OPTIMAL INVESTMENT STRATEGY FOR ENERGY PERFORMANCE IMPROVEMENTS IN EXISTING BUILDINGS

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OPTIMAL INVESTMENT STRATEGY FOR ENERGY PERFORMANCE IMPROVEMENTS IN EXISTING BUILDINGS

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LIST OF SYMBOLS

μ	Mean
σ^2	Variance
max	Maximizing function
Δ	Change in value (delta)
MJ	Mega Joule
i	Technology
j	Building
r	Minimum attractive rate of return
$\sum$	Summation
M_{gas}	Gas proportion of energy source mix
M_{elec}	Electricity proportion of energy source mix
c	Energy consumer

LIST OF ABBREVIATIONS

ASP	Active Server Pages
BTU	British Thermal Units
DM	Decision Maker
EIA	Energy Information Administration
EPC	Energy Performance Coefficient
ESF	Energy Saving function
FM	Facility Manager
GSA	General Service Administration
GUI	Graphic User Interface
HVAC	Heating Ventilation and Air Conditioning
LSG	Light to solar gain coefficient
IRF	Investment Return Function
MPI	Modified Performance Indicator
NPV	Net Present Value
PIs	Performance Indicators
RCx	Retro- Commissioning
SHGC	Solar heat gain coefficient
UI	User Interface

SUMMARY

Globally, it has been found that buildings contribute significantly to energy consumption, as well as to other environmental impacts such as greenhouse gas emissions and solid waste generation (Scheuer, et al. 2003, Craighill and Powell 1995). It has been estimated that building operations are responsible for 38% of which 21% is in residential and 17% is in commercial sectors of the total energy consumption, (Energy Information Administration 2007) and 45% (including 17% commercial and 28% industrial buildings) of all greenhouse gas emissions annually in the United States (USEPA 2007).

Current global efforts for energy conservation and optimization are focused on improvements in energy supply and production systems, and on encouraging the adoption of energy-efficient devices and equipment. However, systematic assessments of economic and technical implications when adopting energy-efficient alternative systems in buildings have not yet been explored thoroughly. The uncertainty about the consequences of investing in alternative energy-efficient systems has led to a prolonged utilization of obsolete building systems (underperforming HVAC systems, inefficient lighting systems, badly maintained and equipment, and so forth). This has led to overall poor energy efficiency, creating considerable burden on the building operation budget.

This research discusses the procedure for formulating an investment strategy to improve existing building energy performance. The approach is suitable for large building portfolios where a plethora of potential refurbishment interventions can be

considered. This makes our approach especially suited for use on university campuses and most of this report will focus on that particular application utilization protocols especially for use on campuses. The calculation of performance improvements is based on normatively defined energy Performance Indicators (PIs). The approach determines the best investment option from a set of available energy efficient systems and expected long range energy costs. PIs are calculated for every building on campus and used to benchmark the buildings and indicate poorly performing ones. All facilities are screened for potential improvement with one of the selected energy performance improvement methods, henceforth referred to as retro-commissioning interventions and retro-commissioning technologies

The investment strategy is based on getting the highest return for a fixed investment sum. Underperforming facilities may yield the highest return if their energy systems can be dramatically improved with relatively inexpensive technologies. In addition to highest return, the investment strategy can be modulated to obtain maximum energy saving portfolio for the given investment; this approach caters to tangible environmental appraisal of facilities. Our approach only looks at the energy related savings versus investments; it is well understood that the ultimate selection of the optimal set of improvement options of a portfolio will be determined by additional considerations, such as overall value, occupant satisfaction, productivity improvements, aesthetics, etc. Nevertheless, many campus managers are confronted with the question how much energy they can save with a given investment amount. This is exactly what our approach helps to answer. The investment optimization strategy is implemented in software that systematically calculates the costs and benefits of all possible building-technology pairings, taking uncertainties in the saving/investment calculations and estimates into account. All calculations take uncertainty into account and calculations produce Mean-Variance values. All the pairings are then subjected to portfolio optimization using the principle of mixed integer programming. Investment risk is controlled through Mean-variance paradigm. Wherein, the basic assumption is that the decision criteria should be to minimize the variance for a given mean value of return or to maximize return for the given value of variance i.e., the decision maker would like to increase the probability of mean occurrence by controlling its variability. Under the given financial constraint and time period, the tool generates an optimal investment portfolio based on user selected investment options, and allows the decision maker to specify risk tolerance. The tool empowers decision makers in facility management to make complex investment decisions during continuous building commissioning.

CHAPTER 1

INTRODUCTION

Facility management deals with managing buildings and maintaining them to the required operational level. As defined by the International Facility Management Association "Facility management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology" (IFMA 2007). It not only requires facility managers to meet the operational requirements for the business activity, but also the maintenance of the building fabric(building's roof, floor slabs, walls, windows, and doors) in terms of its redecoration and repair both internally and externally (Balch 1994).

After the facility has been handed over to the owner or occupants, throughout its economic life, facility managers (FM) have to maintain the building's operational level to its peak performance. In that effort, FMs might encounter a series of refurbishment programs which can be have major disruptions that can be detrimental to positive cash flows (Hutcheson 1994). Adding to this challenging task, FMs of large campuses, and portfolio managers (investment professionals dealing with asset management) would face critical risk and uncertainties in the coming years. They have to make investments in energy retrofits of existing buildings and advocate novel energy saving technologies in new buildings, but have no actionable information and no decision tools to do this responsibly. As Finch states, "there are 3 factors that bring about the existence of risk: lack of control; lack of information and lack of time" (Finch 1992). FM is unlikely to have the luxury of favorable situations like having complete project information, control or unlimited time. Risk behavior should seek to gain time, gain information, or gain control, so that the risk is at least reduced.

Campuses have traditionally under-invested in the sub-metering of individual buildings and have in general not paid enough attention to collecting up to date information about their existing buildings other than basic monitoring. However, there are intelligent utilities management systems like Central Building Utilities Metering System (CBUMS) installed at Yale University, which provide real-time monitoring, alarm reporting, on-line diagnostics, and report generation for billing, energy management, and engineering relevant to the utilities systems (Viktor 2000). Yet, campuses face enormous challenges:

- An increasing public pressure to improve their energy performance; the "Greening the campus" initiative is just one of the high profile initiatives in the public sector, promoted by U.S. Environmental Protection Agency (Shriberg 2002).
- Facility managers would face energy price shocks in the near and long term for which they are ill prepared. Utility contract renegotiation will increase as electricity, gas and oil are going to increase (Energy Information Administration 2007).
- Campuses allocate budget line items to their large plants without being able to judge them in relation to investments in retrofits or innovative systems in new buildings.

Facility managers would require a continuous monitoring tool to determine energy retrofits required by each building in the campus. As each one of them undergoes constant changes like internal reorganizations, refurbishments, change of tenants, and even natural degradation of building systems. An energy performance assessment tool developed by Augenbroe and Park (2005) for GSA, henceforth named as GSA Toolkit, allows for fast and efficient assessment of the energy use of a building, and all its separate energy consumers: heating, cooling, lighting, pump/fans, hot water, humidification, and appliances plug load.

In GSA toolkit, quantifiable measures are implemented as a set of uniquely defined “performance indicators” that provide cost-effective, quantitative assessments of how well buildings perform. The tool is already being used large scale by GSA, and on the University of Pennsylvania campus, where 160 buildings are assessed with the tool to develop an energy cost allocation model. This research proposes an investment decision making instrument based on the GSA toolkit that would help facility managers meet their challenges.

1.1 Research Significance

Facility managers face critical uncertainties while making decisions for campus refurbishments. They will have to make investments in energy retrofits of existing buildings and advocate novel energy saving technologies in new buildings, but have no actionable information and no decision tools to do this responsibly in the light of uncertain investment costs, possible energy savings and utility prices. Therefore facility managers or portfolio managers will benefit from the answers to the following question posed in this research: Can we come up with an investment strategy which helps in allotting funds to the poorly performing buildings and at the same time helps in forecasting the possible benefits of allotted investment under uncertainty? This question and other related issues led to the following hypothesis

"*A decision making model is needed by the facility managers to deal with investments focused on campus energy retrofits*"

In this research, we basically provide the benefits of investments in terms of "Investment Return" and "Energy Savings". Investment return is the monetary value that will be saved in the operations, when a particular technology is deployed in the campus building. Energy Saving is the total energy saved (in Mega Joules) by the modifying technology. This value can be considered as a measure of "Greenness", which is more significant from a pure energy saving perspective than credits provided by any green building rating system. As it is not possible to let the system (automatically) select the best retro commissioning technology for a building, our approach assumes that a human expert chooses appropriate technology or combination of technologies to be modified in the selected campus building.

1.2 Research Objective

The research objective of this thesis is to define a decision making model that would assist facility managers in forming an investment strategy to improve building performance, with an expected investment return, or an energy savings requirement. The investment strategy would integrate the risk of fluctuating energy prices, uncertain investment costs of possible technology improvements and resulting building performance.

1.3 Scope of Work

The scope of this research thesis is restricted to formulate a decision making model based on the investment strategy, and to develop a platform independent, Graphic User Interface (GUI) software for decision makers, to avail the benefits of this model. Validation of this α- software version does not fall under the scope.

1.4 Limitations

Limitations of this research thesis are listed below, whereas application software related issues would be explained in more detail under the "Issues and workaround section". Most of these limitations form the basis of future scope of work.

- Every candidate retro-commissioning technology for a given building has to be tested for change in building performance through GSA toolkit. But these technologies should have some input parameters which are linked to GSA toolkit. For example, glazing system for a building can be tested for its benefit through toolkit if we have its characteristic U-value and SHGC (solar heat gain coefficient); although a similar glazing system which has higher LSG (Light to solar gain) coefficient would be indifferent to the GSA toolkit, as LSG is not an input parameter.

- Electricity and gas are considered to be the only source of energy to the campus. Building systems can be categorized under “Electricity” or “Gas” or “both” in each building, for determining energy usage. However, for the whole campus it would be impossible to differentiate. As a result, the energy source mix (proportion of electricity and gas) would be determined as an average value throughout the campus, irrespective of individual building usage.
- Investment return and energy savings are not the only two criteria that the decision makers (DM) consider prior to investing in a campus. It should be noted that this is deliberate limitation, as our approach is meant to help inform the overall decision making process from the energy saving perspective. Many other perspectives need to be considered to fully inform the decision making process
- It is assumed that no additional cost will be incurred in the maintenance contract of the buildings, by the proposed retro-commissioning technology.
- The underlying GSA toolkit calculates every technology option as if it were the only technology applied in the selected building. If the investment portfolio contains two or more technologies that are applied in the same building, this manner of calculation does not obey the “Law of diminishing investment returns”. The reason is that the combined benefit two technologies A and B for a given building, is not equal to the separate independent benefits of A and B. This limitation forces the DM to inspect this potential overestimation of benefits in the optimal investment portfolio

- The DM has to rely on previous experience or external experts to come up with the initial cost estimate of implementing a retro-commissioning technology in a building; such cost estimates are very market and situation dependent and can only be relied on if quotes from companies have been received; our approach is meant to be used as a pre-stage to RFQ which means that experts have to make rough cost estimates, often leading to considerable uncertainty in the estimate. This uncertainty is an input value into the tool, based on self assessed uncertainty by the costing expert
- Accuracy and practical applicability of the software generated results is unknown, as validation of software is not considered in the scope of work.
- The software is incapable of distinguishing between mutually exclusive investment-alternatives, i.e. ones wherein the same building has been modified with two or more competing technologies. The decision maker has to carefully inspect options, to prevent the presence of these alternatives in the same portfolio.

