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GINA CODY SCHOOL OF ENGINEERING AND COMPUTER SCIENCE

BLDG 6581

DECISION ANALYSIS

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Final Project Report

Energy Conservation in Residential Building

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Submitted to,

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Contribution Table

Name	Contribution
Gianina Martinez	Motion Sensing Lights, Utility Analysis, Calculations in Excel, Final Report and Presentation Preparation
Vivekkumar Nathabhai chatrola	SolarWall, Multiple Objective Analysis, Calculations in Excel, Final Report and Presentation Preparation
Nishit Jagdishkumar Kadia	SolarWall, Multiple Objective Analysis, Calculations in Excel, Final Report and Presentation Preparation
Mohammad mehmood syed	Motion Sensing Lights, Utility Analysis, Calculations in Excel, Final Report and Presentation Preparation

Contents

Executive Summary

This project addresses the decision analysis alternatives of a potential renovation, in the apartment located on 3605 Saint Urbain Street, Montreal, Quebec, in order to decrease energy consumption using energy efficiency designs. To select the best decision, we apply several theories to determine the cost savings from using two options: SolarWall and Motion Sensing Lights. After collecting data, the alternatives were branched by creating a decision tree, such decisions were made using the Net Present Worth of each alternative. Alternatives with positive net present worth are likely to generate profit, and are therefore considered for their sensitivity of parameters, utility values and multiple objective approaches.

1. Introduction

This project aims to improve the inadequate energy efficiency of the residential apartment building located on 6305 St. Urbain, Montreal. The apartment was built in 1966. It has 15 floors, and 8 apartments per floor. Lights on the ground floor are not considered since they should be on 24/7. Natural gas is the single source of energy for heating. A renovation project is proposed to integrate new energy conservation technologies and strategies into the existing building system. It will reduce the overall energy consumption, and thus lower down the cost to run the building for the property owner. According to the lease, the owner is responsible for covering all the energy cost other than electricity within the units. The team has come up with preliminary solutions, among which two are closely examined, and the scenarios simulated for each one of them. The goal is to have the long-term saving from an efficient energy system to pay for the initial cost of renovation.

The first step is to evaluate the current system quantitatively, identify major inefficiencies, and then to look for possible solutions. In most residential buildings, the majority of energy is used for heating, cooling, ventilation and large equipment such as elevators and water heaters. Nevertheless, this approach does not cover all alternatives, instead the owner along with a team decided to start evaluating cost saving by implementing SolarWalls and motion sensor lights in the building's common areas to avoid considerable investments. This report includes details on the parameters considered, data collection, expected monetary value, sensitivity analysis, utility values and decisions under multiple objective criteria. The analysis helps to further develop the most profitable alternatives into simulation.

2. Problem Statement

The goal of this project is to minimize cost of energy for the property owner. The single source of energy in this building is natural gas for heating purposes, the price of which is determined by the market, as wells as the electricity cost is stated by the market rate. The problem, therefore, is approached from lowering the consumption of energy. However, the demand for energy does not change, if the apartment stays fully occupied. Considerations in terms of medium and low occupation are made as well as using different bulb's watts in the motion sensitive light alternative. The team intentions are to improve the efficiency of the current energy system without compromising the 53-year-old building performance. Also, the potential alternative to make more efficient use of energy through solar panels, that will function in both conditions high efficiency and low efficiency considering the location, Montreal. These alternatives will be examined in detailed analysis. There are several basic assumptions for the analysis, nonetheless the entire assumptions are going to be detail in each analysis:

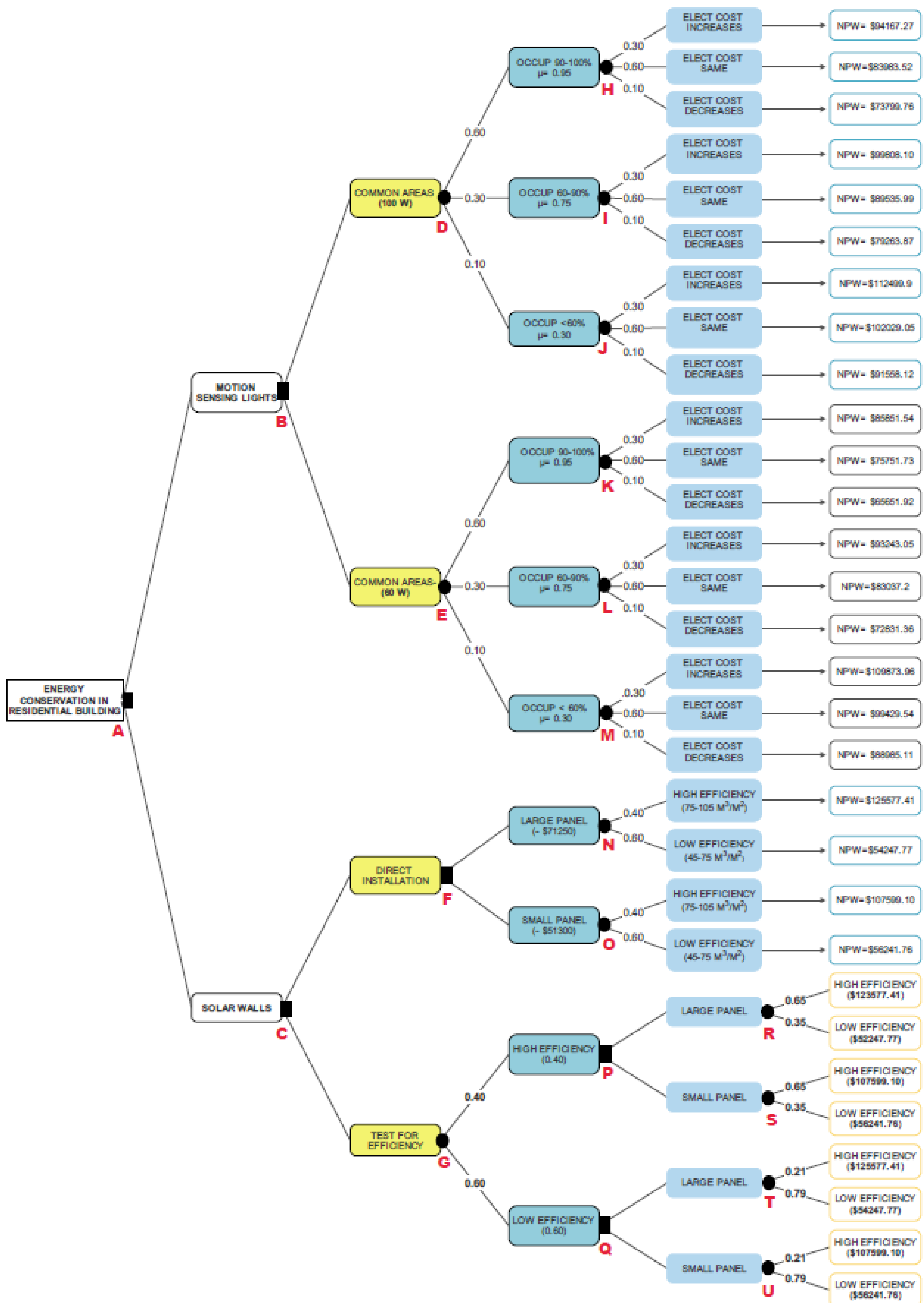
a. Lifetime of this project = 30 years
b. Price of natural gas, fixed rate = $0.55/m^3$.
c. Price of electricity = $0.05/kWh.

3. Data Collection

The first collection of data comes from existing information on similar buildings, site visit, field trips, along with using official data sources from governmental websites. Suppliers of energy improvement related services also have useful information to conduct cost estimation, such as market prices. Some assumptions were made in turn to make this analysis suitable with the requirements. The interest rate for this project is 4% in both analyses, when the cost saving generates return on revenue.

4. Decision Alternatives

Figure shows the decision tree of the problem with all the available alternatives, probabilities and terminal values.


