree so on.

From amongst the large available variety of sensor options, three ceiling mount occupancy/vacancy sensors were selected that are considered best for application in hallways areas with a focus on three price ranges– economical/ costly /most expensive. Ease of installation, 360-degree coverage and high linear activity detection feature are also considered for selection of occupancy/vacancy sensors suitable and matching with the space characteristics of East Hall, refer Appendix A – Table 2 for detailed space characteristics. For the purpose of this project analysis, below mentioned are the only 3 occupancy/vacancy sensors [8] [9] [10] evaluated, but there is scope for other sensor options that can also be considered.

Table 4 provides list of ceiling mount occupancy/vacancy sensors that were analyzed to control the lights on/off time in case for hallway/stairway fixtures excluding rooms/classrooms and offices.

	Sensor
Alternative 1 (360-degreePassive Infrared) [8]	Lutron LRF2-OCR2B-P-WH
Alternative 2 (360-degree Ultrasonic) [10]	WT-2255
	CI-305
	CI 3051
Alternative 3 (360-degree Ultrasonic) [9]	SLSCUS2001
	SLSCUS1001
	SLSCUS501

Table 4: Option Analysis - Occupancy/Vacancy Sensors

Option 1:

Option 1 is the most economical alternative compared to alternative 2 and 3 with respect to price. Lutron's LRF2-OCR2B-P-WH, is a battery powered passive infrared technology occupancy/vacancy sensor capable of covering 29 linear feet hallway area when mounted at a ceiling height of 9 feet and it detects heat from people moving within an area to determine when the space is occupied. It requires CR 123 lithium battery and is designed to have 10-year battery life (For reference – see Appendix D for datasheet). The initial investment cost is $1386.25 and total quantity of required sensors is 25 for all three floors of East Hall - hallway and stairways. The details are mentioned in summary table 5 below. The present worth of option 1 is as follows:

Present Worth = -$1,386.25 + $306.03 (P/A, 11%, 7) =**$ 55.81**

Option 2:

Option 2 considers 3 different specification occupancy/vacancy sensors of brand Wattstopper –

(1) Ultrasonic Sensor - WT 2255 (360-degree two-sided, 90 linear feet)

(2) PIR Sensor – CI-305 (44 linear feet)

(3) PIR Sensor – CI – 305 -1 (24 linear feet)

The PIR sensor are required only for Floor 1 – Hallway space: C104 (120 sqft), V101 (131 sqft) and C105 (128 sqft). The ultrasonic sensor has bigger coverage range 90 linear feet and the required coverage range for the space mentioned is less than 40 linear feet. Therefore, PIR sensors of the same company brand, suitable for smaller hallways, can cover all the 3 mentioned areas of floor 1. The wattage (voltage and current) requirement for the all three mentioned sensors is negligible and therefore it is not considered in the further calculations. The initial investment cost is $1841.88 and total quantity of required sensors is 12 for all three floors of East Hall - hallway and stairways. The details are mentioned in summary table 5 below. The present worth of option 2 is as follows:

Present Worth = -$1,841.88 + $306.03 (P/A, 11%, 7) = **- $ 399.82**

Option 3:

Option 2 considers 3 different specification occupancy/vacancy sensors of brand Schneider are is the most expensive sensors of all the three evaluated alternatives–

(1) Ultrasonic Sensor - SLSCUS2001 (360-degree two-sided, 90 linear feet)

(2) Ultrasonic Sensor – SLSCUS1001 (360-degree two-sided, 1000 sqft area)

(3) Ultrasonic Sensor – SLSCUS501 (360-degree two-sided, 500 sqft area)

Similarly as in case of option 2, the SLSCUS1001 and SLSCUS501 sensor are required only for Floor 1 – Hallway space: C104 (120 sqft), V101 (131 sqft) and C105 (128 sqft). The ultrasonic sensor-SLSUS2001 has bigger coverage range 90 linear feet and the required coverage range for the space mentioned is less than 40 linear feet. The wattage (voltage and current) requirement for the all three mentioned sensors is negligible and therefore it is not considered in the further calculations. The initial investment cost is $2300 and total quantity of required sensors is 12 for all three floors of East Hall - hallway and stairways. The details are mentioned in summary table 5 below. The present worth of option 3 is as follows:

Present Worth = -$2,300 + $306.03 (P/A, 11%, 7) = **- $ 857.94**

For each option – Total number of sensors required and initial investment cost is summarized in below table:

	Option 1	Option 2	Option 3
Sensor 1	Lutron LRF2-OCR2B-P-WH	WT-2255	SLSCUS2001
Sensor 2		CI-305	SLSCUS1001
Sensor 3		CI 3051	SLSCUS501
Cost 1	$55.45	$132.99	$158
Cost 2		$87	$142.50
Cost 3		$72	$119
Floor 1 – Hallway	$388.15	$512	$720
Left side	3	2,1	2,1
Right side	2	1	1
Center	2	1	1
Floor 2 - Hallway	$332.70	$399	$474
Left side	2	1	1
Right side	2	1	1
Center	2	1	1
Floor 3 - Hallway	$332.70	$399	$474
Left side	2	1	1
Right side	2	1	1
Center	2	1	1
Stairs	332.7	531.96	632
Sensors- stairway	6	4	4
Total Cost of Alternative	$1,386.25	$1,841.88	$2,300.00
Total Sensors	25	12	12