1.5 Structure of this thesis

In this research thesis, the “Literature review” chapter looks into the issues of energy, GSA toolkit, utility function, mean variance paradigm, and portfolio optimization. The basic working strategy of the thesis is explained in detail under the “Methodology” chapter. The “Strategic investment model” chapter explains the fundamentals of the model in schematics. The functioning and mechanism of the software, dubbed “InvEnergy” is explained under the “Prototype development” chapter. Conclusions and further scope are listed in the final chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Energy Scenario in U.S

According to United States government, the world demand for all forms of energy is expected to grow by 54 % over the next two decades (Reuters 2007).The United States is the world's largest energy consumer of energy , estimated as using 100 quadrillion BTU in 2005, and also ranks 7th in energy consumption per-capita (EarthTrends 2007). In 2005, it was estimated that 40 % of the nation's energy came from petroleum, 23% from coal, and 23% from natural gas while the remaining 14% was supplied by nuclear power, hydroelectric dams, and miscellaneous renewable energy sources (Energy Information Administration 2007). Of the four major energy consumer sectors in U.S. i.e., industrial, transportation, residential and commercial, it has been recorded in 2004 that the residential and commercial sectors account for 21% and 17% respectively of the total energy usage (Energy Information Administration 2007).

As shown in Table 2.1, space heating, cooling, lighting and water heating constitute the major consumers both in residential and commercial sectors.

Table 2.1: Break up of energy consumers in residential and commercial sectors
(Source: Department of Energy 2006)

Residential Sector	Commercial Sector
30.7 % space heating	25.5 % lighting
12.3 % space cooling	14.2 % space heating
12.2 % water heating	13.1 % space cooling
11 % lighting	6.8 % water heating
7.5 % refrigeration	6 % ventilation
7.4 % electronics	6.3 % electronics
4.8 % wet-clean	4.1 % refrigeration
4.5 % cooking	3.2 % computers
9.6 % Others	20.8 % Others

In Table 2.1, the category "Others" includes service station equipment, ATM's telecommunications equipment, medical equipment, pumps, emergency generators, combined heat and power in commercial buildings, and also energy adjustments done by the Energy Information Administration (EIA) to relieve discrepancies between the data sources.

The commercial energy use per capita is projected to continue rising as per EIA's annual energy outlook. In the commercial sector, the consumption has increased by 8% from 1980 to 2005. Due to the shift of economy to service sector, and to energy price changes, the commercial usage is projected to increase by a total of 19% from 2005 to 2030 (Energy Information Administration 2007).

2.2 Energy Saving Potential in Facilities

Energy conservation and optimization efforts are focused on improvements in the energy production and supply systems. Figure 2.1 illustrates this fact of improvements in the energy supply side. But on the consumer end, energy-efficient alternative systems in buildings have not yet been explored thoroughly; as a result buildings still utilize redundant ones.

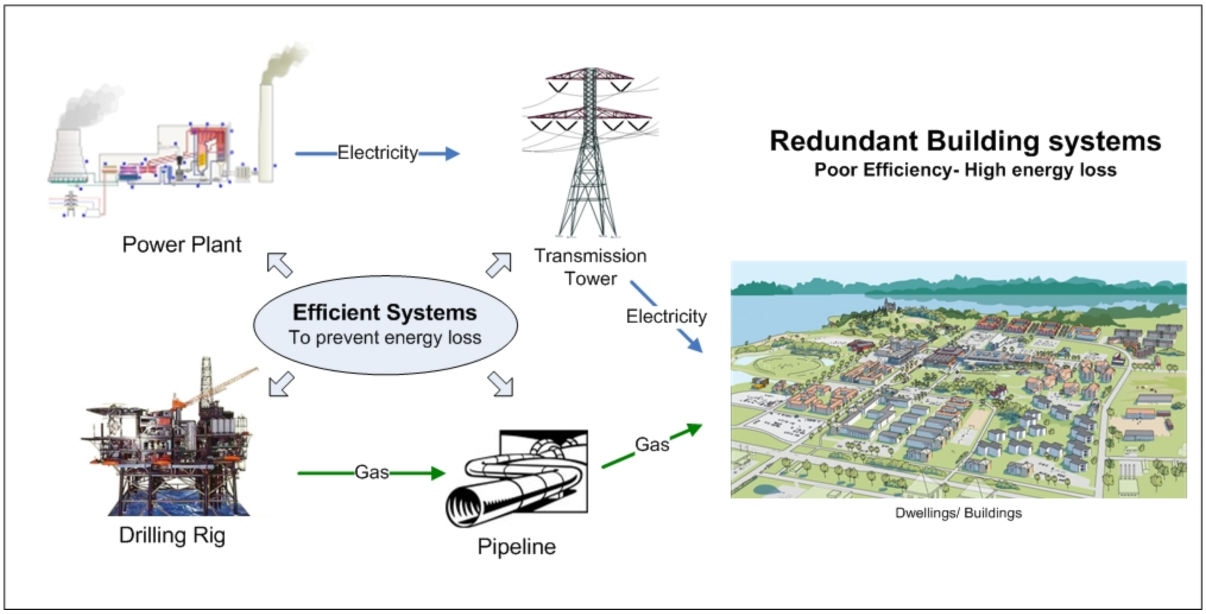

Figure 2.1: Redundant Building systems

Several technologies like the combined cycle plant arrangement or the heat recovery steam generator in the thermal power plant, have been introduced and successfully implemented to improve the efficiency in energy production (Shanmugam and Kulsheretra 2005). Even transmission systems have been researched on to reduce losses while supplying energy. According to the Energy Efficiency and Renewable energy - Energy Savers Guide (U.S. Department of Energy), using compact florescent lamps instead of incandescent lamps would reduce the lighting energy by 50-75%(Lin 2007). Advances in lighting controls like occupancy sensors, dimming controls can further reduce the energy consumption. Buildings constitute the major consumers of energy accounting to 38% of the total energy use (Energy Information Administration 2007). Redundant systems in buildings, not only increase the operating costs to the occupants, but it also downgrades all efforts carried on the supply side to improve energy efficiency and utilization.

2.3 Retro Commissioning

Redundant systems could hinder optimal operations of buildings and may lead to excessive energy use, high maintenance requirement, etc. In a study of 60 commercial buildings, Lawrence Berkeley national laboratory found that more than half of buildings suffered form control problems, 40% had HVAC equipment problem, 30% had problems with the sensors, 25% had problems with the Energy Management System (EMS), economizers and variable speed drives, and the remaining 5 % had equipments missing (Piette 1996) . Redundant systems can be systematically optimized so that they operate in an effective and efficient manner through a process called as Retro-commissioning (RCx) (Haasl and Sharp 1999).

RCx is applied to existing buildings to restore them to optimal performance. As stated by Evan Mills, et al. “RCx provides a third-party assessment of project quality, helping to ensure a safe, healthy, and high-performance (low-operating-cost) environment, and it also serves as a risk-management strategy to ensure that programmatic goals (e.g., anticipated energy savings) are attained" (Mills et al. 2004).

In another case study carried out from 1995 to 2003 for a large office building in Colorado, the original RCx project resulted in verified savings of 14 % in electrical demand, 25% in electrical use, and 74% in gas use (Selch and Bradford 2005). Field results have shown that proper RCx can yield cost-effective savings between 5 and 20 % with a typical payback of 2 years or less (Thorne and Nadel 2003). While RCx is not a panacea, it can play a major and strategically important role in achieving national energy savings goals, with a cost-effective savings potential of $18 billion per year or more in commercial buildings each year across the United States (Mills, Friedman et al. 2004). However, improvement opportunities in the building are unknown, until the buildings are put through the RCx process (Haasl and Sharp 1999). Even with the established fact of RCx benefit, it frequently faces a major barrier when decision makers are uncertain about its cost-effectiveness(Mills et al. 2004).

2.4 Measuring Building Performance

Performance can be defined as a parameter that quantifies the efficiency and effectiveness of an action. Building performance relates specifically to design performance in relation to the occupants and owners of the building (McDougall et al. 2002).

With the surge in environmental performance and sustainability measuring tools, there has been a new emerging issue of continuous improvement in buildings, which is to analyze performance on a systematic basis (McDougall et al. 2002). There is a need for continuous monitoring of the technical performance of buildings over the lifetime as that building undergoes drastic changes including natural degradation of technical systems (Augenbroe and Park 2005). To compare performance over time and between buildings, one needs objectively quantifiable measures. In the GSA toolkit developed by Augenbroe and Park (2005), quantifiable measures are implemented as a set of uniquely defined “performance indicators” that provide cost-effective, quantitative assessments of how well buildings perform.

2.5 GSA Toolkit

GSA toolkit is a building performance assessment tool developed for use by large corporate owners and portfolio managers in the U.S. This tool provides Performance Indicators (PIs), that are quantifiable measures for energy, lighting, thermal comfort and maintenance. Normative calculations based on the Dutch NEN 2916(1999), are performed to reflect the building in its current state, environment and its actual usage situation (Augenbroe and Park 2005). For energy consumption, eight major consumers are calculated, namely heating, cooling, humidifying, lighting, pumps, fan, domestic hot water, and equipment plug load. Figure 2.2 shows the main webpage of GSA toolkit.

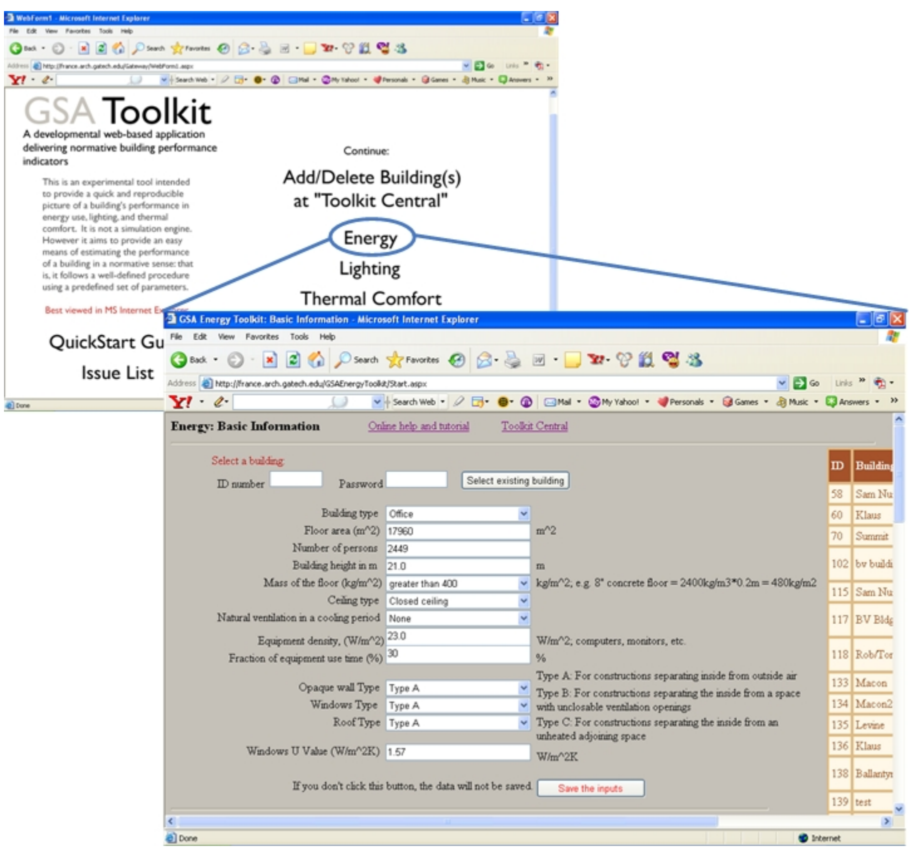

Figure 2.2: GSA Toolkit webpage

As shown in Figure 2.2, the toolkit was programmed into an MS.NET ASP web application with pre-stored reference climate data for 252 cities in the U.S. It can be assessed on "http://france.arch.gatech.edu/Gateway/WebForm1.aspx". This website enables toolkit's rapid deployment and integration in the owner's asset management processes (Augenbroe and Park 2005). Figure 2.3 explains the structure of the toolkit website, and its components.