ENERGY CONSERVATION IN RESIDENTIAL BUILDING
A
MOTION SENSING LIGHTS
B
SOLAR WALLS
C
COMMON AREAS (100 W)
D
COMMON AREAS- (60 W)
E
DIRECT INSTALLATION
F
TEST FOR EFFICIENCY
G
0.60
0.30
0.10
OCCUP 90-100% μ= 0.95
H
OCCUP 60-90% μ= 0.75
I
OCCUP <60% μ= 0.30
J
OCCUP 90-100% μ= 0.95
K
OCCUP 60-90% μ= 0.75
L
OCCUP < 60% μ= 0.30
M
0.30
0.60
0.10
ELECT COST INCREASES
ELECT COST SAME
ELECT COST DECREASES
NPW= $94167.27
NPW=$83983.52
NPW= $73799.76
NPW= $99808.10
NPW= $89535.99
NPW= $79263.87
NPW=$112499.9
NPW=$102029.05
NPW= $91558.12
NPW= $85851.54
NPW= $75751.73
NPW= $65651.92
NPW= $93243.05
NPW=$83037.2
NPW= $72831.36
NPW=$109873.96
NPW= $99429.54
NPW= $88985.11
LARGE PANEL (- $71250)
N
SMALL PANEL (- $51300)
O
0.40
0.60
HIGH EFFICIENCY (75-105 M^3/M^2)
LOW EFFICIENCY (45-75 M^3/M^2)
NPW=$125577.41
NPW=$54247.77
NPW=$107599.10
NPW=$56241.76
HIGH EFFICIENCY (0.40)
P
LOW EFFICIENCY (0.60)
Q
LARGE PANEL
R
SMALL PANEL
S
LARGE PANEL
T
SMALL PANEL
U
0.65
0.35
0.21
0.79
HIGH EFFICIENCY ($123577.41)
LOW EFFICIENCY ($52247.77)
HIGH EFFICIENCY ($107599.10)
LOW EFFICIENCY ($56241.76)
HIGH EFFICIENCY ($125577.41)
LOW EFFICIENCY ($54247.77)
HIGH EFFICIENCY ($107599.10)
LOW EFFICIENCY ($56241.76)

1. SolarWall

SolarWall is a technology that uses the heat of the sun to produce the heating in the building. It heats the ventilation and passes process the air required for the commercial and industrial buildings. SolarWall Air heating systems produce substantial energy and economic benefit by heating fresh air to improve the air quality with solar collection efficiency up to 80%. SolarWall systems produce up to 1.5-3.5 GJ/m2 per year of thermal energy.

When the sun warms the surface of the collector, the heated air is drawn through thousands of tiny perforations on the surface and ducted to the existing air intake. The solar heated air is then distributed throughout the building via the conventional ventilation system or dedicated fans and ducting. SolarWall can be specified as part of building remediation and building envelope upgrades in older buildings that have localized deterioration, air infiltration, and moisture damage. Heating this large volume of air with conventional means is expensive, hence many housing authorities and condo developers are interested to use SolarWall systems in their buildings. SolarWall system having heating feature is one of the few economical and efficient technologies that is easily integrated into an existing high-rise building where it doubles as the exterior cladding, in addition to generating on-site heat energy for the next 30 years.

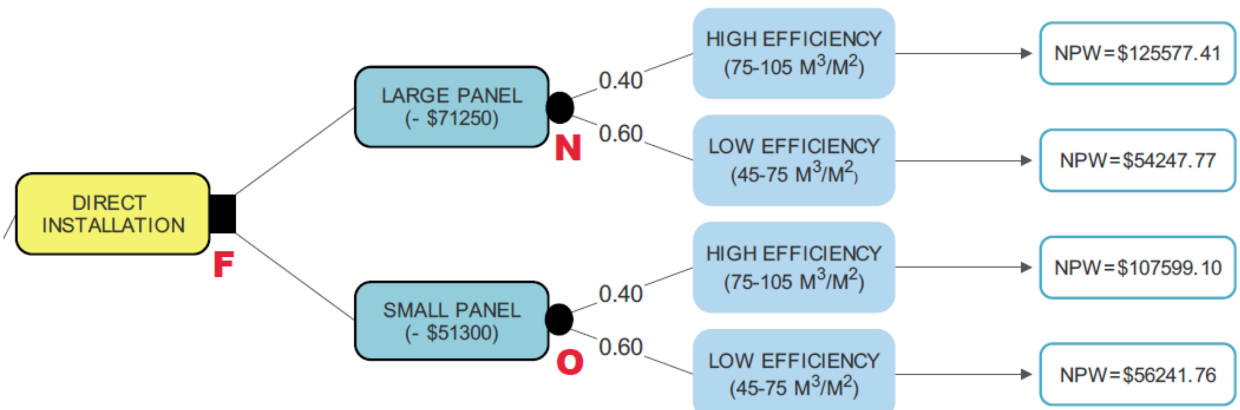
The cost of the SolarWall as obtained from the manufacturer for each square meter of SolarWall, viz. $285/m^2. This amount included the cost of installation, material and labour. While, the energy saving obtained from the specifications of the manufacturer of SolarWall is converted into cubic meters of natural gas saved per year for each square meter of SolarWall installation. It is estimated to range from 120 m^3/m^2 at highest efficiency to 56 m^3/m^2 at lowest efficiency. Now the annual savings can be directly obtained as the size of SolarWall installation is known and the price of the natural gas is known.

Annual Savings = Size of SolarWall (m^2) x Price of Natural Gas (\$/m^3) x Efficiency (m^3/m^2)

For the ease of the comparison the savings from the SolarWall is calculated in the form of Net Present Worth (NPW). The service period of SolarWall is taken as 30 years and the rate of interest at which the savings are invested is considered as 4%. Moreover, annual maintenance cost of the installation is subtracted from the savings. Hence, NPW of each size of installation can be obtained.

SolarWall Alternatives

The feasibility studies determined that two sizes of SolarWall installations are possible on the building that could yield a beneficial result in the present conditions. The sizes of installation can be 250 m^2 and 180 m^2 termed as Large Panel and Small Panel from hereon respectively. It must be understood that the Large Panel demands higher investment while also saving higher amount for the owner and vice versa for the Small Panel. Moreover, it has been considered that up to $50,000 of SolarWall installation the government does not demand any tax, instead provided $5000 rebates, while if the total cost of installation exceeds $60,000, normal taxation at 21% is applied. The benefits that can be obtained from the natural gas savings are uncertain and are depended on efficiency of the SolarWall. Figure shows the decision tree for the direct installation of the solar panel.



The key specification and special conditions that arises with each size of panel is discussed under:

I. Large Panel:

The total initial cost of the large panel installation is calculated as: $285/$m^2$ x 250 m^2 = $71,250. Moreover, the annual maintenance and repair cost is considered as $1500. While an additional tax of $15,000 is levied on the owner.

The appropriate estimate of the efficiency is obtained by dividing the entire range of efficiency viz. from 56 m^3/m^2 to 120 m^3/m^2 into two parts and naming from High Efficiency and Low Efficiency. High Efficiency is defined as the efficiency of 100 m^3/m^2 with a deviation of $\pm$ 20%. While, Low Efficiency is defined as 70 m^3/m^2 with a deviation of $\pm$20%. Moreover, due to the weather conditions of the Montreal and location of the building, it has been roughly estimated by the manufacturer that there are 40% chances of SolarWall working at High Efficiency and 60% chances that the SolarWall will work that Low Efficiency.

The calculation of Net Present Worth is carried as under:

NPW = PV (rate, years, annual savings) - (Initial Cost + Govt. Benefits)

Hence, two chance nodes are formed from each size of panel which provides the efficiency and furthermore gives the corresponding NPW. We also calculate the Rate of return (ROR) for each of the cases as under:

	Cost	Maintenance	Govt. Benefits		
Large P	-\$71,250	-\$1,500	-\$15,000		
	Probability	Mean Efficiency (m^3/m^2)	Mean Savings (annual)	**Mean NPW**	Rate of Return
High Eff.	0.4	100	\$12,250.00	**\$125,577.41**	13.92%
Low Eff.	0.6	70	\$8,125.00	**\$54,247.77**	8.64%

The calculation of EMV for NPW = **\$82,779.63**

While the EMV for ROR = **10.75%**

II. Small Panel:

The total initial cost of the large panel installation is calculated as: \$285/m^2 x 180 m^2 = \$51,300. Moreover, the annual maintenance and repair cost is considered as \$1,000. While an additional government benefit of \$5,000 reduces the cost to the owner.