Table 5: Options Summary: Investment Cost and No. of Sensors

Sensitivity Analysis:

Therefore, as the present worth of option 2 and 3 is negative, option 1 is the only alternative that is further analyzed for sensitivity study and the effect of cost of electricity, MARR and capital investment change is evaluated. As can be observed from the figure below, capital investment and cost of electricity are considered more sensitive to the PW, due to steeper slope. The MARR seems less sensitive to the PW, compared with the capital investment.

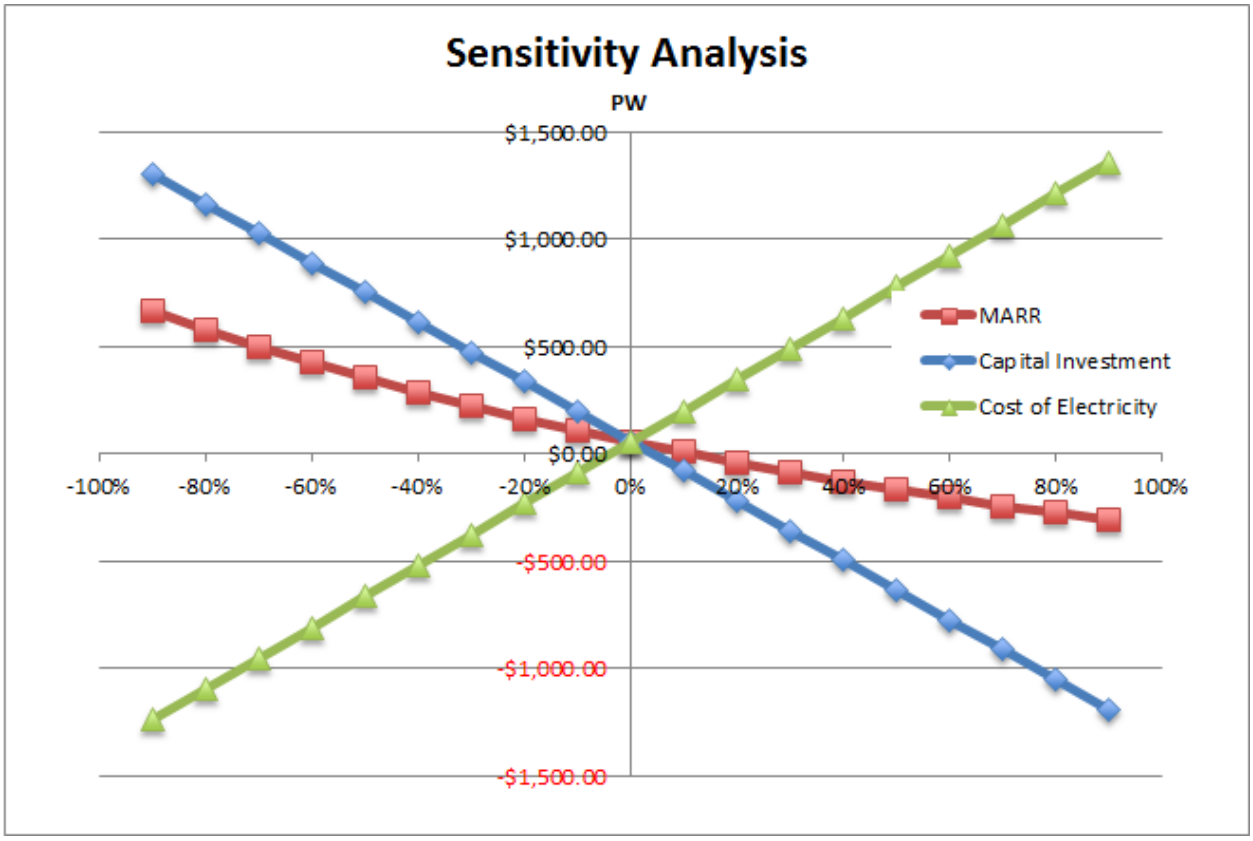

Figure 3: Sensitivity Analysis - Lighting - Energy Efficiency Measure

Refrigerator

Previous study shows that some mini refrigerators consume as much energy as a full-sized refrigerator [11]. For example, the Magic Chef MCBR445W has a claimed capacity of 4.4 cubic feet, along with glass shelves, a can dispenser, and other useful features. It costs $180 but could cost you $40 per year to run if the refrigerator temperature is set to the recommended 37 degrees (based on the Oregon average of 6 cents per kilowatt hour) [12]. Refer Appendix B for detailed description.