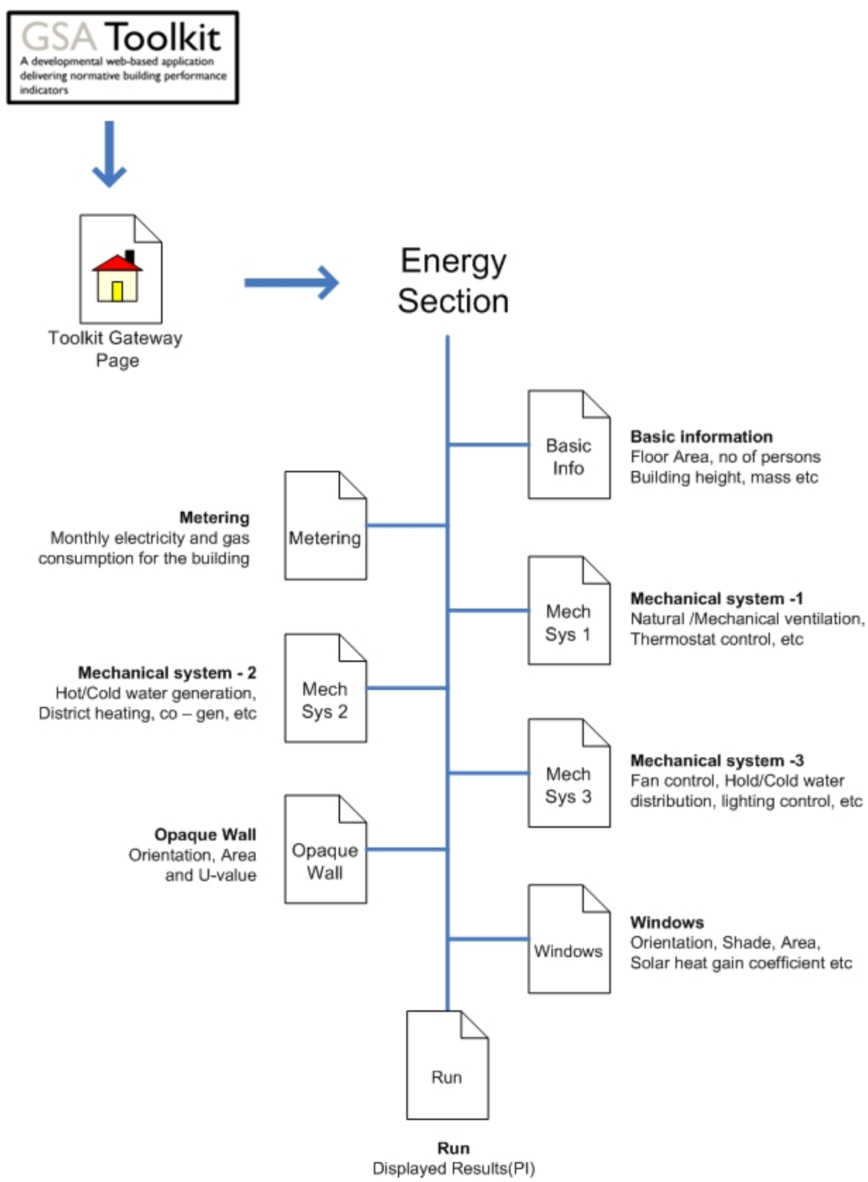

Figure 2.3: GSA toolkit webpage structure

As shown in Figure 2.3, the web-structure of energy aspect in the GSA toolkit is a collection of eight active server pages. To utilize this tool, the user would first have to feed in basic building information in the "Building Information" page. The "Metering" page requires user to fill in monthly energy consumption for the building, though not mandatory for the toolkit to calculate energy performance coefficient. In each page "Mech-1", "Mech-2", "Mech-3", "Opaque walls" and "Windows", the user records existing building systems data through interactive form fields; there is no linear pattern which is to be followed while recording data in these pages. After all building data is been recorded, the user can determine building performance in "Run" page. Figure 2.4 shows the result generated by the GSA toolkit.

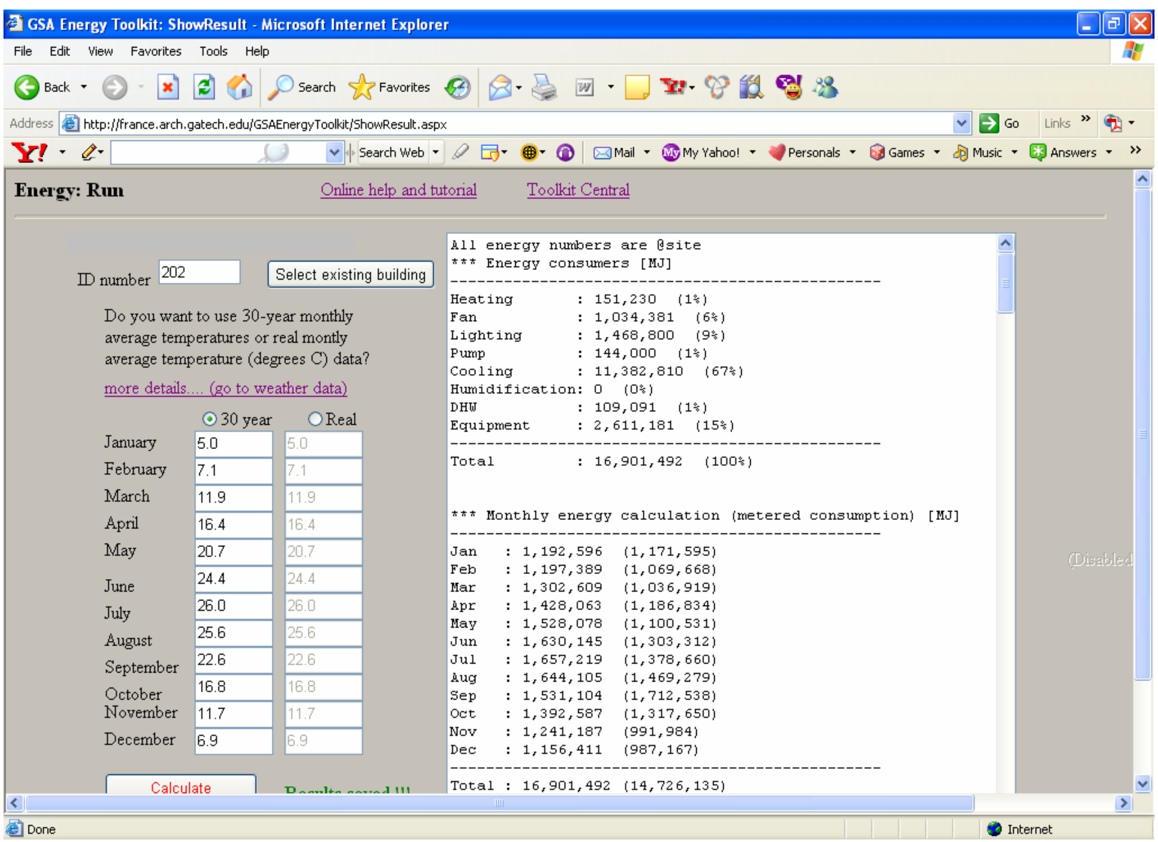

Figure 2.4: GSA toolkit results webpage

2.6 Utility function

As stated by Kwon, "In any situation, regardless of the size of the monetary reward or penalty a decision maker is either indifferent to two or more projects or he prefers one over the other" (Kwon 1978). It is useful to assign a numerical value to indicate the degree of desirability when considering the relative worth of one option over against other. This numerical value for satisfaction is called Utility function (Kim 1992). It is a subjective concept, and the number assigned to utility function is arbitrary, which is known as Util or Utile. Utility function can refer to non-linearity of satisfaction; for example, 2 candies will have higher utile than 1 candy, but utile for 120 candies can be less than 2 candies (Morgan 1968). Figure 2.5 illustrates a sample expected utility curve for investments payoffs with P and Q as the maximum and minimum values.

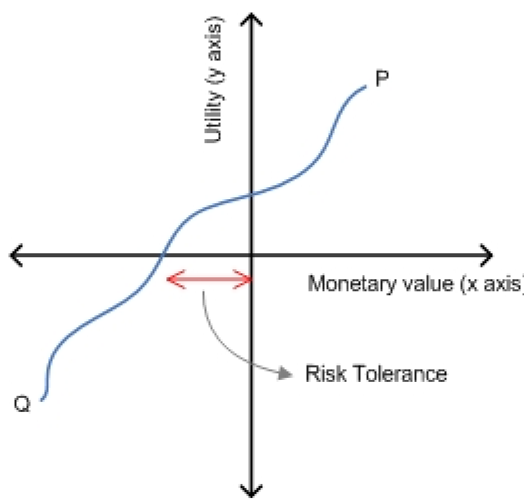

Figure 2.5: Expected utility curve

As illustrated in Figure 2.5, a utility curve is generally a non-linear curve or a combination of concave and convex curves. This curve is developed by the measurement of likelihood through indifference method based on the maximum and minimum utile values (Kwon 1978). It can be clearly seen that utility curve maps the risk behavior of the decision maker, where concave curve represents risk averse nature of the decision maker while the convex curve represents risk prone nature. Here, risk tolerance depicts the minimum monetary value for which the decision maker has “0” utile. This amount can be considered as the minimum money set aside by the decision maker for insurance purpose.

For a given investment problem, all possible outcomes are determined and suitable utility values are assigned to each outcome. The most beneficial outcome or payoff is assigned the highest utility, while the worst expected outcome is assigned the least utility. Scale of utility values is decided by the decision maker and generally it ranges from -1 to +1 utile.

Expected utility is used as a selection measure, which is obtained when probability of the outcome is multiplied by their respective utility value. If a decision maker has two identical utiles but have different probability of success then the decision maker would select the one with higher probability. For selecting the best investment return/payoff option from the given set using utility, one has to follow this procedure:

1. Assign utility for each payoff and generate utility curve
2. Calculate the expected utility value based on the probability
3. Select the payoff with maximum expected utility.

2.7 Mean -Variance paradigm as Decision making tool

Decision theory deals with the evaluation and selection of an alternate course of action in the face of uncertainty. According to Steve Kim, "Decision theory has shaped the development of statistics, a field largely devoted to the evaluation of data and their interpretation under conditions of imperfect knowledge" (Kim 1992). The decision making process differs based on three conditions: certainty, risk and uncertainty (Kwon 1978). In a situation where decision making is done under conditions of risk, the degree of knowledge associated with each state is unknown, but its likelihood can be determined either through subjective judgment or through a mathematical function (Kwon 1978).

In statistics, Mean (μ) or arithmetic mean, is defined as the sum of all observations divided by the number of observations. Standard deviation (σ) which is square root of variance is defined as a measure of spread of about the mean value (μ), whereas Variance (σ^2) is the measure of statistical dispersion of values with respect to mean (Dixon and Massey 1983). If a random variable X takes the value $x_1, x_2 \ldots, x_n$, then mean value (μ) is given by the following formula, where N = total number of samples:

$$\mu = \frac{x_1 + x_2 \ldots\ldots + x_n}{N}$$

Standard deviation for the random variable can be given by the following formula:

$$\sigma = \sqrt{\left(\frac{1}{N} \sum_{i=1}^{n} (x_i - \mu)^2 \right)}$$

. The relation between mean and standard deviation can be described though the normal curve (Gaussian distribution). Figure 2.6 shows the normal distribution curve with mean (μ) and standard deviation (σ). A large standard deviation indicates that the samples are far from the mean and a small standard deviation indicates that they are clustered closely around the mean. Figure 2.7 illustrates the impact of variance on curves.