The appropriate estimate of the efficiency is obtained by dividing the entire range of efficiency viz. from 56 m^3/m^2 to 120 m^3/m^2 into two parts and naming from High Efficiency and Low Efficiency. High Efficiency is defined as the efficiency of 100 m^3/m^2 with a deviation of $\pm$ 20%. While, Low Efficiency is defined as 70 m^3/m^2 with a deviation of $\pm$20%.

Hence, two chance nodes are formed which provides the efficiency and furthermore gives the corresponding NPW. We also calculate the Rate of return (ROR) for each of the cases as under

	Cost	Maintenance.	Govt. Benefits		
Small P	-\$51,300	-\$1,000	\$5,000		
	Probability	Mean Efficiency (m^3/m^2)	Mean Savings (annual)	**Mean NPW**	Rate of Return
High Eff.	0.4	100	\$8,900.00	**\$107,599.10**	19.12%
Low Eff.	0.6	70	\$5,930.00	**\$56,241.76**	12.43%

The calculation of EMV for NPW = **$76,784.69**

While the EMV for ROR = **15.10%**

Results of Prior Analysis:

The prior analysis of the situation shows that according to the EMV of NPW, large panels should be preferred, while according to the EMV of ROR, small panels should be preferred. On further investigation it can be understood that large panels are a favorable choice when the efficiency of the panels is high, while small panels are deemed to be profitable when the efficiency is low.

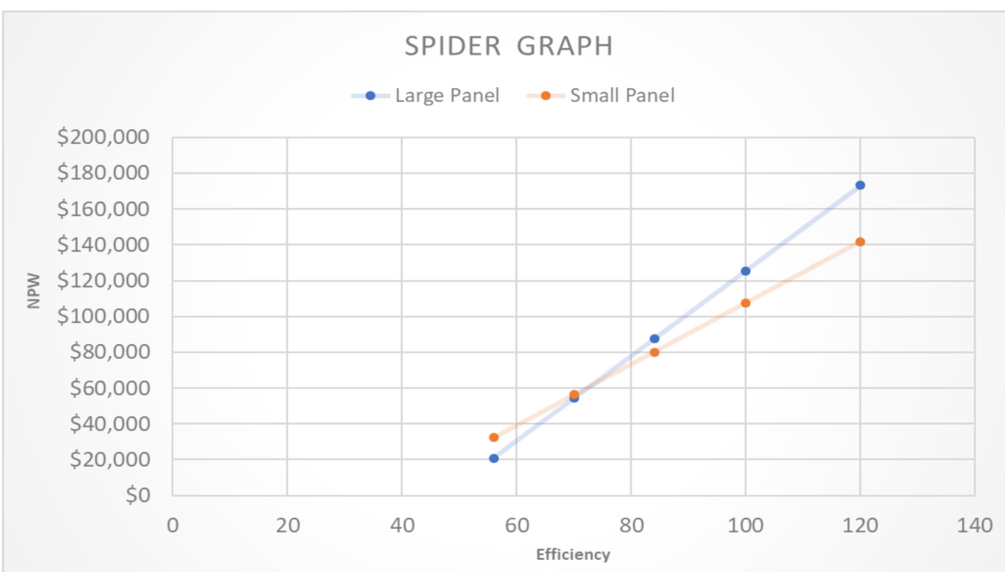
Sensitivity Analysis:

A Sensitivity analysis for SolarWall is carried out to find out the variations that can happen in the NPW with the variations in the efficiency of the panel. It has been carried for each type of SolarWall viz, Large Panel and Small Panel. The variation of ±20% for each case of High and Low efficiency.

The NPW obtained for each of the alternative is shown in the table below:

Efficiency	NPW -Large Panel	NPW – Small Panel
120	$ 173,130.50	$141,837.32
100	$ 125,577.41	$107,599.10
84	$ 87,534.93	$80,208.52
70	$ 54,247.77	$56,241.76
56	$ 20,960.61	$32,275.00

Combined graph of sensitivity is prepared and shown below:



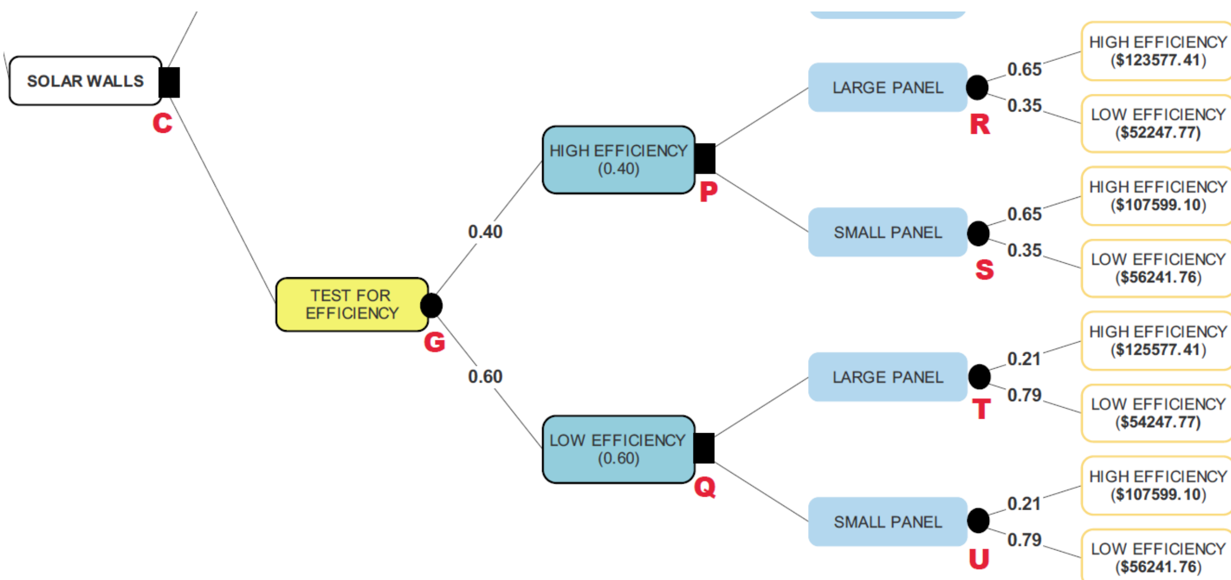
Preposterior Analysis

As the results obtained from the prior analysis are not enough to come to decision with full confidence, it was decided that a test to measure the efficiency of the SolarWall should be considered. The cost of the test is $2000. Although the test is imperfect, it considerably narrows the probability. The probability table obtained from the effectiveness of the test is shown as under:

	Actual	
Indicated	High Eff	Low Eff
High Eff	0.7	0.25
Low Eff	0.3	0.75

As it can be observed that the test indicated high efficiency correctly with 70% accuracy and it indicated low efficiency correctly by 75% accuracy. The level of uncertainty is due to the changing weather conditions, but the better probabilities are obtained because of factoring the certainty of the location.

This addition of data, results in changing to probability at the chance node after the test are performed. Figure shows the decision tree based on the test.



As shown under the change in probabilities after the test is performed:

- High Efficiency – The initial probability of high efficiency was 40%, but after the test the new probability is obtained as $\frac{0.7*0.4}{(0.7*0.4)+(0.25*06)} = 0.65$, similarly the probability of low efficiency changes to 0.35 after the test indicates high efficiency.
- Low Efficiency – The initial probability of low efficiency was 60%, but after the test the new probability is obtained as $\frac{0.75*0.6}{(0.3*0.4)+(0.75*0.6)} = 0.79$, similarly the probability of high efficiency changes to 0.21 after the test indicates low efficiency.