According to the results of the site survey of East Hall, there are 16 mini and old refrigerators in the building that cost as much as $1,576.8 annually. Since the yearly electricity bill is around $7,000, the electricity cost of mini refrigerators is more than 20% of the total electricity usage. Refer below table for summary of old refrigerator data:

Average capacity of a mini refrigerator= 4.4 cubit feet

Average wattage for a min refrigerator= 0.45 kWh

Electricity cost in the city of Portland= $0.06 kWh

Old Refrigerators:

Floor	Number	Total capacity cubit feet	Wattage kWh	Annual Electricity Cost
1	3	13.2	1.35	$295.65
2	3	13.2	1.35	$295.65
3	10	44	4.5	$985.50
Total Annual Cost				$1,576.80

Table 6: Annual Electricity Cost of Old Refrigerators

Therefore, as one of the measure it was determined to replace the old, mini refrigerators with energy efficient full-sized refrigerators. In order to decrease the electricity cost of refrigerators with a minimum capital investment, some survey on the new refrigerators is done, such as purchasing prices, after-sale services, and estimated annual energy cost. Among all the researched energy efficient refrigerators, it was found that FFTR1821QB and LTCS24223S are more suitable for East Hall with regard to the purchasing price and capacity.

New Refrigerators:

Floor	Number	Capacity cubic feet	Model	Purchasing Price	Wattage kWh	Annual Electricity Cost
1	1	18	FFTR1821QB	$497.70	0.404	$53.09
2	1	18	FFTR1821QB	$497.70	0.404	$53.09
3	2	47.76	LTCS24223S	$997.20	1.002	$131.66
				(Home Depot)		
Total Cost				$1,992.60		$237.83

Table 7: Annual Electricity Cost of New Refrigerators

Therefore, the annual saving of the replacing option will be

$$Annual\ Saving = \$1{,}576.8 - \$237.83 = \ \$\ 1{,}338.97$$

With a capital investment $1,992.60, it is possible to calculate the breakeven point of this investment. To find the breakeven point in years (N), the PW is set equal to zero.

$$PW = \$ - 1{,}992.6 + \$1{,}338.97(P/A\,, 11\%, N) = 0$$

From TABLE, it can be seen that $1 \leq N \leq 2$ year.

Air-conditioning

AC Requirements Analysis

After conducting the site survey, it was found that first floor had equipped with central AC system in almost every room/offices. However, there is some AC in-sufficiency found in 2nd and 3rd floor. The current 3 AC in each floor are not sufficient enough to meet East Hall second and third floor cooling requirements. Based on the Energy Star website, the 700 up to 1,000 sq. ft. will need 18,000 BTU per hour [13]. This will give us the minimum cooling capacity of 112,626 and 114,822 BTUs/hr for these two floors respectively. Therefore, the current capacity of 54,000 BTU is indeed not sufficient enough to provide a sense of comfortable work environment. The minimum total capacity needed is 108,000 BTU in 2nd and 3rd floor after calculation with estimating 95% of variance in each floor. The calculation is shown in the table below.

	Second floor	Third floor	Total
Square Footage of East Hall (sq. ft.)	6,257	6,379	12,636
Minimum cooling capacity required (BTU/hr)	112,626	114,822	227,448
Current Air Conditioning (3 Air Conditioning)(BTU/hr)	54,000	54,000	108,000
The required capacity needed (95%~100%)	54,000~58,626	54,000~60,822	Minimum 108,000
Total minimum cooling capacity required (BTU/hr)	108,000	108,000	216,000

Table 8: Requirement analysis for AC in 2nd and 3rd floor

Options Analysis

In order to meet the gap that we observed during the site survey, there are three options proposed to both consider the energy efficiency and work environment improvement, which are listed as follows:

1. Option 1: Install 3 additional Air Conditioners in both second and third floor.
2. Option 2: Upgrade the AC (two 36,000 BTU AC) + sell two old ACs (save the installation cost) for both second and third floor.
3. Option 3: Install 58 Window mounted AC (30 for second floor and 28 for third floor)

The above 3 options are proposed to operate 10 hours per day and 22 days per month in order to exactly meet the working requirement. The analysis of these 3 options is briefly described in the following sections. The detailed Excel calculation is attached in Appendix C.

Option 1 Analysis

Based on the existing AC setting in East Hall and consider the insufficiency of cooling capacity, 3 similar types of AC system with each 18,000 BTU capacity is suggested to be installed in both 2nd and

3rd floors. After collecting market information and conducting estimation of expenses, the calculation is depicted in the table 9 below.