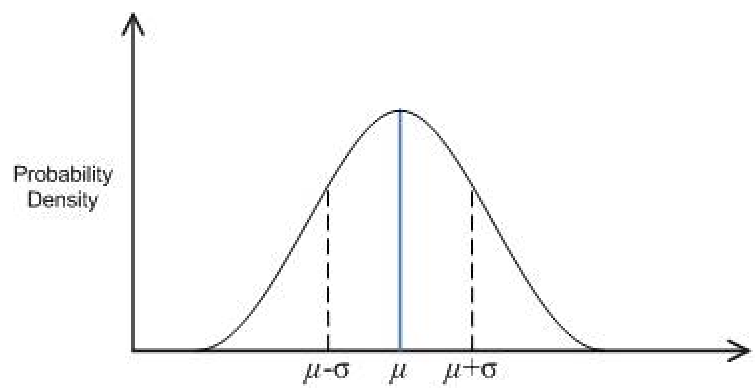

Figure 2.6: Normal distribution curve

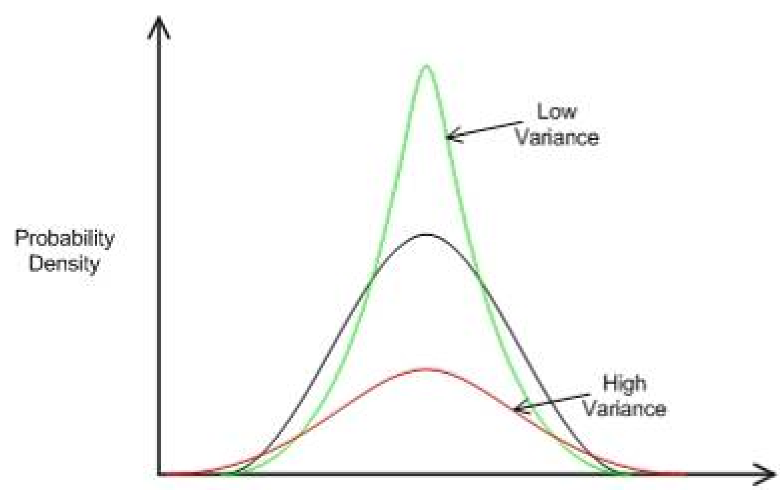

Figure 2.7: Effect of variance

As shown in Figure 2.7, the greater the variance, the probability of mean value decreases, whereas, lower the variance, probability of mean value occurrence increases (Dixon and Massey 1983). In other words, higher variance has the effect of making values located away from the mean more likely.

Properties of variance significant to this research are listed below:

- Variance of a finite sum of variables is the sum of their variance.
- If the values of the variables are multiplied by a constant value, then the variance is multiplied by the square of the constant value (Dixon and Massey 1983).
- If two given variables "A" and "B" follow normal distribution, then their product "C" would not be normal curve, even though its mean and variance can be calculated as follows:

  Mean (μ)

  $$\mu_C = \mu_A \times \mu_B$$

  Variance (σ^2)

  $$\sigma^2{}_C = (\sigma^2{}_A \times \sigma^2{}_B) + (\mu_A)^2 \times \sigma^2{}_B + (\mu_B)^2 \times \sigma^2{}_A$$

In 1952, Markowitz proposed the "Mean-Variance paradigm" to deal with risk, involving many financial instruments (F.Sharpe 2006). The basic assumption is that the decision criteria should be to minimize the variance for a given mean value of return or to maximize return for the given value of variance (Odegaard 1999). So, here the variance serves as a measure of risk.

2.8 Optimization Methods

Optimization stands for finding the best solution for a given problem. It deals with problems of maximizing or minimizing a function of several variables usually subject to equality or inequality constraints (Nemhauser et al. 1989). Mathematically, a function $f(x_1, x_2 \ldots, x_n)$ where integer $n \geq 0$ may be unconstrained or may be subject to constraints by some other function say $r(x_1, x2, \ldots, x_n) \leq y$; maximizing or minimizing this function $f(x)$ is considered optimization. Generally, functions and their controlling constraints would have a real physical meaning; like in the above case f can be mathematical model for investment, while r might be a budget constraint with a maximum limit of y($). Although, optimization falls under statistics and mathematical realm, it is mostly used in the field of operational research. Operational research is an interdisciplinary field of applying advanced knowledge of mathematics to arrive at the best possible solution for a complex problem (Beale and Mackley 1988). Of all the available optimization methods like dynamic programming, convex programming, constraint satisfaction, etc, linear integer programming is the most suitable optimization method in this research thesis.

Linear Integer programming (LIP), also known as integer programming or mixed integer programming (MIP), deals with problems of maximizing or minimizing, a function of many variables subject to only *linear* inequality constraints, and with additional restrictions that some or all of the variables are required to take integer values (Beale and Mackley 1988). This is a well established method, and is being applied to many operational research problems involving investment problems, distribution of goods, production scheduling and machine sequencing. They also include planning problems such as capital budgeting, facility location and portfolio analysis, and design problems such as communication and transportation network design (Nemhauser and Wolsey 1999). MIP involves extensive calculations, for example, if there is *n* number of assets then there would be 2^n possible combinations to pick from. In the past, when the cost of computing was high, utilization of this tool was restricted to certain long to mid tern investments. Now with the available technology, this technique is now both cheap, and robust to calculate up to 8000 variables (Frontline Systems Inc 2007).

Figure 2.8 shows a sample mixed integer programming problem, with an objective function and constraints.

Objective function: Maximize $2x_1 + 3x_2$

Constraints: $2x_1 + x_2 \leq 12.0$

$3x_1 + 4x_2 \leq 24.0$,

where $x_1, x_2 \geq 0,$ integer

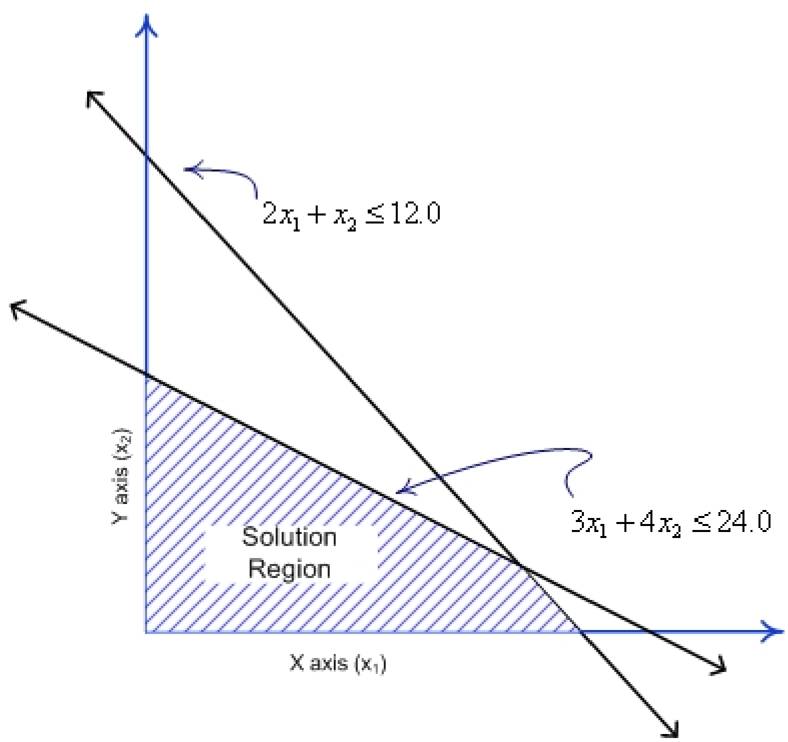

Figure 2.8: Mixed integer programming plot

As shown in Figure 2.8, a solution region is obtained that satisfies both the constraint equations. The solution lies within the region that will provide the highest value for the objective function.

2.8.1 Knapsack problem

This is very common type of optimization where the selection of a project subset from a given solution set is either 1 or 0, i.e. they can either be selected (1), or discarded (0). It is called the knapsack problem because of the analogy to the hiker's problem of deciding what should be put in a knapsack; given a weight limitation on how much can be carried. A typical knapsack problem would have a mathematical model as shown below

If x be a variable where,

$$x = \begin{cases} 1 \text{ if selected} \\ 0 \text{ if not selected} \end{cases}$$

For n projects, the j-th project, $j = 1, 2\ldots n,$ has a cost of a_j and a value of c_j ; there is also a budget (b) available to fund the projects. The solution set is given in equation 1.

$$\max\left\{\sum_{j=1}^{n} c_j x_j : \sum_{j=1}^{n} a_j x_j \leq b\right\} \ldots\ldots\ldots\ldots\ldots \text{(Eq: 1)}$$

In general, a problem of this sort may have many constraints, which is then referred to as the multi –dimensional knapsack problem (Nemhauser et al. 1989). We will see below that our investment portfolio optimization is in fact a variant of the knapsack problem.

CHAPTER 3

RESEARCH METHODOLOGY

This research work has been divided into following phases:

- *Initiation*: Defining the objective and performing an extensive literature review
- *Analysis*: Understanding the basic approach and software architecture of the GSA toolkit, and selection of suitable software compiler which would enable communication between our stand-alone investment optimization tool and the GSA toolkit.
- *Development*: Creating a communication protocol, interactive user forms, and integrating mixed integer programming tool; performing tests on the prototype application.

All these linear phases are explained as flow diagram in Figure 3.1

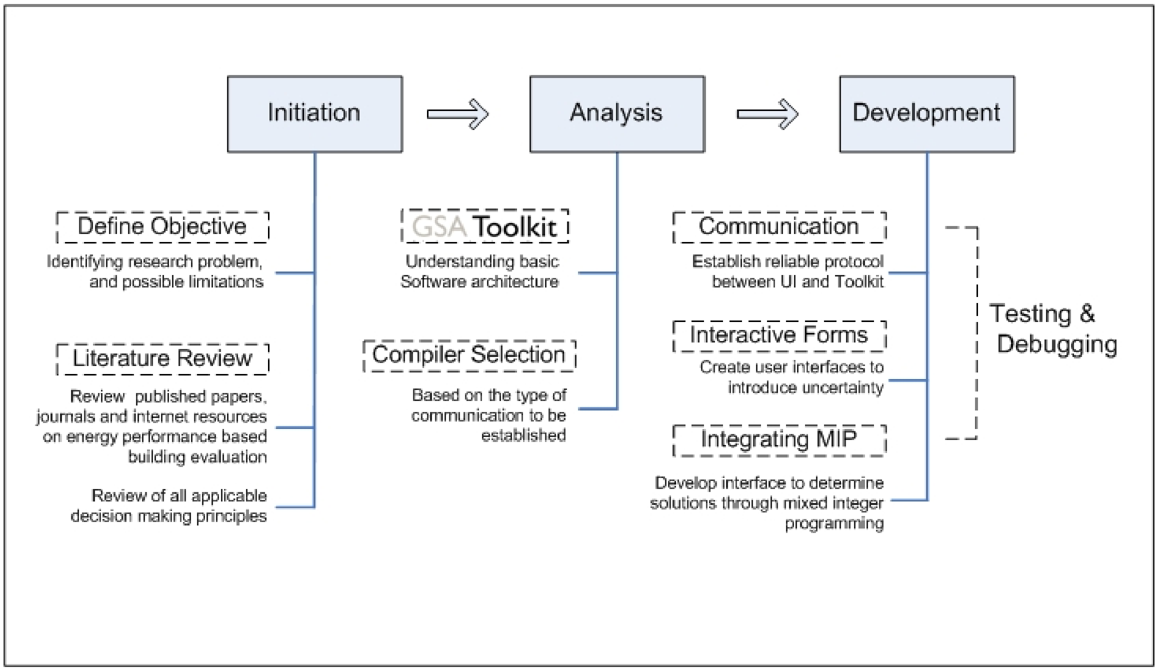

Figure 3.1: Research Methodology

3.1 Initiation Phase

The objective along with possible limitations that might be encountered in the research project was defined in the earlier stages of the project. Also an extensive literature review was performed to analyze relevant published research papers in the building performance, energy investments, and the basics of decision making under uncertainty.

As explained earlier in the literature review, utility function can be used as a method to distinguish among investment options, and it has an added benefit to map risk behavior of the decision maker. But in this research all investment options have equivalent probability of occurrence, so expected utility cannot be utilized and also due to certain inconsistencies in the formulation of indifference utility curve, utility function was replaced by the straightforward "Mean – Variance" paradigm to handle risk behavior of the decision maker.

Mean-Variance approach proved to be promising, when dealing with uncertainties involved in the future energy cost, technology investment cost and the resulting modified building performance. Mixed Integer programming and more specifically the knapsack problem was selected as the optimization method, as it is required to generate a portfolio in which an investment option can either be selected or discarded.