The calculation of Net Present Worth is carried as under:

NPW = PV (rate, years, annual savings) - (Initial Cost + Govt. Benefits + Test Cost)

The EMV obtained after test is calculated as the shown in the table as under for each of the decision cases, viz. Large Panel and Small Panel

High Eff 0.4	Large		Probability	NPW	ROR	EMV	EMV
		HE	0.65	$123,577.41	13.58%	$98,694.98	$98,694.98
		LE	0.35	$52,247.77	8.38%	11.77%	
	Small		Prob	NPW		EMV	
		HE	0.65	$107,599.10	18.31%	$89,683.75	
		LE	0.35	$56,241.76	11.85%	16.06%	16.06%
Low Eff 0.6	Large		Probability	NPW	ROR	EMV	EMV
		HE	0.21	$125,577.41	13.58%	$69,264.54	$69,264.54
		LE	0.79	$54,247.77	8.38%	9.47%	
	Small		Prob	NPW		EMV	
		HE	0.21	$107,599.10	18.31%	$67,053.83	13.21%
		LE	0.79	$56,241.76	11.85%	13.21%	

The final EMV of the test alternative is obtained as, $EMV_{(test)}$ = **$81,036** and,

the Rate of $Return_{(test)}$ = **14.35%**

Results of Preposterior Analysis:

According to the EMV the preference is obtained as

Large Panel ≻ Test Alternative ≻ Small Panel

While according to the Rate of Return the preferences are as follows,

Small Panel ≻ Test Alternative ≻ Large Panel

Value of Information (VI)

In monetary terms, the value of an experiment will be measured as,

VI = EMV(after test) – Max EMV(before test)

= \$81,036.71 – Max(\$82,779.63, \$76,784.69)

= - \$1742.91

Since the expected profit in test alternatives is less than that of the optimal alternative before the test, the test is not worthy to be performed.

2. Motion Light Sensor

According to the government of Canada motion sensor light is one of the most beneficial equipment for energy conservation. Led sensors are not expensive to set up and can be used practically anywhere in and out of the house. Motion sensor light technology is not too complicated thus it can be used by anyone. Many residence homeowners are opting for such a system.

Benefits of LED motion sensor lights compared to conventional lights are as follows:

1. Electrical Efficiency
2. No Need of Switch
3. It Act as a Deterrent
4. Led Sensors Can Be Used Anywhere
5. Motion Sensitivity

At present, there are total 10 conventional 100W lights installed at each floor in the building which runs for 24 hours resulting in more energy consumption and more cost. Our objective is to replace these lights with motion sensing lights which can sense the occupants and turn on and off accordingly. We can either use 10 numbers of 100W motion sensing lights or 20 numbers of 60W motion sensing lights. We must decide between them and find a best option which is economical. 100W lights uses 1 kwh electricity in 10 hours of continuous use whereas 60W lights can run for 16.67 hours with 1 kWh energy. Maintenance and Replacement cost for 100W conventional lights, 100W motion sensing lights and 60W conventional lights are \$250, \$1500 and \$2000 respectively for 100% occupancy.

Use of these lights is highly dependent on occupancy rate of the building. Our Building is in downtown, so it is generally occupied. Based on past data and market demand, there are 60% chance of 90-100% occupancy and 30% chance of 60-90% occupancy for the next year. Also, Electricity cost is not fixed as well. In Quebec, it mostly either increases or stays same for the next year. According to Hydro Quebec's past data, there is 40% probability of increment in electricity cost for the next year and 10% probability of decrease in cost for the next year.

To find the best economical alternative, net saving generated by each light per each year for 30 years is calculated and it is converted into net present worth to compare it with other alternatives.

Net Saving is calculated by using the following formula:

$$\textbf{Net Saving} = [C_{CONV} * P * \Delta E) + M_{CONV}] - [(C_{ML} * P * \Delta E) + M_{ML}]$$

Where, C_{CONV} = Energy consumed by conventional lights in one year

P = Price of the Electricity

ΔE = multiplication factor due to change in electricity price

M_{CONV} = Maintenance cost of the conventional lights

C_{ML} = Energy consumed by Motion Sensing lights in one year

P = Price of the electricity

ΔE = % difference in electricity price

M_{ML} = Maintenance cost of the motion sensing lights

Sample Calculations:

Assumptions in calculation are:

- Conventional lights and Motion Sensing lights require maintenance and replacement each year.
- Motion Sensing lights turns on 3 times a day per apartment and it stays on for around 2.5 minutes (150 Seconds).
- Electricity charge: $0.05/kWh
- Interest rate is 4%.
- Decision horizon for the alternative is 30 years.

- Supplier is giving 10% discount on the replacement cost of the 100W and 60W motion sensing lights.

Calculations of hours of usage and Electricity consumed in one year for 100% Occupancy

- No. of hours convention lights used in a year

= No. of floors * Lights in each floor * Hours per day * Days per year

= 14 * 10 * 24 * 365

= 1226400 hours/year

100W lights consumes 1kWh energy in 10 hours

-Energy consumed by conventional lights in one year

= 1226400 / 10

= 122640 kWh / year

-No. of hours 100W motion sensing lights used in a year

= No. of floors * Lights in each floor * No. of apartments in each floor * No. of time turned on * seconds it stays on * Days per year / 3600

= 14 * 10 * 8 * 3 * 150 * 24 * 365

= 51100 hours/year

100W lights consumes 1kWh energy in 10 hours

-Energy consumed by 100W motion sensing lights in one year

= 51100 / 10

= 5110 kWh / year

-No. of hours 60W motion sensing lights used in a year

= No. of floors * Lights in each floor * No. of apartments in each floor * No. of time turned on * seconds it stays on * Days per year / 3600

= 14 * 20 * 8 * 3 * 150 * 24 * 365

= 102200 hours/year

60W lights consumes 1kWh energy in 16.67 hours

-Energy consumed by 100W motion sensing lights in one year

= 102200 / 16.67

= 6132 kWh / year

Calculations of cost in one year for 90%-100% Occupancy and fixed electricity cost

Take 0.95 as a multiplication factor for average occupancy and 10% discount on maintenance for motion sensing lights

Cost of the Conventional lights per year

= Electricity costs + Maintenance Cost

= (122640 * $0.05) + $250

= $ 6382 / year

Cost of the 100W motion sensing lights per year

= Electricity costs + Maintenance Cost

= (5110 * $0.05 * 0.95) + ($1500 * 0.90 * 0.95)

= $ 1525.23 / year

Cost of the 60W motion sensing lights per year

= Electricity costs + Maintenance Cost

= (6132 * $0.05 * 0.95) + ($2000 * 0.90 * 0.95)

= $ 2001.27 / year

Calculations of net savings in one year for 90%-100% Occupancy and fixed electricity cost

Net Saving of 100W motion sensing lights per year

= Cost of Conventional lights – Cost of 100W motion sensing lights

= $6382 - $1525.23

= $4856.78 / year

Net Saving of 60W motion sensing lights per year

= Cost of Conventional lights – Cost of 60W motion sensing lights

= $6382 - $2001.27

= $4380.73 / year

Calculations of Net Present Worth(NPW) for 90%-100% Occupancy and fixed electricity cost

Based on the net saving and 4% interest rate, Net Present Worth (NPW) for 30 years decision period is calculated for each one. The calculation of Net Present Worth is carried as under:

NPW = PV (rate, years, annual savings)

NPW for 100W motion sensing lights for no change in electricity price = $83,983.52

NPW for 60W motion sensing lights for no change in electricity price = $75,751.73

Similarly, NPW for all the terminal nodes is calculated and shown in the figure.