	2nd Floor	3rd Floor	Total	Notes
Capital investment	5,400	5,400	10,800	DAIKIN equivalent split system (unit price: $1,800) with total 54,000 BTU capacity (18,000 BTU*3 units) for each floor.
Operating cost per year	332.16	332.16	664	Based on $0.06 of unit cost per kWh, 1.398 kW power per unit, 10 hr. daily usage, 132 working days per year.
Useful life	7	7		Based on "office furniture and equipment" asset class 00.11.
MARR	11%	11%		
Annual maintenance fee	137	137	275	[14]
Installation cost	1,239	1,239	2,479	[14]

Table 9: AC option 1 analysis

PW (Option 1) = -10,800 - (664+275) (P/A, 11%, 7) - 2478.87 =$ -17,701.56

AW (Option 1) = $3,756.54

Option 2 Analysis:

Considering the lowest impact of the current East Hall pipeline layout, option 2 contains upgrading 2 AC systems, selling the 2 old AC and making the best use of the current pipeline structure, so that the installation can be reduced to some extent. The calculation is listed below.

	2nd Floor	3rd Floor	Total	Notes
Capital investment	8,000	8,000	16,000	DAIKIN equivalent split system with 36,000 BTU capacities.
Operating cost per year	681.12	681.12	1362	Based on 0.06 of unit cost per kWh, 4.3 kW per unit, 10 hr. daily usage, 132 working days per year.
Useful life	7	7		Based on office furniture and equipment asset class 00.11.
MARR	11%	11%		
Annual maintenance fee	137	137	275	[14]
Installation cost	620	620	1,239	[14]
Market value after 1 year	3,085.56	3,085.56	6,171.12	1 year depreciation (0.901)

Table 10: AC Option 2 analysis

PW (option 2) = -16000-(1362+275)*(P/A, 11%, 7)-1239+6171.12*(P/F, 11%, 1) = $ -19,400.09

AW (option 2) = $4,116.99

Option 3 Analysis:

For the sake of meeting better individual needs of temperature setting, option 3 is proposed to install 58 window mounted ACs in offices located in 2nd and 3rd floor. The capital investment seems to be cheaper, however, the operating cost seems to be higher than other options. The detailed comparison will be made in the following sections.

	Second floor	Third floor	Total	Notes
Capital investment	3,820	3,566	7,386	Based on 30 and 28 EA window ACs in second and third floor respectively
Operating cost per year	3,038.43	3,038.43	6,077	Based on total 17.99 kW, $0.06 cost, 10 hr a day, 132 days per year
Useful life	7	7		Based on office furniture and equipment asset class 00.11.
MARR	11%	11%		
Annual maintenance fee	870	870	1,740	Based on 1 hr. labor
Installation cost	1800	1680	3,480	Based on 2 hr labor + supplies = $60 per unit. *

Table 11: AC Option 3 Analysis

PW (Option 3) = -7386 - (6077+1740) (P/A, 11%, 7) - 3480 = -47,683.40

AW (Option 3) = $10,119.15

Sensitivity Analysis

Although every effort has been made to make the above analysis reflect the actual situation, the uncertainty involves in almost every scenario. Thus, it is necessary to conduct sensitivity analysis and try to investigate the potential range of variations when input variable changes. In addition, for more clearly to identify the benefits/savings of the above options, it is needed to calculate the potential savings as result of implementing these optional initiatives. The annual saving is calculated by comparing the operating cost difference between new options and the current AC setting in East Hall as shown in the table below. The driving factors for the saving include the operating hours (time aspects) and kWhs (energy consumption aspect). From this analysis, the ways of energy saving of East Hall are shown in Table 12 although options require capital investments. And the saving values in options were used as annual saving data in sensitivity analysis for each option.

Energy Saving	Current (24hr)	Saving (10hr)	Option 1	Option 2	Option 3
Operating Time (hour) per day	24.0	10.0	10.0	10.0	10.0
Power consumption (kW) per AC unit	3.0	3.0	1.4	4.3	0.7
Cost of Power consumption per unit per day	4.3	1.8	0.8	2.6	0.4
Total Cost of Power consumption per day	25.9	10.8	5.0	5.2	23.0
Operating cost per year	4,708.8	1,962.0	664.3	1,362.2	6,076.9
Difference (Saving) per year		2,746.8	3,063.5	2,692.6	(2,349.1)
	Saving/unit	457.79916			
	Cost/unit	326.9994			

Table 12: AC cost saving analysis for proposed options

Option 1 Sensitivity Analysis

Since the option 1 has the highest PW value, it is necessary to look at how the changes factors can influence the PW value. As can be seen from the figure below, capital investment and annual saving are considered more sensitive to the PW, due to the steeper slope. The Annual expense (including electricity cost) and MARR seems not that sensitive to the PW, compared with the capital investment.