3.2 Analysis Phase

In the analysis phase, the GSA toolkit was explored thoroughly. It is a web based tool used to determine energy performance of the existing building. It generates comparable indicators like heating, cooling, lighting, pump/fans, hot water, humidification, and appliances plug load; without the need for metered utilities data. This toolkit is made with active server pages developed with .NET compilers. All the web pages along with their source code were investigated to look for links between user controls, and to capture the webpage navigation pattern. Various compilers like Visual prolog, Visual C, C++, and VB.net were considered as possible candidates for programming the tool. As the Toolkit was developed on .NET platform, it was advisable to have the prototype system also developed in the same environment; VB.NET was selected as a suitable compiler.

3.3 Development Phase

In the development phase, an appropriate communication protocol between the prototype application and the toolkit was established. Transfer of data and variables between them was performed using a method similar to HTTP post. The multiple integer program method was incorporated in the application to generate portfolios satisfying the optimization criteria of the decision maker. At every stage during the development, the prototype application was tested and debugged to catch unforced errors in a real time environment.

CHAPTER 4

INVESTMENT STRATEGY MODEL

The investment strategy model as described in this section is intended for use by facility and portfolio managers, to determine the best retro-commissioning investment portfolio for their campus under the given budget, optimization criteria and designated uncertainty in energy costs. Figure 4.1 illustrates the schematic diagram of the strategic investment model.

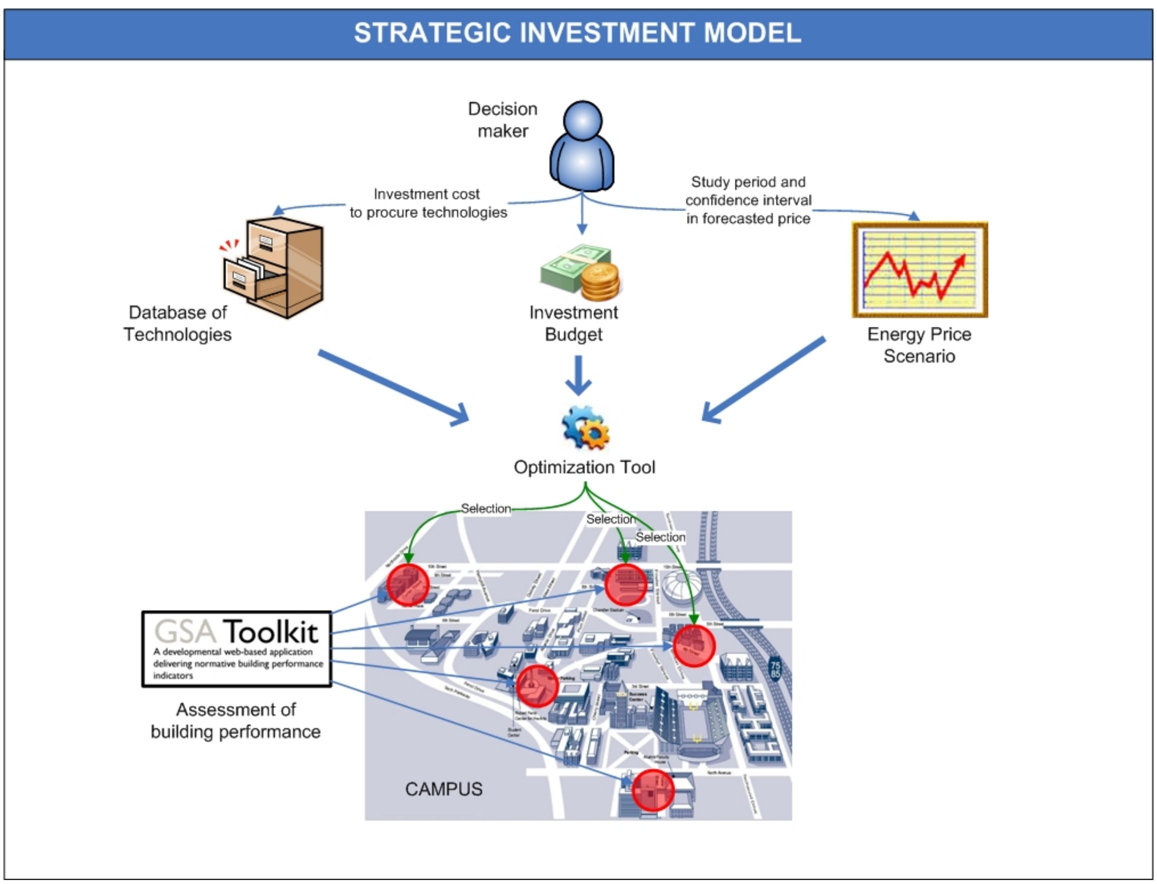

Figure 4.1: Schematic diagram of strategic investment model

As shown in the Figure 4.1, the core of this model is an existing energy performance assessment tool –“GSA toolkit” that allows very fast and efficient assessment of the energy use of a building, and all its separate energy consumers: heating, cooling, lighting, pump/fans, hot water, humidification, and appliances plug load.

This investment model is developed as a decision making shell around the performance assessment toolkit. For a given a set of portfolio buildings and an applicable range of retrofit, re-commissioning, or new energy saving technologies, the portfolio optimization tool will select the best combination of improvements within a given investment budget, time horizon and risk tolerance. The tool calculates the optimal investment portfolio under uncertainty, and driven by optimization criteria of the decision makers, e.g. investment risk attitudes and/or commitment to “greenness”. Greenness in this case is translated as “amount of total energy saving for all selected options, within the period of the investment horizon, expressed in primary (fossil) energy units.

4.1 Stages in decision making

Figure 4.2 schematically represents the five major stages in decision making, which are explained in subsequent sections.

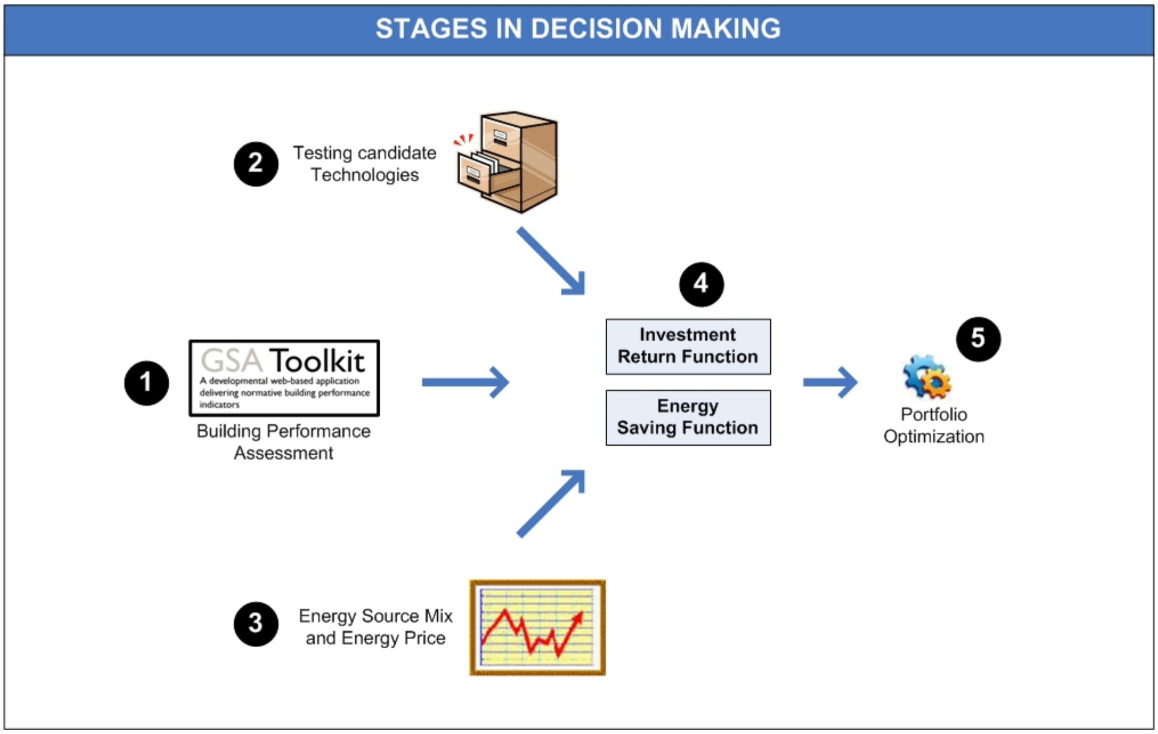

Figure 4.2: Stages in decision making

4.1.1 Stage 1: Building performance assessment in as-is situation

The first stage consists of performing portfolio performance assessment, using normative calculations, with the help of the GSA Toolkit. PIs for each energy consuming system like heating, cooling, domestic hot water, etc. in every selected building will be calculated. The DM will then have a better understanding of energy consumption among campus facilities. Buildings that may need retro-commissioning can then be demarcated. It is important to note here that the calculations are purely normative, based on readily observable building and systems data. Hidden defects in building systems control and operation will not be detected, unless a deeper energy audit precedes the use of the investment tool. In such case the GSA toolkit as-is parameters will be based on the outcome of the deep energy audit.

4.1.2 Stage 2: Testing candidate technologies

In this stage based on the decision maker's preference, candidate retro-commissioning technologies will be applied to each building that is deemed a good candidate for that retro commissioning technology. Every candidate retro-commissioning technology for a given building has to be tested for change in building performance through GSA toolkit. As explained earlier, these technologies should have some input parameters which are linked to GSA toolkit. For example, glazing system for a building can be tested for its benefit through toolkit if we have its characteristic U-value and SHGC (solar heat gain coefficient); although a similar glazing system which has higher LSG (Light to solar gain) coefficient would be indifferent to the GSA toolkit, as LSG is not an input parameter.

In this stage every applicable technology is assessed by the following set of parameters:

- Improvement potential: This can be computed by the GSA toolkit with the new set of input parameters associated with the specific technology option. Every change in associated input parameter would generate new energy performance coefficient (EPC). The difference obtained in EPC i.e., Δ EPC would define the improvement potential.
- Initial investment cost: associated with a expert supplied level of uncertainty, mean value and standard deviation of the cost are collected

from the decision maker, or in most cases hired building technology expert/consultant.

4.1.3 Stage 3: Energy source mix and price

Additional input parameters required for determining the benefit of implementing the candidate technology are collected in this stage. The DM can either provide energy cost/price or determine energy costs by incorporating uncertainty, if any to the forecasted energy costs (provided by EIA until year 2030) as confidence interval. Figure 4.3 illustrates the electricity price (cents/kWh) forecasted by the Energy Information Administration. Although this forecasted data would be dependable, the user has been given complete liberty to alter it. This allows integrating any future uncertain energy price shocks perceived by the DM that contradicts the forecasted values for both electricity and gas prices.

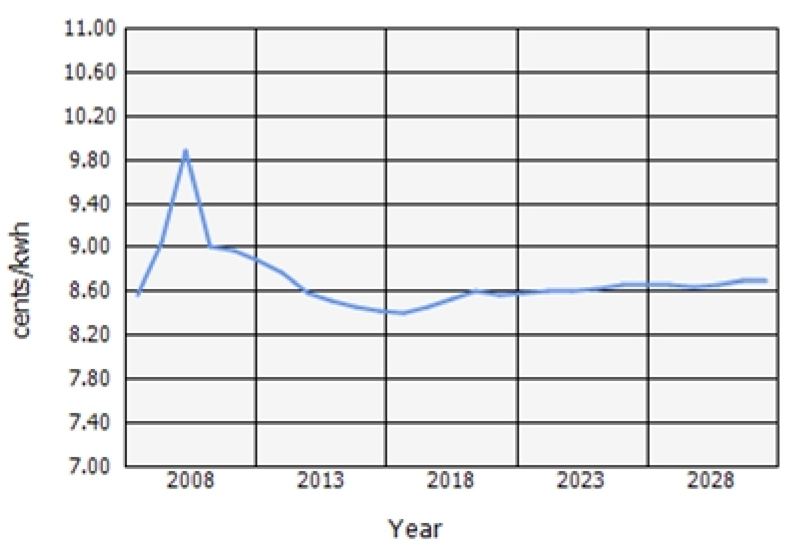

Figure 4.3: Electricity price forecast

Figure 4.4 shows the corrected electricity forecast, where the DM has provided suitable confidence interval to the electricity costs beyond 2013. The resulting energy cost would be a combination of mean and variance value for the given investment horizon/study period also provided by the DM at this stage. As explained earlier, electricity and gas are considered to be the only source of energy to the campus. Building systems can be categorized as utilizing “Electricity” or “Gas” or “both” in each building. However, for the whole campus it would be impossible to differentiate. As a result, the energy source mix (proportion of electricity and gas) is collected in this stage as an average value throughout the campus, irrespective of individual building usage.