Prior Analysis

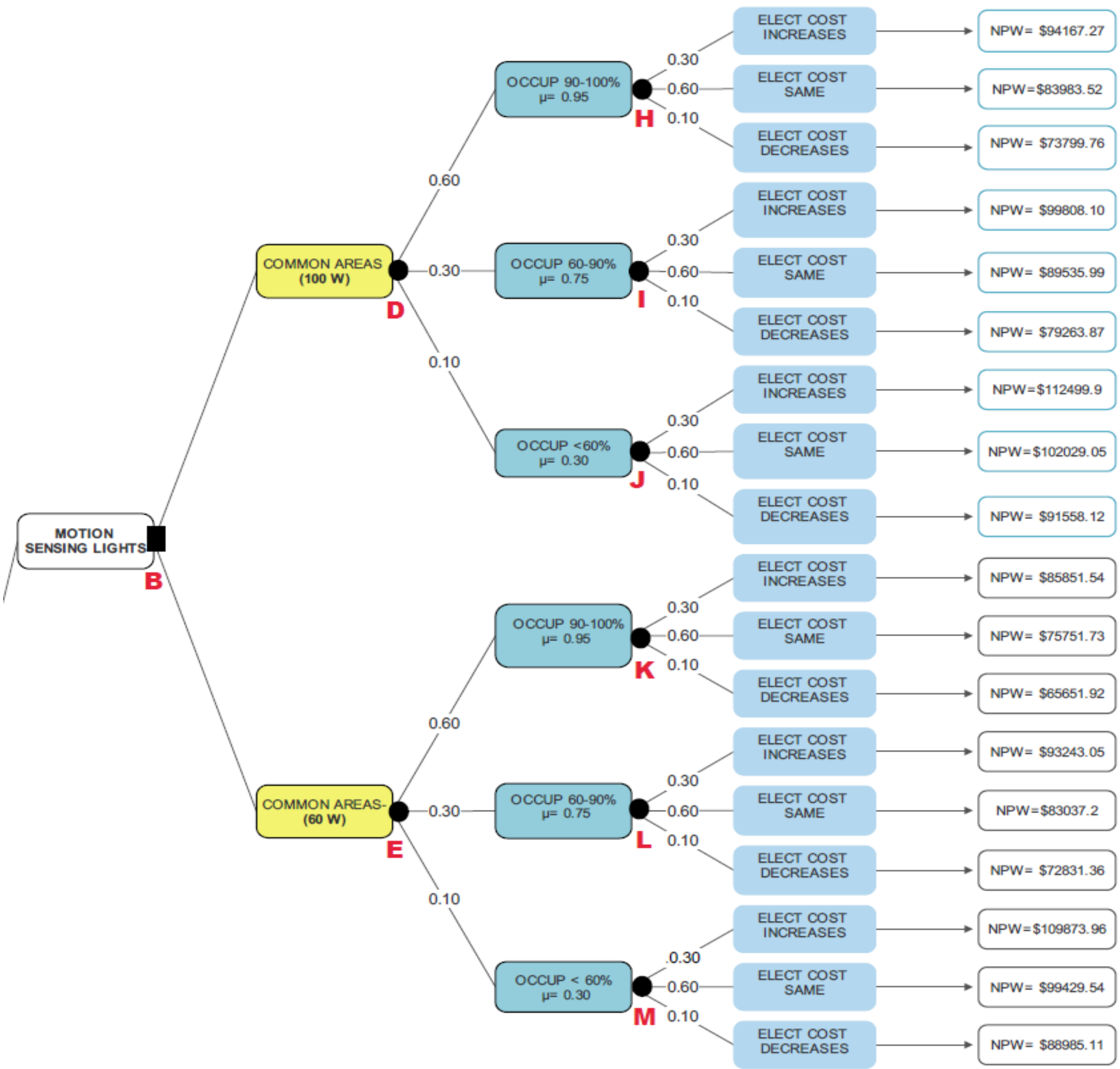
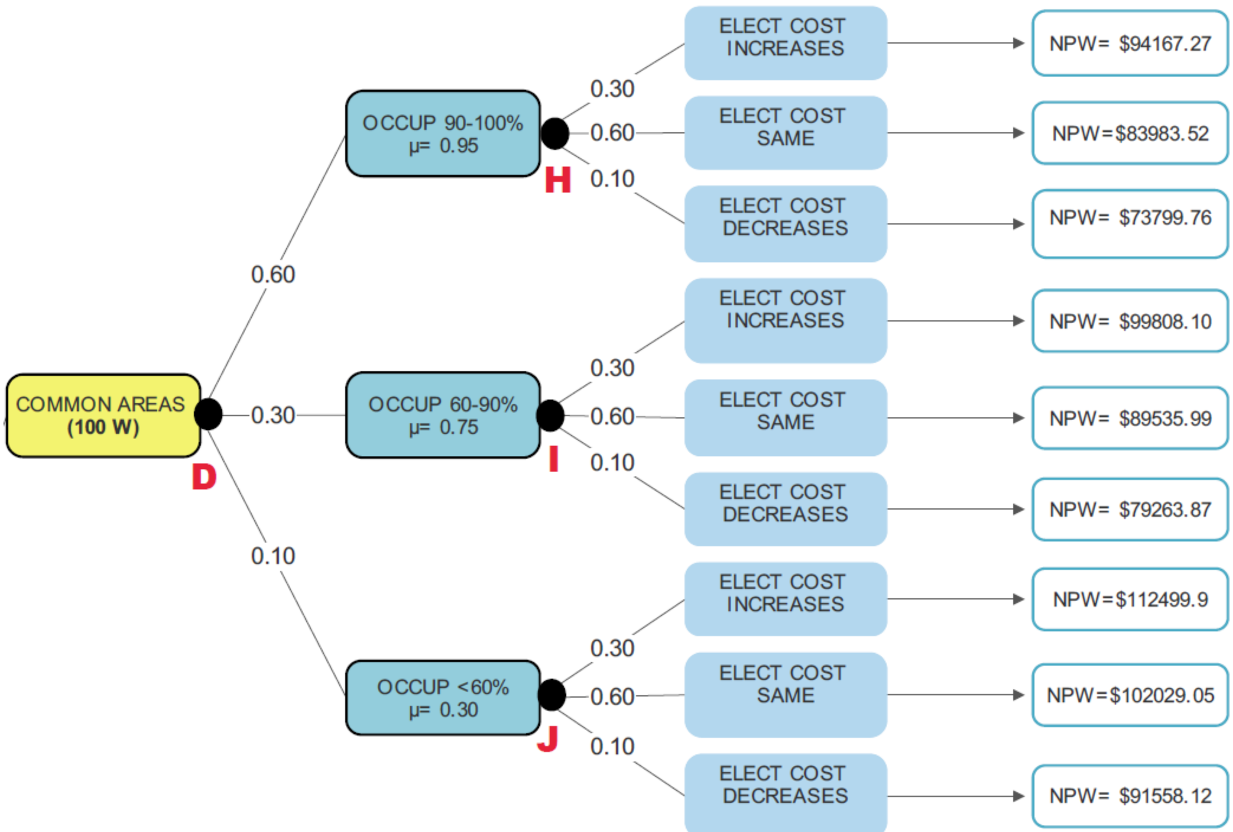


Figure shows the complete decision tree for motion sensing lights with all the associated probabilities and NPW at terminal node.

To find out the best alternative from 100W and 60W motion sensing lights depending on the occupancy rate and electricity cost, prior analysis is performed based on Expected Monetary

Value (EMV) method considering all the probabilities. Figure 1 shows the EMV of NPW for 100W motion sensing lights and figure 2 shows EMV of NPW for 60W.

For 100W motion sensing lights,



EMV at node H = 0.3 * ($94,167.27) + 0.6 * ($83,983.52) + 0.1 * ($73,799.76) = $86,020.27

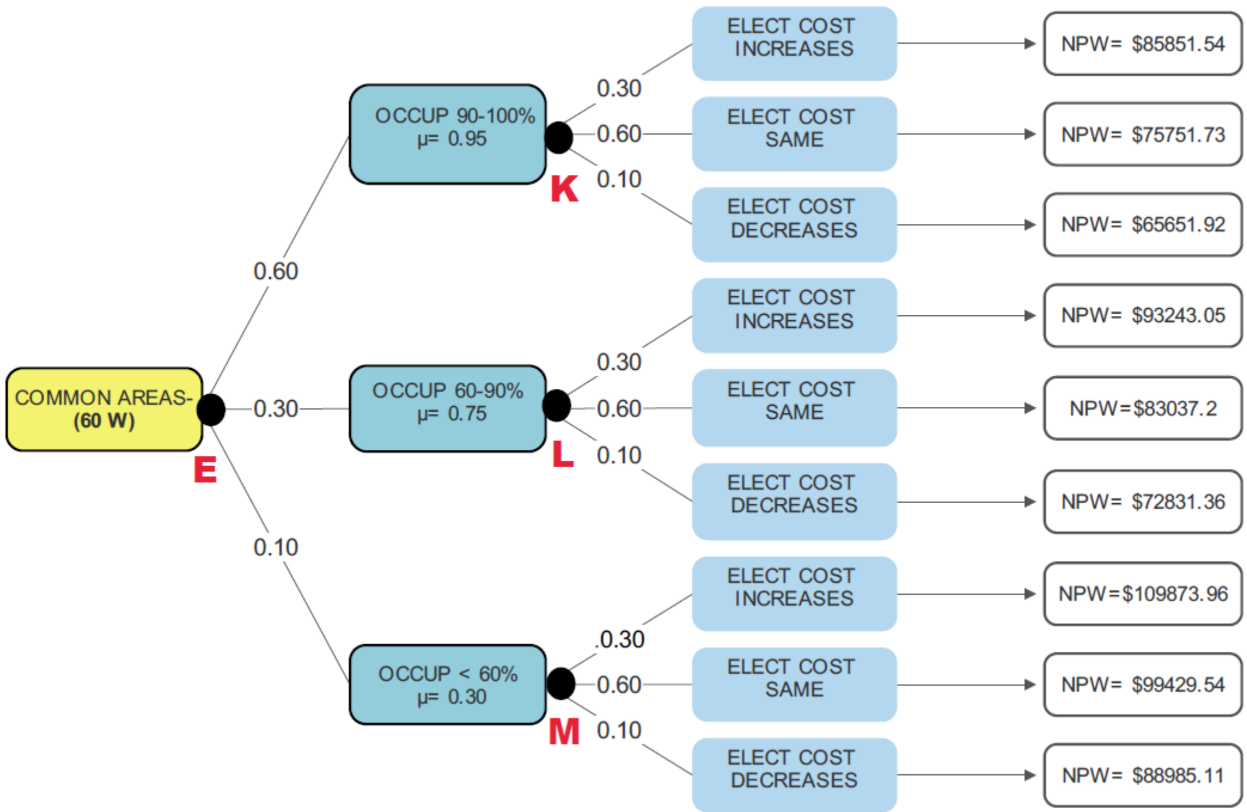
EMV at node I = 0.3 * ($99,808.10) + 0.6 * ($89,535.99) + 0.1 * ($79,263.87) = $91,590.41