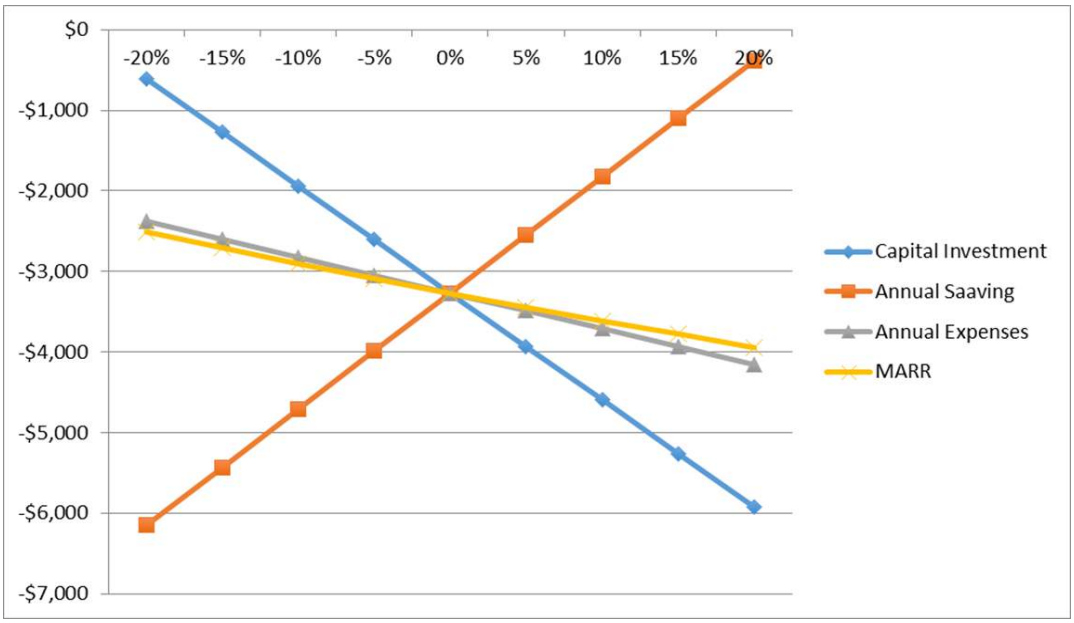

Figure 4: AC Option 1 Sensitivity Analysis

Option 2 Sensitivity Analysis

As can be seen from the figure 5 below, option 2 has the similar sensitivity results with option 1. The capital investment and annual saving are again considered more sensitive to the PW, due to the steeper slope. The annual expense (including electricity cost) and MARR seems not that sensitive to the PW, compared with the capital investment and saving. This means that the other different class/level of potential AC with different energy consumption may influence the PW more significantly.

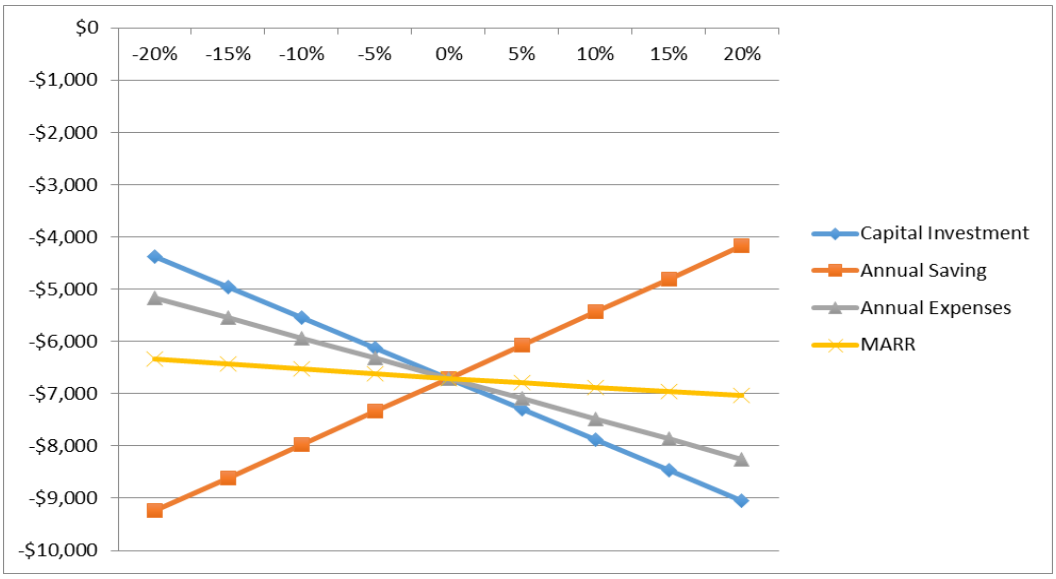

Figure 5: AC option 2 Sensitivity Analysis

Option 3 Sensitivity Analysis

Option 3 has different sensitivity results with option 1 and 2. The annual expense and MARR are considered more sensitive to the PW, due to the steeper slope. The annual saving seems not that sensitive to the PW. This means that the input variables in the option 3 Analysis tend not to influence the PW value significantly.