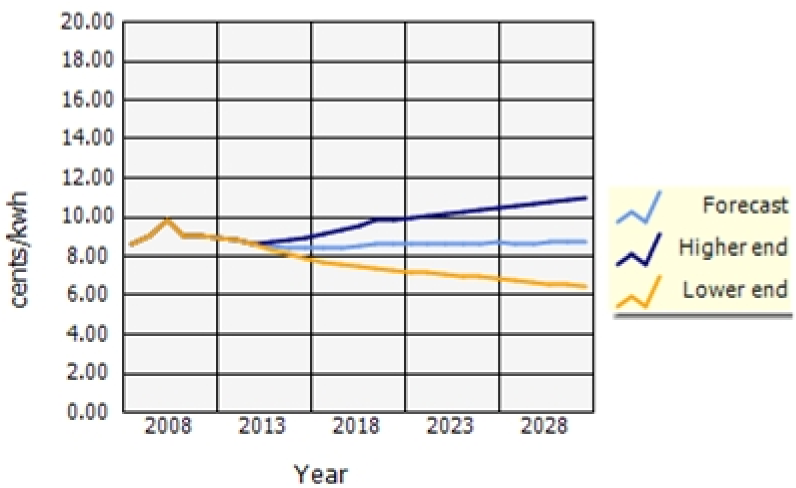

Figure 4.4: Corrected electricity forecast

4.1.4 Stage 4: Investment return and energy saving functions

The investment return (monetary, in $) and energy saving (primary energy units, in MJ) values are calculated using their respective functions (given below); both of them will be utilized to distinguish between mutually exclusive investment options. The investment return value for the given building technology pair (Investment option) is calculated by the equation given below (Eq-2), where i = technology, j = building, r = minimum attractive rate of return, t = investment horizon/ study period.

$$IRF_{(i,j)} = \left[NPV(r) \left\{ \text{Change in PI}_{(\text{i,j})} \times Avg\left(\sum_{0}^{\text{t}} \text{Energy Cost} \right) \times \text{t} \right\} \right] - \text{Investment Cost}_{(\text{i,j})}$$

.. (Eq-2)

The investment return function (IRF) calculates the return on investment for the modified technology at the end of investment horizon. It is based on net present value (NPV) calculations for the benefit. It is assumed that the energy saving will remain almost the same throughout the investment horizon / study period (t). The latter means that maintenance is assumed adequate to avoid deterioration of the installed technology. Similarly, the amount of energy saving value for the investment option is calculated based on equation (Eq-3), where i = technology, j = building, c= energy consumer, η = ecosystem efficiency for converting electricity to gas, t = investment horizon/ study period, M_{gas} = gas proportion of energy source mix, and M_{elec} = electricity proportion of energy source mix.

$$ESF_{(i,j)} = \sum_{c=1}^{c=8}\left\{\left(\text{Change in PI}_{(i,j,c)} \times \text{M}_{\text{gas}}\right) + \left(\frac{\text{Change in PI}_{(i,j,c)} \times \text{M}_{\text{Elec}}}{\eta_{\text{Eco-efficiency}}}\right)\right\}$$

…… (Eq-3)

The energy saving function (ESF), calculates total amount of energy which could be saved by implementing a retro-commissioning technology by the end of study period. Eco - Efficiency is the correction factor applied for generating electricity from gas (if at all) at the energy production site. With this approach the decision maker will not only know how much energy is saved at the campus, but also the net energy saving for the ecosystem or community. Both Investment return values and Energy savings values are calculated from normally distributed parameters; resulting in the formation of an undefined curve, illustrated in Figure 4.5.

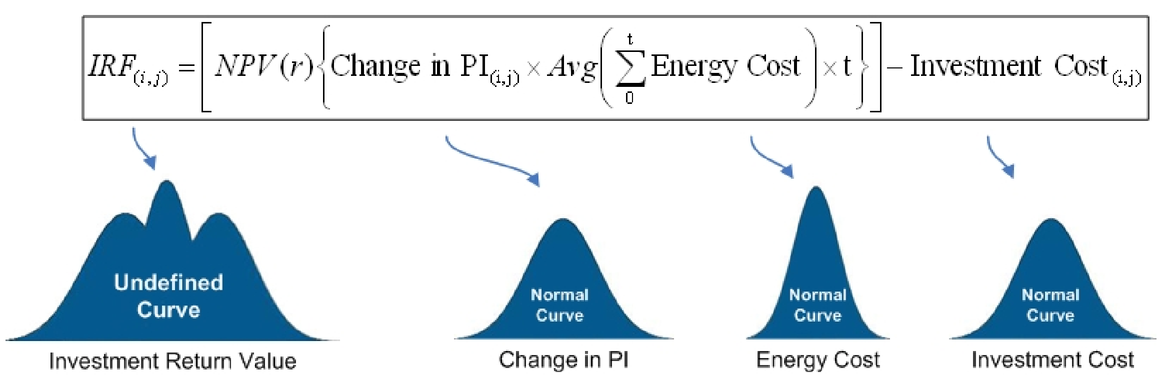

Figure 4.5: Formation of undefined curve

As shown in Figure 4.5, the final mean value and variance can be calculated using the mean and variance properties. The mean value for an investment return function can be calculated as follows:

$$IRF_{mean} = [NPV(\text{Change in PI}_{\text{mean}} \times \text{Energy Cost}_{\text{mean}})] - \text{Investment}_{\text{mean}}$$

While the IRF variance (var) is calculated by the following approach

$$\text{Product}_{\text{var}} = (\text{Change in PI}_{\text{var}})^2 \times \text{Energy Cost}_{\text{mean}} + (\text{Energy Cost}_{\text{var}})^2 \times \text{Change in PI}_{\text{mean}}$$

$$\text{Benefit}_{\text{var}} = \text{NPV}(\text{Product}_{\text{var}})$$

$$IRF_{\text{var}} = \text{Benefit}_{\text{var}} - \text{Investment}_{\text{var}}$$

Even though, the resulting return function has an undefined curve, its “Mean” and “Variance” value can still be used for decision making through “Mean –Variance Paradigm” (Ashton 1982, Kasper 2002). Here the variance serves as a measure of risk, the greater the variance, the higher the risk and vice-versa.

4.1.5 Stage 5: Portfolio Optimization

After determining the investment return and energy saving values (mean, variance) for all the investment options in a given campus, it is required to select the optimal set of investment options in a portfolio ,which suits DM's budget and risk attitude. This problem can be solved using mixed integer programming, or more specifically knapsack problem, where the objective function and generic constraints is given below:

Objective function: Maximize Mean $IRF_{(i,j)}$ or Maximize Mean $ESF_{(i,j)}$

Generic Constraints

- For any portfolio, Investment options can either be selected completely (1) or discarded (0); as they cannot be selected in fractional manner.
- $\sum_{1}^{j} \text{Investment Cost}_{(i,j)} \leq \text{Budget}$

Along with the generic constraints the DM has an option to define selection characteristic of investment option in the portfolio through these mutually exclusive cases:

Case 1: Optimize portfolio with the given variance constraint

Case 2: Optimize portfolio with the given return/energy saving value.

Case 3: Optimize portfolio with no variance constraint

The DM can control variability of the return value by assigning variance constraint, as in Case 1. Under this condition the total variance, i.e., sum of all variance values, of selected investment options would remain within the given constraint. This case stands for "Risk averse" nature of the DM. While in Case 2, the DM can provide an anticipated return value as the constraint. The sum of all return values for selected investment option would equate to constraint value. In this case, the DM is mainly concerned for the mean value (return or energy savings) irrespective of their variance, which stands for the "Risk Prone" nature. In the last case there is no constraint, even though it would optimize the portfolio for given objective function and generic constraints. This case stands for the "Risk Neutral" nature of the DM. All the above described cases can be described as additional constraint as shown below:

- *For Case 1*: $\sum_{1}^{j} \text{IRF/ESF Variance}_{(i,j)} \leq \text{Given Variance}$
- *For Case 2*: $\sum_{1}^{j} \text{IRF/ESF Mean}_{(i,j)} \leq \text{Given Mean}$
- *For Case 3*: No additional constraint

Knapsack problem is utilized to optimize, and generate optimal portfolio. The choice between optimizing either investment return portfolio or optimizing energy saving portfolio is independent from each other, which enables the DM to review both optimized portfolios. This will reveal potential differences between the energy optimal and monetary optimal portfolios.

4.2 Approach to validate model

As described earlier validation of this investment strategy model is not included in the scope of work. Nevertheless, a possible approach to validate this model is described in this section. As it is known, this model heavily relies on the change in building performance attained by modifying building technology, so the model developed should be tested in a real scenario with real building data and investment circumstances. This can be done in the following manner:

1. Obtain Initial PIs: Generate performance indicators for a real set of campus buildings through GSA toolkit. The building data provided to the toolkit should be as realistic as possible with least approximation.
2. Modify PIs: With the help of prototype developed in this research, candidate technologies are tested for each building. Candidate technologies are identified by experts. Their opinion, governs the assignment of a technology or a combination to a given building. A set of 20-30 building technology pair, should be fair enough for validating this model. Estimates (including uncertainty) of investment cost for a technology application in a building should be assigned by an expert cost estimator.
3. Return Analysis: To determine investment return or energy saving, parameters like energy source mix, eco efficiency etc are required by the prototype, have to be provided by an expert, most probably an on-campus energy systems expert. Typically a preliminary research/study would be required to identify these parameters. After obtaining the investment

return and energy saving values, the decision maker can the generate optimal investment portfolio.

Based on the results obtained, any inconsistencies perceived by the expert decision maker in the model should be taken as a need for improvements in the model. Another aspect of the validation is to check whether the use of the approach for energy investment, ignoring all other impacts of the investments in campus performance improvements. The basic argument for our approach is that at some early stage, energy saving investment considerations is the most relevant. At this stage the proposed investment tool will be used. In the follow-up stages a multi-criterion decision making approach is necessary to compare energy improvements with other targets of the investment. The validation exercise should deal with a study of the decision making process in a campus master planning and investment strategies, with the aim to verify the relevance of our approach in this process.

CHAPTER 5

PROTOTYPE DEVELOPMENT

This section mainly describes the graphic user interface software application or prototype based on the investment strategy model.

The objectives of the prototype are

- To select buildings that have been assessed with the performance toolkit and transfer their data records to the prototype without further user intervention
- To facilitate the DM in analyzing change in performance for the selected retro-commissioning technology without having to enter the new data into the GSA Toolkit.
- To easily express uncertainty in cost parameters, and visualize their impact.
- To develop a communication channel between the prototype and other generic applications that provide auxiliary support in mixed integer programming, storage of records and also create dynamic charts.

5.1 Software Architecture

To utilize this prototype, as a preliminary requirement the user is required to employ the GSA toolkit to calculate existing building performance in terms of PIs. The user should then select an available technology option which modifies the building data and re-calculates the energy performance of all energy consumers in the building. Energy costs forecasted based on EIA are pre-set in the prototype, and the user has to provide confidence intervals (if required), investment horizon/study period, and the estimated mix of energy sources on campus. For each technology or combination of technology changes, the user has to provide investment cost with a suitable uncertainty (standard deviation). This generates an investment option (each discrete pairing of a building and retro-commissioning technology is an investment option) in the dataset, with benefit and cost values associated with it.