EMV at node J = 0.3 * ($112,499.98) + 0.6 * ($102,029.05) + 0.1 * ($91,558.12) = $104,123.23

For 100W lights,

EMV at node D = 0.6 * ($86,020.27) + 0.3 * ($91,590.41) + 0.1 * ($104,123.23) **= $89,501.61**

For 60W motion sensing lights,



EMV at node K = 0.3 * ($85,851.54) + 0.6 * ($75,751.73) + 0.1 * ($65,651.92) = $77,771.69

EMV at node L = 0.3 * ($93,243.05) + 0.6 * ($83,037.21) + 0.1 * ($72,831.36) = $85,078.38

EMV at node M = 0.3 * ($109,873.96) + 0.6 * ($99,429.54) + 0.1 * ($88,985.11) = $101,518.42

For 60W lights

EMV at node E = 0.6 * ($77,771.69) + 0.3 * ($85,078.38) + 0.1 * ($101,518.42) **= $82,338.37**

Expected monetary value of NPW for 100W is more than 60W lights. So, we should select 100W motion sensing lights since it will be more profitable.

According to the EMV the preference is obtained as

$$100\text{W lights} \succ 60\text{W Lights}$$

5. Utility Analysis:

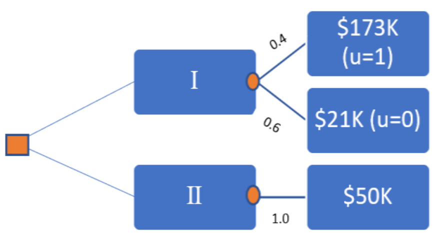
The monetary value may not always represent a true utility scale. Like, the maximum EMV criterion will not always give the proper criterion for selecting alternatives that will reflect the decision maker’s actual preference. Moreover, sometimes the results may be different for a case; and decision makers make their decisions on some other criterions. So, EVM criterion fails in some cases. However, there is a more general criterion for decision makers which is utility criterion. Therefore, we used the expected utility value of each alternative by using the following equation.

We have total four pairs of lotteries which is presented to the decision maker.

- Utility (M)
- Utility (V)
- Utility (G)
- Utility (N)

The first pair of lotteries is presented to the decision maker as follows: Utility(M)

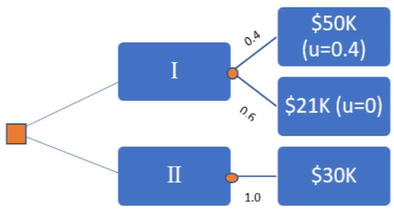
1.To establish the utility scale, the utilities of $173K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $50K for sure with II.

U($50k) =0.4*1=0.4

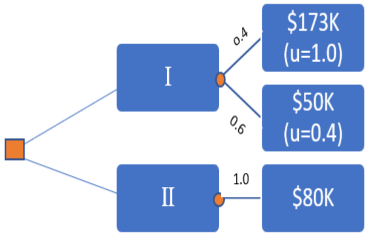
2. To establish the utility scale, the utilities of $50K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $30K for sure with II.

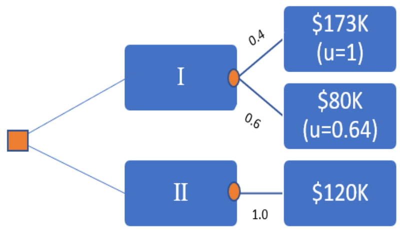
U($30k) =0.4*0.4=0.16

3. To establish the utility scale, the utilities of $50K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $50K; whereas he will get $80K for sure with II. **U($80k) =0.4*1.0+0.6*0.4=0.64**

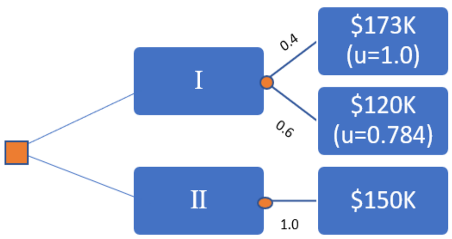
4.To establish the utility scale, the utilities of $173K and $80K are assigned arbitrarily to be 1.0 and 0.64, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $80K; whereas he will get $120K for sure with II.

U($120k) =0.4*1+0.6*0.64=0.784

5. To establish the utility scale, the utilities of $173K and $120K are assigned arbitrarily to be 0.4 and 0.6, respectively.

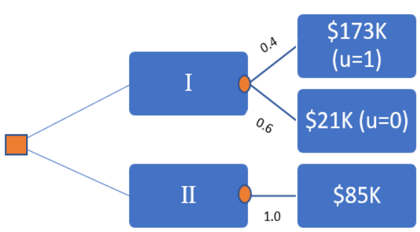


With I, the engineer stands 40-60 chance of gaining $173K and $120K; whereas he will get $150K for sure with II.

U($150k) =0.4*1+0.6*0.784=0.87

The second pair of lotteries is presented to the decision maker as follows: Utility(N)

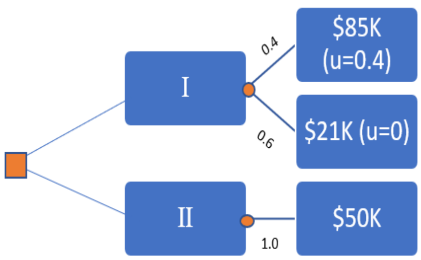
1.To establish the utility scale, the utilities of $173K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $85K for sure with II.

U($85k) =0.4*1=0.4

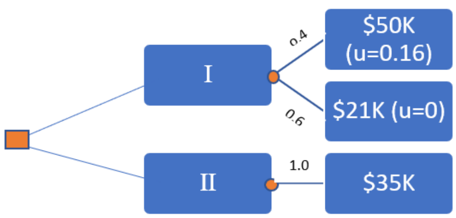
2. To establish the utility scale, the utilities of $85K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $85K and $21K; whereas he will get $50K for sure with II.

U($50k) =0.4*0.4=0.16

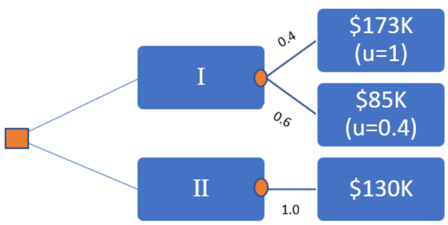
3. To establish the utility scale, the utilities of $50K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $35K for sure with II.