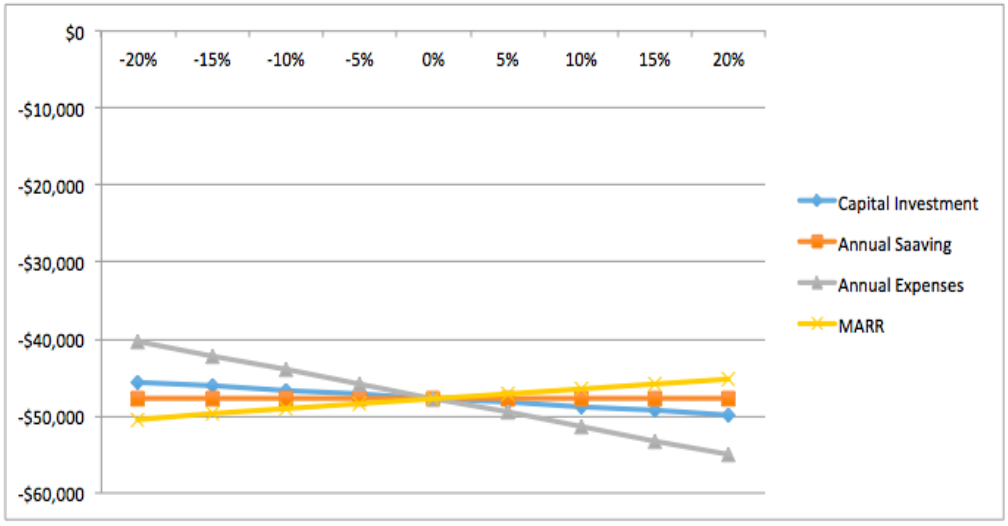

Figure 6: AC Option 3 Sensitivity Analysis

Results

Lighting: Occupancy/Vacancy Sensor

Based on the analysis it can be summarized that Lutron- LRF2-OCR2B-P-WH – Passive Infrared sensor is the most cost efficient occupancy sensor alternative for East Hall and it is worth the investment.

Refrigerator

Old refrigerator's consumes more energy. If the new refrigerators were installed by replacing the old refrigerators, it would take approximately 2 years of energy savings to offset the initial investment of new refrigerators. Therefore, it is a good investment over a long-term period.

Air-conditioning

Based on the above investigation, the AC analysis is briefly summarized as shown in the table below and listed as follows:

- Option 1 is featured with lowest operating cost and should be preferred, due to the largest PW (lowest AW) value.
- Option2 has the lowest installation cost; nevertheless, it is the capital investment making the PW relatively decreased.
- Option 3 has the lowest capital investment; however, the operating cost per year is so high that makes this option unfavorable.
- $5.4 annuity per month per room seems to justify the improvement of working environment in East Hall.
- According to the result of sensitivity, capital investment and annual saving are regarded as major factors contributing to the variations of PW value. This may require utility manager's attention when considering option 1 or 2.

Summary	Option 1	Option 2	Option 3
Capital Investment	10,800	16,000	7,386
Operating cost per year	664	1,362	6,077
Annual maintenance	275	275	1,740
Installation cost	2,479	1,239	3,480
Useful life	7	7	7
MARR	11%	11%	11%
MV		6171.12	
PW	-17,702	-19,400	-47,683
AW	3,757	4,117	10,119
Annuity per month	313	343	843
Annuity per month per room	5.4	5.9	14.5

Table 13: Summary of AC analysis on East Hall

Conclusion and Recommendations

Working condition is generally considered as one of the important factors affecting employee's performance. Although East hall has made some improvements by installing some AC in hallway, the second and third floor still encounter the problems of insufficient AC capacity. By considering capital investment, installation cost, annual maintenance and cost saving, to install 3 new AC in both second and third floor (option 1) is identified as the most preferred way of both enhancing the AC capacity and balance the energy efficiency. The rationale for this proposition is based on the annual worth value (AW) method and sensitivity analysis addressed in Engineering Economics theory. The AC analysis result can be simplified into the following statement: "To expense $5.4 per room per month will be very likely to meet the AC capacity requirement and improve the working condition of East Hall."

With regard to the calculation above for Refrigerator energy efficiency measure, it is obvious that after two years, the initial investment will breakeven. Therefore, replacing old, mini refrigerators with energy efficient, full-sized refrigerators could be taken into consideration.

Reducing lighting energy usage helps in controlling associated energy cost. Turning the lights on and off based on the occupancy and user adjustable time delays along with different modes such as day-light sensing so on are few of the benefits of installing occupancy/vacancy sensors. This is important not only from economic aspect but it is also a positive effort towards conserving and saving energy.

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Appendix

Appendix A

Table 1: Hallway – Stairs Lighting Fixture – Floor 1, Floor 2 and Floor 3

Floor	Quantity (Light Fixtures)	Wattage (Watts)
Floor 1	6 - 2	34 W – 13 W
Stairs – Level 1	8	13W
Floor 2	12	13 W
Stairs – Level 2	8	13 W
Floor 3	12	13 W
Stairs – Level 3	6	13 W

Table 2: Space Characteristics for East Hall

Space Characteristics of each hallway and stairway of East Hall:

	Floor 1	Floor 2	Floor 3
Hallways Space (Left Side) (Sqaure Feet)	120	349	300
Ceiling Height (Feet)	8	8.4	8.4
Linear length of Hallway(Feet)	25.00	72.71	53.57

Hallways Space (Right Side)(Square Feet)	300	326	300
Ceiling Height (Feet)	8	8.4	8.4
Linear length of Hallway(Feet)	53.57	67.92	53.57