The user has to provide a minimum attractive rate of return and eco-efficiency values to generate the IRF matrix, and Green (ESF) matrix. After the user provides a minimum budget and optimization choice, the prototype will accordingly generate an optimized portfolio. The output in this application will mainly be the initial PIs, and portfolio reports. All other variables and calculated values will be internally stored temporarily in the prototype. The application behavioral is further explained through subsequent sections of obtaining modified performance indicators, generating investment return-green matrix and portfolio optimization. Figure 5.1 illustrates the software architecture of the prototype developed.

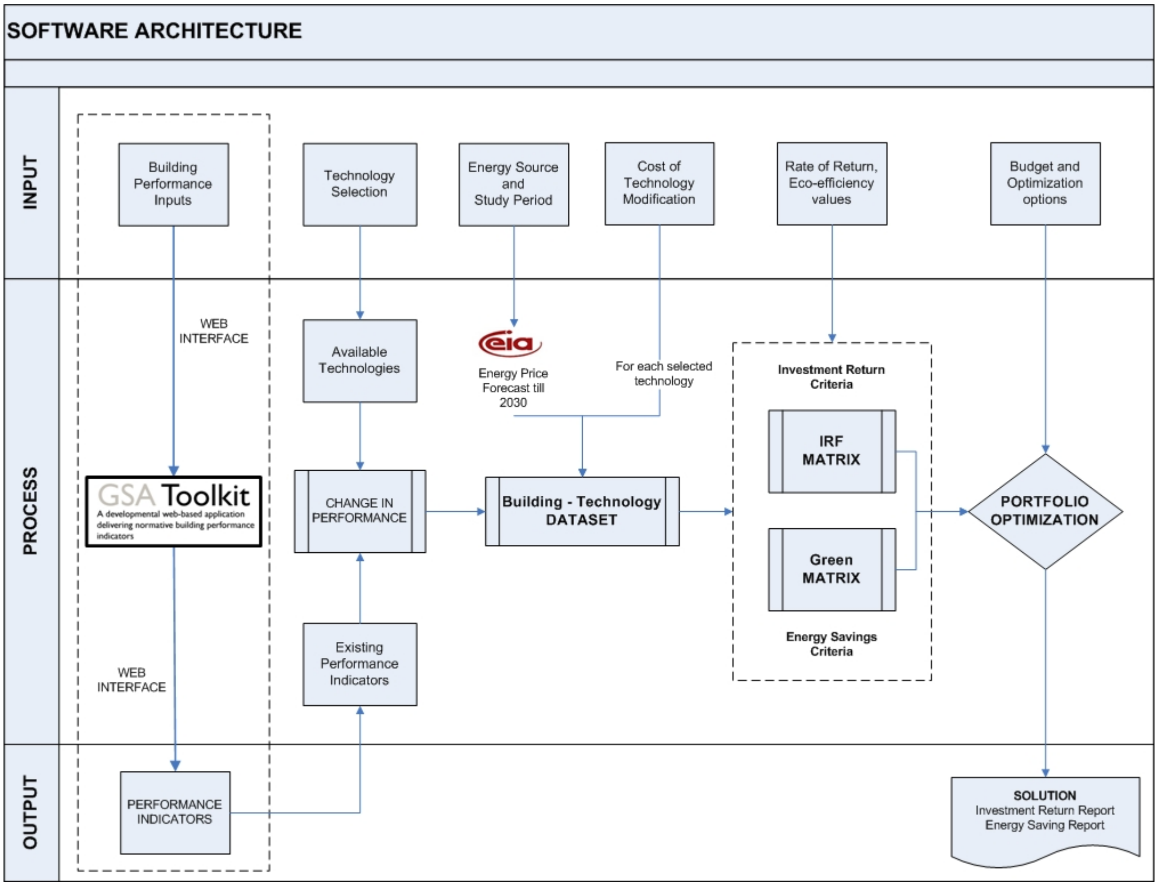

Figure 5.1: Software architecture

5.1.1 Obtaining modified performance indicators

Figure 5.2 illustrates the user interaction with GSA toolkit and the prototype application.

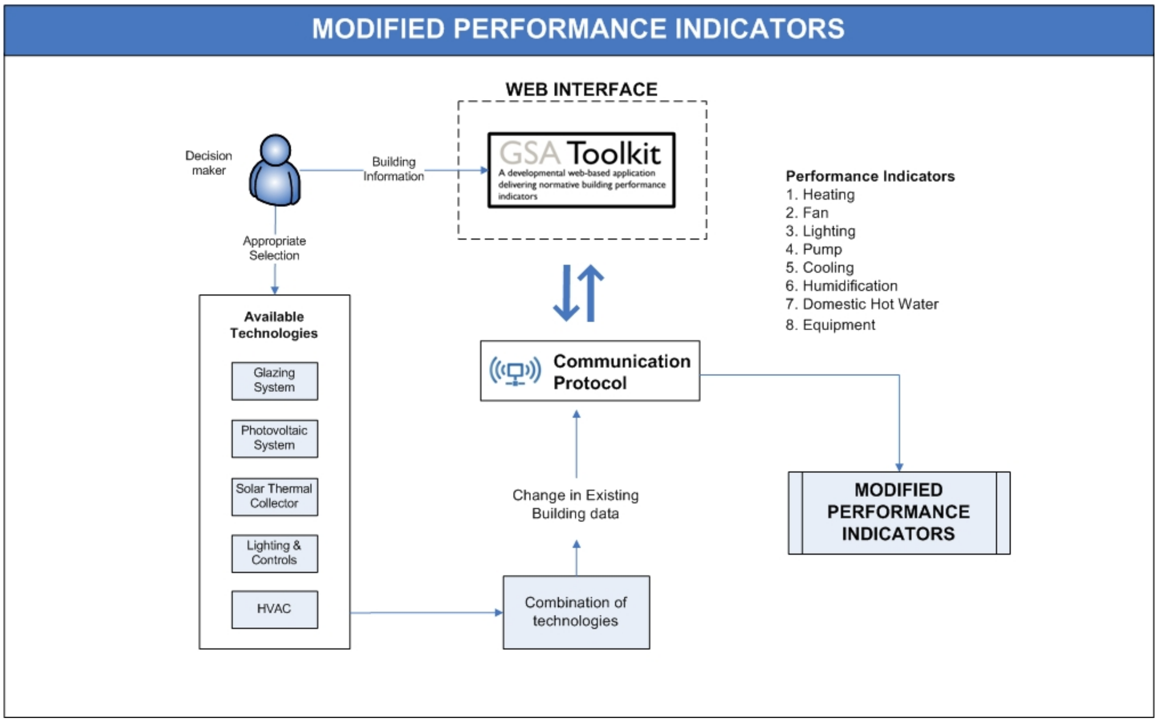

Figure 5.2: Modified performance indicators

Steps for obtaining modified performance indicator (MPI) are:

- Firstly, the decision maker will provide the building information to the GSA toolkit to generate initial PIs, namely heating, fan, lighting, pump, cooling, humidification, Domestic hot water and Equipment as shown in Figure 5.2.
- Then from the available list of technologies, i.e., glazing system, photovoltaic system, solar thermal collector, lighting and controls, and

HVAC, the user will select any or a combination of technologies for the selected building.

- The prototype will display existing values for the selected technology. Finally, the user will then enter the respective values. Any modification made is considered as candidate technology. With the help of a communication protocol, the modified PIs are generated through the GSA toolkit.

5.1.1.1 Communication protocol

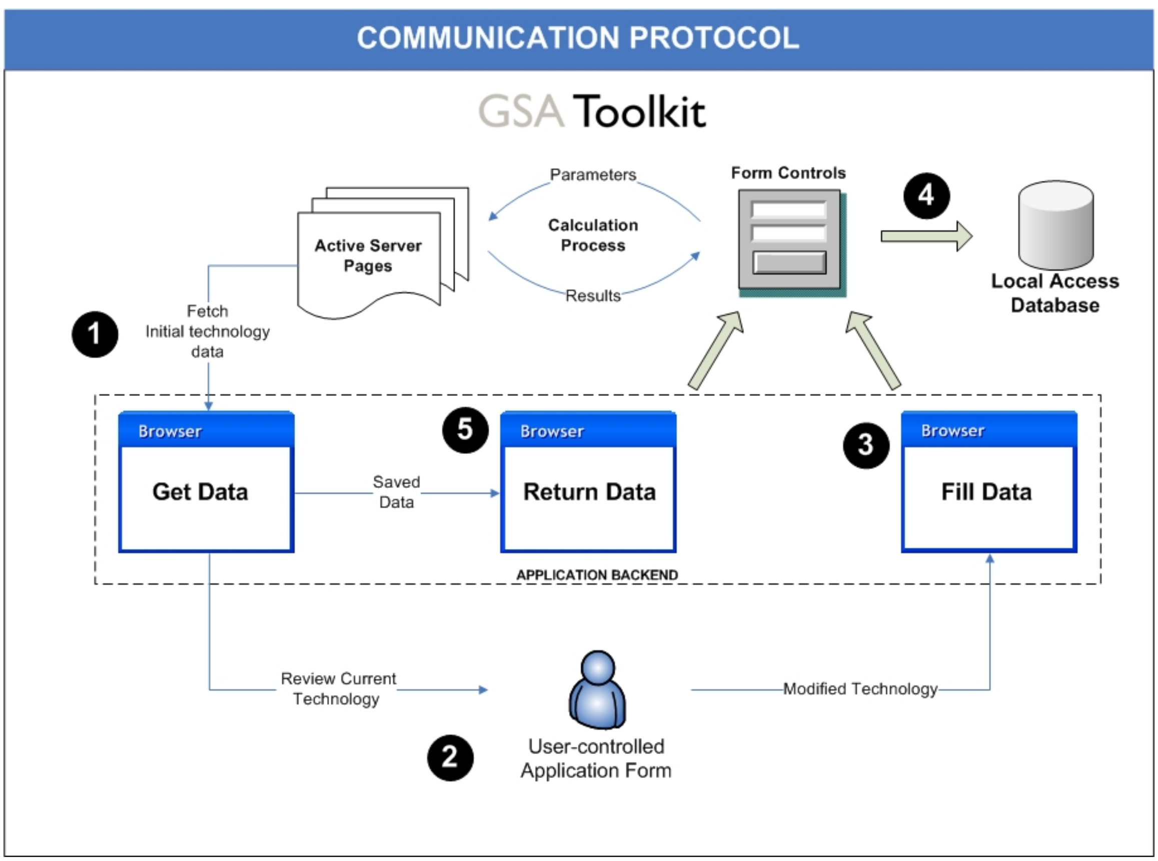

Figure 5.3: Communication protocol

This communication protocol helps the user to analyze change in performance without opening a single webpage. This method is similar to HTTP post, but with a variation to cater ASP webpage. As shown in Figure 5.3, the working of protocol comprises of the following steps:

1. In the first step, the "Get Data" browser in the application backend will obtain the initial building data, display it to the user, and also store the data temporarily.
2. In the second step, the user is allowed to modify existing building data value or enter new value as modification of building technology.
3. In the third step, the "Fill data" browser fills GSA toolkit respective form fields and triggers calculation of MPIs
4. In the fourth step, all calculated MPI values available with the toolkit is stored in the local database.
5. In the fifth step, the "Return data" browser instills initial building data back to the GSA toolkit.

In short, this protocol utilizes the GSA toolkit as an instrument to calculate change in building performance by only changing certain parametric values; at the same time it is observed that the initial building data is safe and unaltered with the GSA toolkit.

5.1.2 Generating Investment return and energy saving matrix

Figure 5.4 illustrates the process of determining investment return (IRF) and energy saving (Green) values in the prototype.