U($35k) =0.4*0.16+=0.064

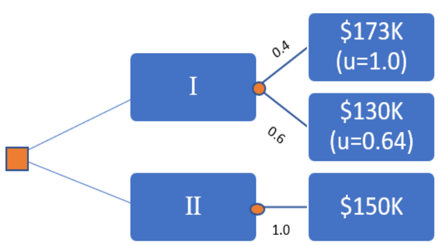
4.To establish the utility scale, the utilities of $173K and $85K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $85K; whereas he will get $130K for sure with II.

U($130k) =0.4*1+0.6*0.4=0.64

5. To establish the utility scale, the utilities of $173K and $130K are assigned arbitrarily to be 0.4 and 0.6, respectively.

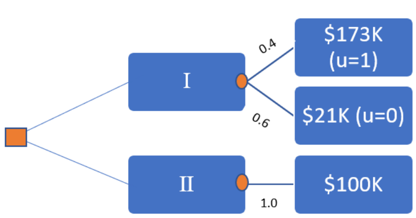


With I, the engineer stands 40-60 chance of gaining $173K and $130K; whereas he will get $150K for sure with II.

U($150k) =0.4*1.0+0.6*0.64=0.784

The third pair of lotteries is presented to the decision maker as follows: Utility(V)

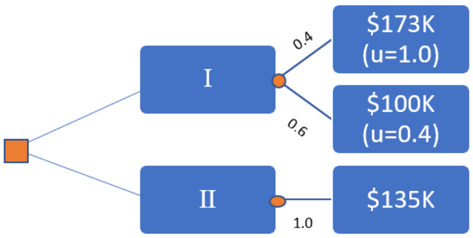
1.To establish the utility scale, the utilities of $173K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $100K for sure with II.

U($100k) =0.4*1=0.4

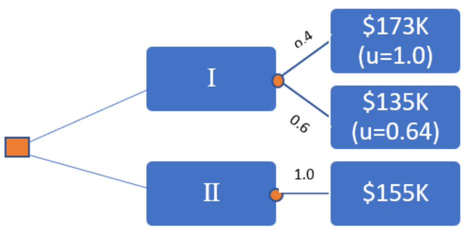
2. To establish the utility scale, the utilities of $173K and $100K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $135K for sure with II.

U($135k) =0.4*1.0+0.6*0.4=0.64

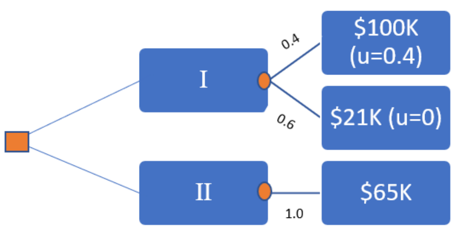
3. To establish the utility scale, the utilities of $173K and $135K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $50K; whereas he will get $155K for sure with II.

U($155k) =0.4*1.0+0.6*0.64=0.784

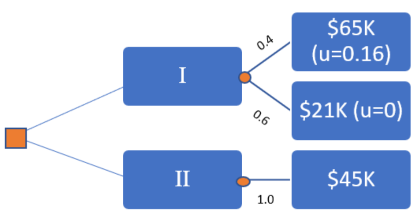
4.To establish the utility scale, the utilities of $100K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $65K for sure with II.

U($65k) =0.4*0.4=0.16

5. To establish the utility scale, the utilities of $65K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.

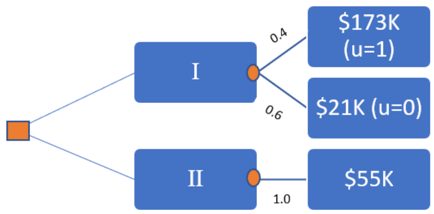


With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $45K for sure with II.

U($45k) =0.4*0.16=0.064

The fourth pair of lotteries is presented to the decision maker as follows: Utility(G)

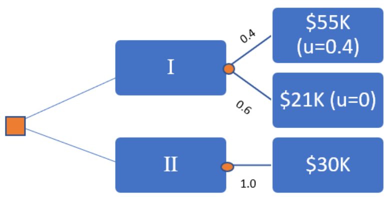
1.To establish the utility scale, the utilities of $173K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $50K for sure with II.

U($55k) =0.4*1=0.4

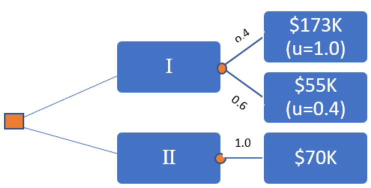
2. To establish the utility scale, the utilities of $55K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $30K for sure with II.

U($30k) =0.4*0.4=0.16

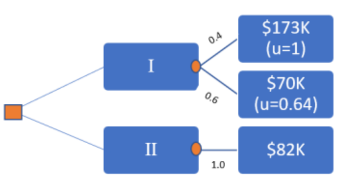
3. To establish the utility scale, the utilities of $173K and $55K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $50K; whereas he will get $70K for sure with II.

U($70k) =0.4*1.0+0.6*0.4=0.64

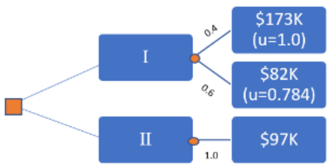
4.To establish the utility scale, the utilities of $173K and $70K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $21K; whereas he will get $82K for sure with II.

U($82k) =0.4*1+0.6*0.64=0.784

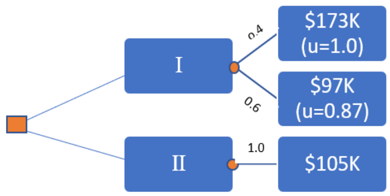
5. To establish the utility scale, the utilities of $173K and $82K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $50K and $21K; whereas he will get $97K for sure with II.

U($97k) =0.4*1.0+0.6*0.784=0.87

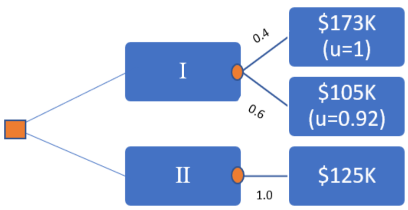
6. To establish the utility scale, the utilities of $173K and $97K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $50K; whereas he will get $105K for sure with II.

U($105k) =0.4*1.0+0.6*0.87=0.92

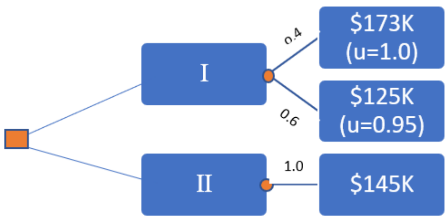
7.To establish the utility scale, the utilities of $173K and $21K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $105K; whereas he will get $125K for sure with II.

U($125k) =0.4*1+0.6*0.92=0.95

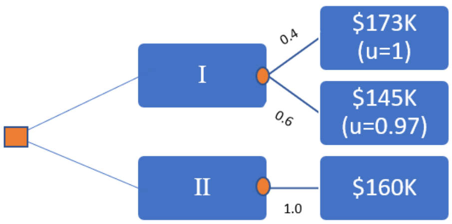
8. To establish the utility scale, the utilities of $173K and $125K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $50K; whereas he will get $145K for sure with II.

U($105k) =0.4*1.0+0.6*0.95=0.97

9.To establish the utility scale, the utilities of $173K and $145K are assigned arbitrarily to be 0.4 and 0.6, respectively.



With I, the engineer stands 40-60 chance of gaining $173K and $105K; whereas he will get $160K for sure with II.

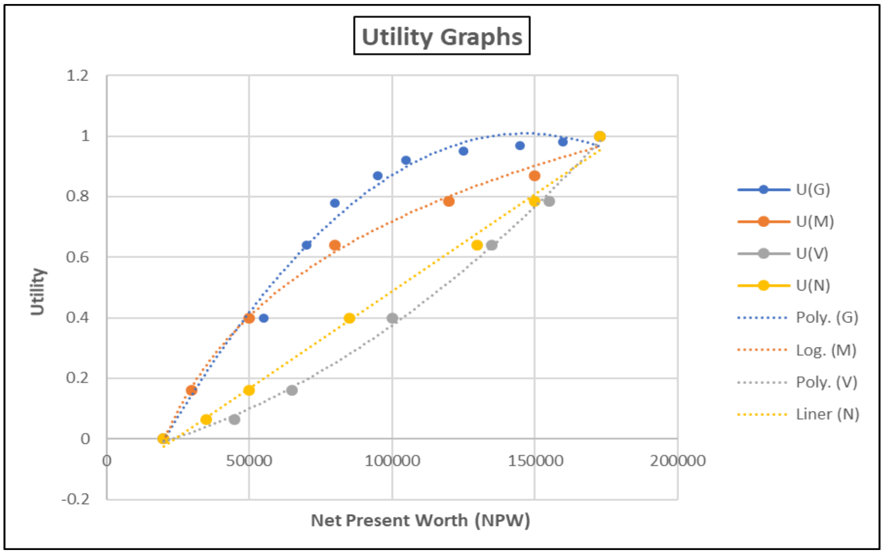
U($160k) =0.4*1+0.6*0.97=0.98

Now, the following points on the utility function for the range of monetary values from $20 to $173K have been determined.