Hallways Space (Center) (Square feet)	388	317	371
Ceiling Height (Feet)	8	8.4	8.4
Linear length of Hallway(Feet)	54.61	48.71	51.08

Stairs: Space (Left Side)	154	154	154
Windows	1	1	1
Area			
Stairs: Space (Right Side)	154	154	154
Windows	1	1	1
Area			

For Floor 1: Floor space is different

Left Side: V101	11.70
C105	30.48

Calculation for Present worth Alternatives:

Present Worth for Alternatives:

MARR	11%
N	7
Cost	$0.06

End of Year	Alternative 1 Cash Flow	Alternative 2 Cash Flow	Alternative 3 Cash Flow
0	-$1,386.25	-$1,841.88	-$2,300
1	306.028	306.028	306.028
2	306.028	306.028	306.028
3	306.028	306.028	306.028
4	306.028	306.028	306.028
5	306.028	306.028	306.028
6	306.028	306.028	306.028
7	306.028	306.028	306.028
Present Worth	$55.81	-$399.82	-$857.94

Sensitivity Analysis Calculations:

[I] Changes in MARR

	MARR	PW
-90%	1%	$664.72
-80%	2%	$579.22
-70%	3%	$499.02
-60%	4%	$423.70
-50%	6%	$352.90
-40%	7%	$286.27
-30%	8%	$223.52
-20%	9%	$164.37
-10%	10%	$108.54
0%	11%	$55.81
10%	12%	$5.97
20%	13%	-$41.19
30%	14%	-$85.85
40%	15%	-$128.18
50%	17%	-$168.32
60%	18%	-$206.44
70%	19%	-$242.64
80%	20%	-$277.07
90%	21%	-$309.82

[II] Changes in Capital Investment

	Capital Investment	PW
-90%	-$138.63	$1,303.44
-80%	-$277.25	$1,164.81
-70%	-$415.88	$1,026.19
-60%	-$554.50	$887.56
-50%	-$693.13	$748.94
-40%	-$831.75	$610.31
-30%	-$970.38	$471.69
-20%	-$1,109.00	$333.06
-10%	-$1,247.63	$194.44
0%	-$1,386.25	$55.81
10%	-$1,524.88	-$82.81
20%	-$1,663.50	-$221.44
30%	-$1,802.13	-$360.06
40%	-$1,940.75	-$498.69
50%	-$2,079.38	-$637.31
60%	-$2,218.00	-$775.94
70%	-$2,356.63	-$914.56
80%	-$2,495.25	-$1,053.19
90%	-$2,633.88	-$1,191.81

[III] Changes in cost of electricity (Annual Savings)

	Annual Savings	PW
-90%	$30.60	-$1,242.04
-80%	$61.21	-$1,097.84
-70%	$91.81	-$953.63
-60%	$122.41	-$809.42
-50%	$153.01	-$665.22
-40%	$183.62	-$521.01
-30%	$214.22	-$376.80
-20%	$244.82	-$232.60
-10%	$275.43	-$88.39
0%	$306.03	$55.82
10%	$336.63	$200.02
20%	$367.23	$344.23
30%	$397.84	$488.44
40%	$428.44	$632.64
50%	$459.04	$776.85
60%	$489.65	$921.06
70%	$520.25	$1,065.27
80%	$550.85	$1,209.47
90%	$581.45	$1,353.68

Appendix B

Average capacity	4.4	Cubit feet
Average wattage for a mini refrigerator	0.45	KWh
electricity cost in Portland	$0.06	KWh

Appendix C

East Hall AC analysis Excel spreadsheet

Option 1: Install 3 additional Air Conditioners in both second and third floor			
	Second floor	Third floor	Total
Square Footage	6,257	6,379	12,636
Mininum cooling capacity required (BTU/hr)	112,626	114,822	227,448
Current Air Conditioning (3 Air Conditioning)(BTU/hr)	54,000	54,000	108,000
Add 3 New Air conditioning (BTU/hr)	54,000	54,000	108,000
Total cooling capacity (BTU/hr)	108,000	108,000	216,000
Capital investment	5,400	5,400	10,800
operating cost per year	332.1648	332.1648	664
Useful life	7	7	
MARR	11%	11%	
Annual maintenance fee	137	137	275
Installation cost	1,239	1,239	2,479
PW (Option 1) = -10800 - (664+275) (P/A, 11%, 7) - 2478.87	-17,701.56		
AW (Option 1) =	$3,756.54		

Supplemental information/calculation for option 1:

DAIKIN cooling capacity (BTU/Hr) per unit	18,000
Square footage (maxmum) for 18,000 BTU	1,000
Unit price for DAIKIN (cooling + fan + remote control)	1,800
Indoor + outdoor power (kW)	1.398
Operating hours per day	10
Operating month (From May to Octobor)	6
Total energy consumed per day (kWh)	13.98
Total energy consumed per month (22 days)(kWh)	307.56
unit cost per kWh	0.06
Total energy cost per month	18.4536
Total energy cost for 6 month (1 year usage) per AC	110.7216
Total energy cost for 6 month (1 year usage) for 3 Acs	332.1648
Annual maintenance cost for 3-tons through 24-tons AC	274.97
Annual installation cost for AC with range: > 65,000 and < 135,000 Btu/h	2478.87