NPW($)	**U(G)**	**U(M)**	**U(V)**	**U(N)**
173000	1	1	1	1
170000				
165000				
160000	0.98			
155000			0.784	
150000		0.87		0.784
145000	0.97			
140000				
135000			0.64	
130000				0.64
125000	0.95			
120000		0.784		
115000				
110000				
105000	0.92			
100000			0.4	
95000	0.87			
90000				
85000				0.4
80000	0.78	0.64		
75000				
70000	0.64			
65000			0.16	
60000				
55000	0.4			
50000		0.4		0.16
45000			0.064	
40000				
35000				0.064
30000	0.16	0.16		
25000				
20000	0	0	0	0
Utility Function	**$y = -6E\text{-}11x^2 + 2E\text{-}05x - 0.3478$**	**$y = 0.4527\ln(x) - 4.4933$**	**$y = 2E\text{-}11x^2 + 2E\text{-}06x - 0.0589$**	**$y = 6E\text{-}06x - 0.1513$**
R^2	$R^2 = 0.9906$	$R^2 = 0.9962$	$R^2 = 0.9977$	$R^2 = 0.9944$

Using the above points, a utility function can be fitted through the utility values.

A Utility function of money (NPW)



After acquiring all the 4 utility functions, we decided to use 'y = 6E-06x -0.1513' associated with Utility(N) since it was obtained solely based on preference and it showed neutral behaviour. We used this function in our decision tree, found the utilities associated with all the NPW at each terminal nodes and performed prior analysis based on utility values. Figure shows the utilities at each node for SolarWall.

Alternatives		Utility Values	EUM		Final EUM
Direct Installation	Large Panel	0.60	0.35		**0.35**
		0.17			
	Small Panel	0.49	0.31		
		0.19			
Test Alternative					
High Efficiency	Large Panel	0.59	0.44	0.44	**0.33**
		0.16			
	Small Panel	0.49	0.39		
		0.19			
Low Efficiency	Large Panel	0.60	0.26	0.26	
		0.17			
	Small Panel	0.49	0.25		
		0.19			

We used Expected Utility Values (EUV) method to find the best alternative having the highest utility.

According to the EUV for SolarWall the preference is obtained as

Large Panel (Direct Installation) $\succ$ Test Alternative

Similarly, we performed prior analysis for Motion Sensing Lights based on EUV. Figure shows the utility at each node and EUV for motion sensing lights.

Alternatives			Utility	EUV	Final EUM
100W Lights	Occupancy 90-100%	Cost Same	0.35	0.36	**0.39**
		Cost Inc	0.41		
		Cost dec	0.29		
	Occupancy 60-90%	Cost Same	0.39	0.40	
		Cost Inc	0.45		
		Cost dec	0.32		
	Occupancy 0-60%	Cost Same	0.46	0.47	
		Cost Inc	0.52		
		Cost dec	0.40		
60W Lights	Occupancy 90-100%	Cost Same	0.30	0.32	**0.34**
		Cost Inc	0.36		
		Cost dec	0.24		
	Occupancy 60-90%	Cost Same	0.35	0.36	
		Cost Inc	0.41		
		Cost dec	0.29		
	Occupancy 0-60%	Cost Same	0.45	0.46	
		Cost Inc	0.51		
		Cost dec	0.38		

According to the EUV for Motion Sensing Lights the preference is obtained as

100W Motion Sensing Lights $\succ$ 60W Motion Sensing Lights

Overall, 100W Motion Sensing Lights has more utility compared to Direct Installation of Large SolarWall. Final utility preference can be obtained as follows:

100W Motion Sensing Lights $\succ$ Large Panel (Direct Installation)

6. Multiple Objective Analysis

Multi Utility is used to consider various factors that cannot be directly quantified. Factors such as conveniences, etc. cannot have an absolute value, but can have a comparative relative value. Hence, to consider these factors into decision making process, Multi-Objective method is used where relative weightage to each of the factors are obtained from expert advices and requirements from the owner. Considering the conditions of the project, four objectives are decided to be considered as follows:

- Net Present Worth (NPW) - A
- Rate of Return - B
- Convenience to Tenants - C
- Chance of Successful Implementation - D

To provide the weightage to each of the parameters, NPW is taken as a reference parameter and considered to have a weightage of 100 as it is the most important a highest preferred alternative.

Furthermore, the preference of other parameters is as under:

$$A \succ B \succ C \succ D$$

The weights to each of the parameters are given as under:

Object	A	B	C	D
Weights	100	75	30	60

According to the results obtained for NPW and ROR their probabilities are noted in the table below, such as probability of 100W motion sensing light is given as 1.0 as it has the highest NPW among all the alternatives, accordingly probabilities of others are given, which are subjective to the person analysing the decision criteria.

The probabilities for convenience to tenants is considered maximum for 60W bulbs as small lights which are well distributed as favorable, while 100W bulbs which are big lights at small number of points are comparatively less favorable among the people. While the convenience factor for SolarWall is less favorable it is installed on one of the facades of the building, also larger the panel less convenient it is.

While considering the probabilities of successful implementation, it was deduced that the SolarWall being a complicated project will attract more potential problems and it is directly related to the size of the installation i.e. larger the panel more the chances of failure and less the chances of success, hence smaller the probability of successful implementation. In case of the bulb, the 100W bulbs will have half the number of bulb holders as that of 60W bulb, hence it has more chances of successful implementation. The probabilities given here are best approximation from the available data and logical conclusions.

The table below shows the probabilities for the Multi-Objective parameters as discussed above:

	Weight	100	75	60	30
	Object	A	B	C	D
Alternative	Large Solar	0.9	0.8	0.2	0.2
	Small Solar	0.8	1.0	0.35	0.4
	100 W	1.0	0.3	0.75	0.9
	60 W	0.9	0.3	0.9	0.8

The results are obtained using the Multi-Objective equations where the probabilities of each parameters are multiplied with their weights for a given alternative. The results are obtained as under:

Alternative	Overall Relative Utility
Large Solar	164.25
Small Solar	188
100 W	194.5
60 W	190.5

The maximum utility according to the devised condition is obtained from the 100W bulb. Hence, the alternative suggested by the decision analysis of the given scenario points that Motion Sensing Lights should be chosen over SolarWall and within the options available for Motion Sensing Lights, 100W bulbs should be chosen according to the Multiple Objective method.

7. Conclusion:

The prior analysis of the SolarWall alternative shows that the option to install large panels instead of small panels when compared using Net Present Worth, while when additional information using the test is obtained the cost of test cannot be justified and hence still the large panel is considered favorable.

While the independent analysis for the two alternatives of Motion Sensing Light shows that the NPW of 100W option yields higher NPW.

Furthermore, when comparing all the alternatives together, Motion Sensing Light of 100W has higher NPW then the best alternative of SolarWall. Thus, according the Expected Monetary Value (EMV) the criteria of 100W is most preferred.

The preference for NPW has been obtained using the Utility theory. Four Utility curves have been obtained simulating the various possible attitude of the owner. Among them, one function was used to find the utilities associated with all the alternatives to perform the prior analysis based on Expected Utility Values (EUV). Motion Sensing Light of 100W has higher EUV then the best alternative of SolarWall. So, according the Expected Utility Value (EUV) the criteria of 100W is most preferred.

Finally, Multiple objective analysis has been carried to consider the other not easily quantifiable parameters that can govern the final decision. According to the results obtained from Multiple objective analysis, the alternative of 100W motion sensing light must be preferred over all the other alternatives.