Indoor unit power consumption (kW)=		0.058
Outdoor unit power comsumption (kW) =		1.34
Total power consumption per unit =		1.398
Unit price =	$1,588.50 + $198.25 shipping	

Average inflation rate (from 2001 to 2014) =		2.30%
Maintenance cost in 2001 =		200.00
Maintenance cost in 2015 =		274.97

Average inflation rate (from 2001 to 2014) =		2.30%
Installation cost in 2001 =		1,803.00
Installtion cost in 2015 =		2,478.87

Option 2: Upgrade the AC (two 36,000 BTU AC) + sell two old ACs for both second and third floor			
Daikin - Initial investment ($4,000/unit)	Second floor	Third floor	Total
Square Footage	6,257	6,379	12,636
Mininum cooling capacity required (BTU/hr)	90,101	91,858	181,958
Current Air Conditioning (3 Air Conditioning)(BTU/hr)	54,000	54,000	108,000
Replace 2 New Air conditioning (BTU/hr) - 36,000BTU*2	72,000	72,000	144,000
Total cooling capacity (BTU/hr)	90,000	90,000	180,000
Capital investment	8,000	8,000	16,000
operating cost per year	681.12	681.12	1,362
Useful life	7	7	
MARR	11%	11%	
Annual maintenance fee	137	137	275
Installation cost	620	620	1,239
Market value after 1 year	3085.56	3085.56	6171.12
PW (Option 2) = -16000-(1362+275)*(P/A, 11%, 7)-1239+3085*(P/F, 11%, 1)*2	-19,400.09		
AW (Option 2)=	$4,116.99		

Supplemental information/calculation for option 2:

DAIKIN cooling capacity (BTU/Hr) per unit	36,000
Square footage for 36,000 BTU	2,500
Unit price for DAIKIN (cooling + fan + remote control)	4,000
Indoor + outdoor power (kW)	4.3
Operating hours per day	10
Operating month (From May to Octobor)	6
Total energy consumed per day (kWh)	43
Total energy consumed per month (22 days)(kWh)	946
unit cost per kWh	0.06
Total energy cost per month	56.76
Total energy cost for 6 month (1 year usage) per AC	340.56
Total energy cost for 6 month (1 year usage) for 2 ACs (36000*2)	681.12
Annual maintenance cost for 3-tons through 24-tons AC	274.97
Annual installation cost for AC with range: > 65,000 and < 135,000 Btu/h	2478.87
Installation saving (using original AC pipeline)(50%)(assumption)	1239.435

Indoor + outdoor unit power consumption (kW)=			4.3
Total power consumption per unit =			4.3
Unit price =		$3,885.99 + $142.25 shipping	

Option 3: Install Window mounted AC in sencd and third floor			
	Second floor	Third floor	Total
Capital investment	3,820	3,566	7,386
operating cost per year	3,038.43	3,038.43	6,077
Useful life	7	7	
MARR	11%	11%	
Annual maintenance fee	870	870	1,740
Installation cost	1800	1680	3,480
PW (Option 3) = -7386 -(6077+1740) (P/A, 11%, 7) - 3480 =	-47,683.40		
AW (Option 3) =	$10,119.15		

Supplemental information/calculation for option 3:

Total window mounted AC needed	30
Total price for 30 window mounted AC	3,820
Total kW consumed by all Window mounted AC in	38.364
Operating hours per day	10
Operating month (From May to Octobor)	6
Total energy consumed per day (kWh)	383.64
Total energy consumed per month (22 days)(kWh)	8440.08
unit cost per kWh	0.06
Total energy cost per month	506.4048
Total energy cost for 6 month (1 year usage) for all	3038.4288
Annual maintenance cost per AC (0.5 hr labor) =	15
Annual installation cost per AC (2 hr labor)=	60

Second floor	Count	Price	Initial Cost	volt	amp	watt	kW	Total kW
5000 BTU	17	119	2023	115	4.8	552	0.552	9.384
6000 BTU	10	115	1150	115	5.2	598	0.598	5.98
8000 BTU	2	209	418	115	6.5	747.5	0.7475	1.495
12000 BTU	1	229	229	115	9.8	1127	1.127	1.127
	30		3820				Total	17.986

Third floor	Count	Price	Initial Cost	volt	amp	watt	kW	Total kW
5000 BTU	11	119	2023	115	4.8	552	0.552	9.384
6000 BTU	14	115	1610	115	5.2	598	0.598	8.372
8000 BTU	2	209	418	115	6.5	747.5	0.7475	1.495
12000 BTU	1	229	229	115	9.8	1127	1.127	1.127
	28		4280				Total	20.378