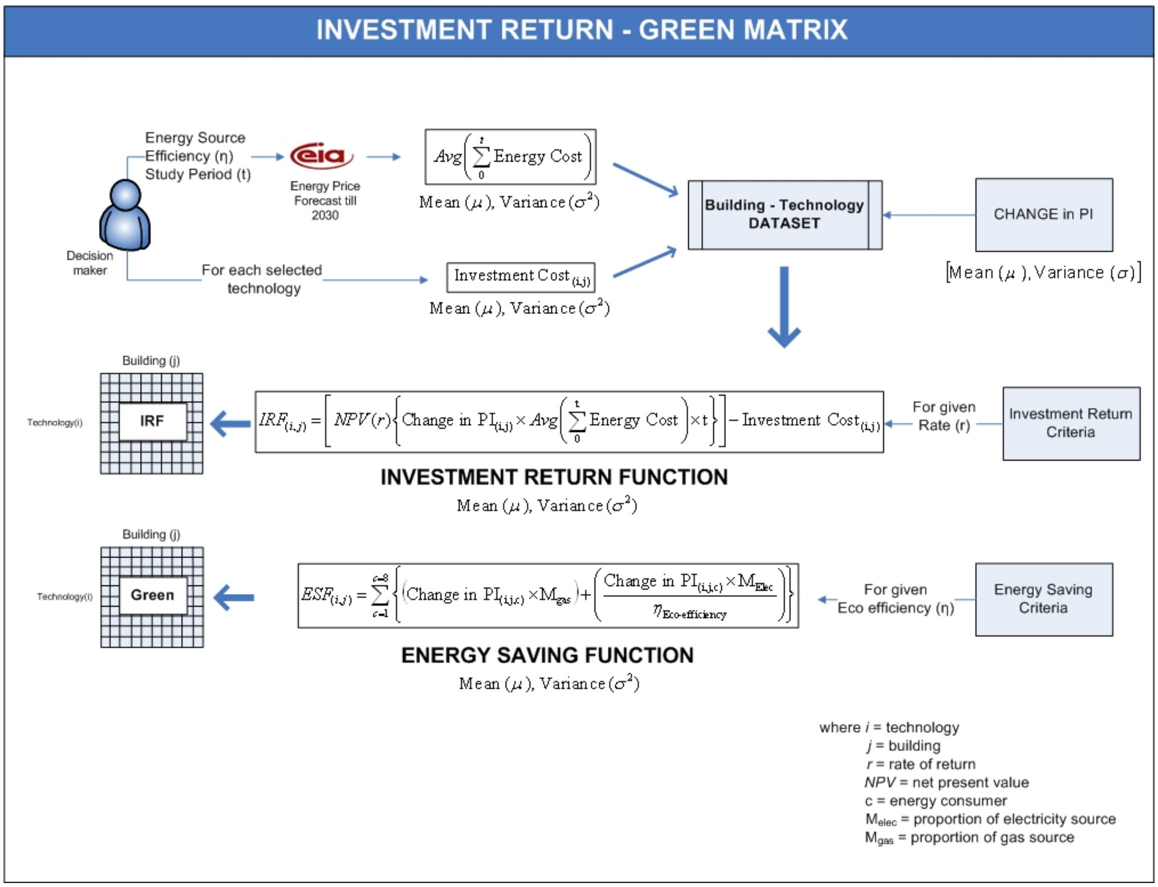

Figure 5.4: Investment return and energy saving matrix

As shown in figure 5.4 the steps for generating matrix values are:

- The user provides energy source mix, study period, and confidence interval to the forecasted energy price (EIA). The investment costs for each modified technology / building combination is also provided.
- With the change in PIs, rate of return, and eco-efficiency values, the prototype generates IRF - Green matrix through their respective functions.
- Each cell in the matrix consists of a set of mean and variance value for a particular building technology pair.

5.1.3 Optimizing Portfolio

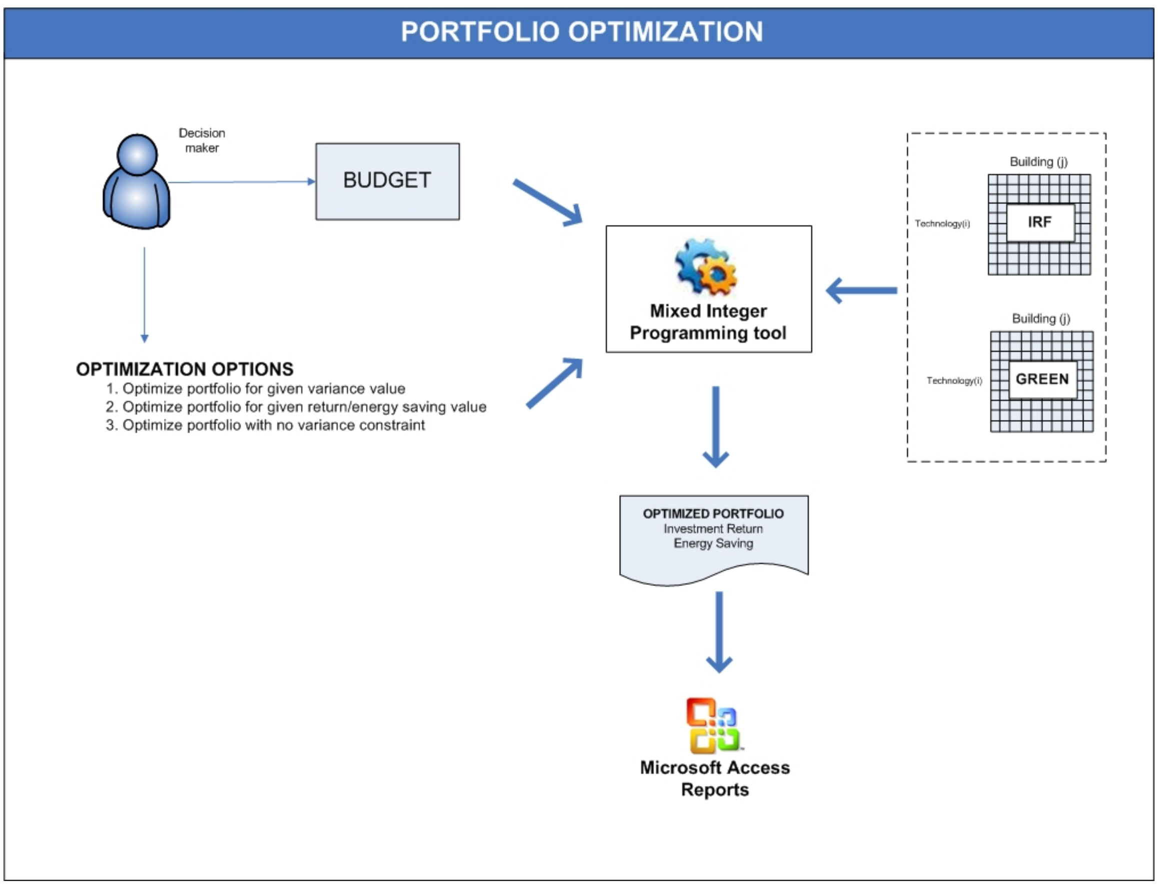

Figure 5.5: Portfolio optimization

As shown in Figure 5.5 the steps for optimizing the portfolio are:

- In this stage based on the initial budget and optimization choice, the optimal set of investment options (building technology pair) from the IRF matrix and the Green matrix is selected by the prototype.
- Optimization is performed using the through "Solver Add in" a Microsoft excel tool which can deal with mixed integer programming. A secure communication channel is established between MS excel and the prototype to transfer variables and results.
- Microsoft Access is used as the data storage and report generating tool.

5.1.4 Software interaction

The prototype interacts with several applications, and provides a single medium to enter, edit and view data. This section describes the interaction of the prototype with applications and tools in the backend. The prototype developed is dubbed "InvEnergy", with interactive forms – building selection wizard, technology selection and portfolio optimization. Figure 5.6 illustrates the interaction of the prototype with the web and the processes in the application backend.

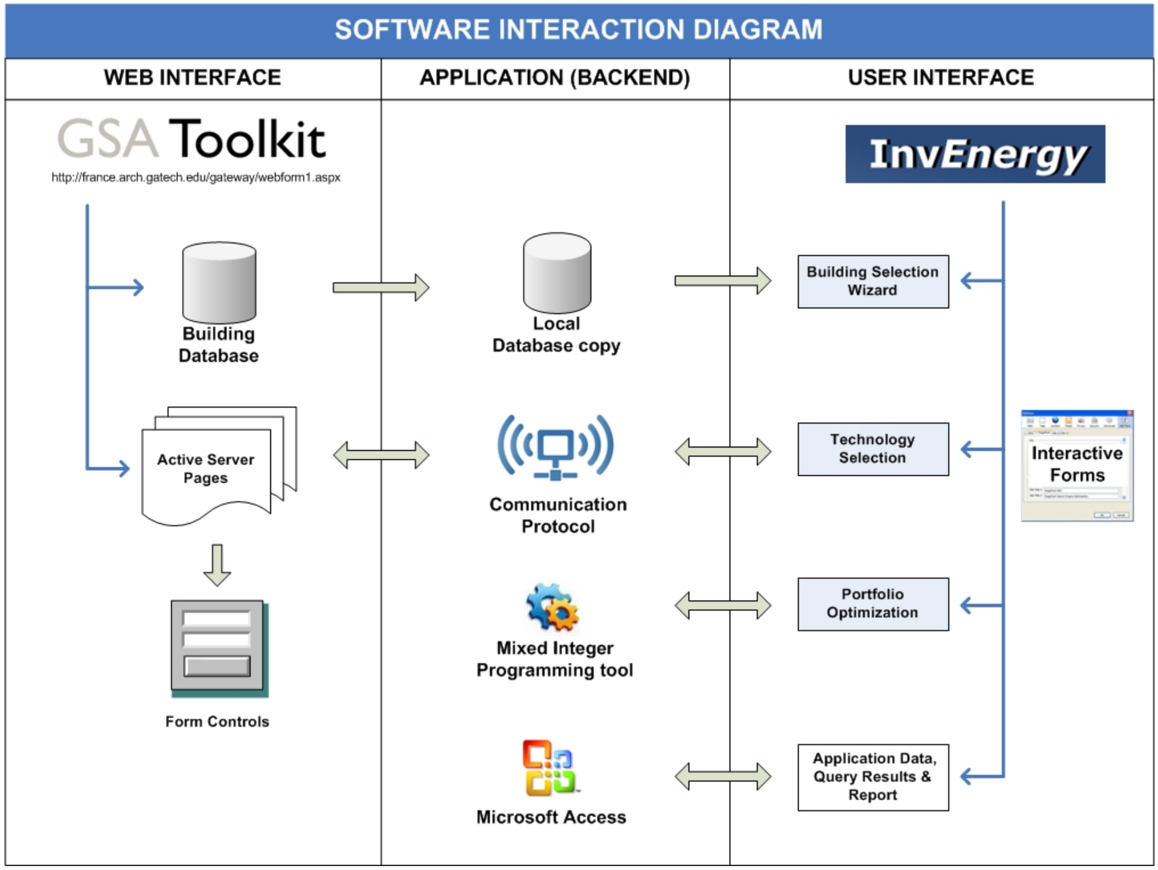

Figure 5.6: Software interaction diagram

The prototype obtains the list of available buildings in the GSA toolkit through a local database (MS Access file); a communication protocol is utilized to determine change in building performance, as explained earlier. The optimization part is handled by a mixed integer programming tool (MS Excel file), whereas the application data, query results and report generation is managed through the local database (MS access file).

5.2 InvEnergy

"InvEnergy" is customized software developed through VB.NET complier. This section explains the form fields within the application, and their working mechanism. The minimum requirements to utilize this software are given below:

- Minimum 128 MB RAM of memory is required, this software can function on any processor platform irrespective of its make.
- Any operating system i.e., Microsoft Windows 98, Windows 98 SE, Windows XP SP 2, Windows Vista. Compatibility with Macintosh, Linux or other operating systems has not been analyzed.
- Microsoft Internet Explorer 6.0 or later, Microsoft Office 2003 or later, with Excel Solver Add-in installed.

Figure 5.7 shows the screenshot of the InvEnergy Gateway page.

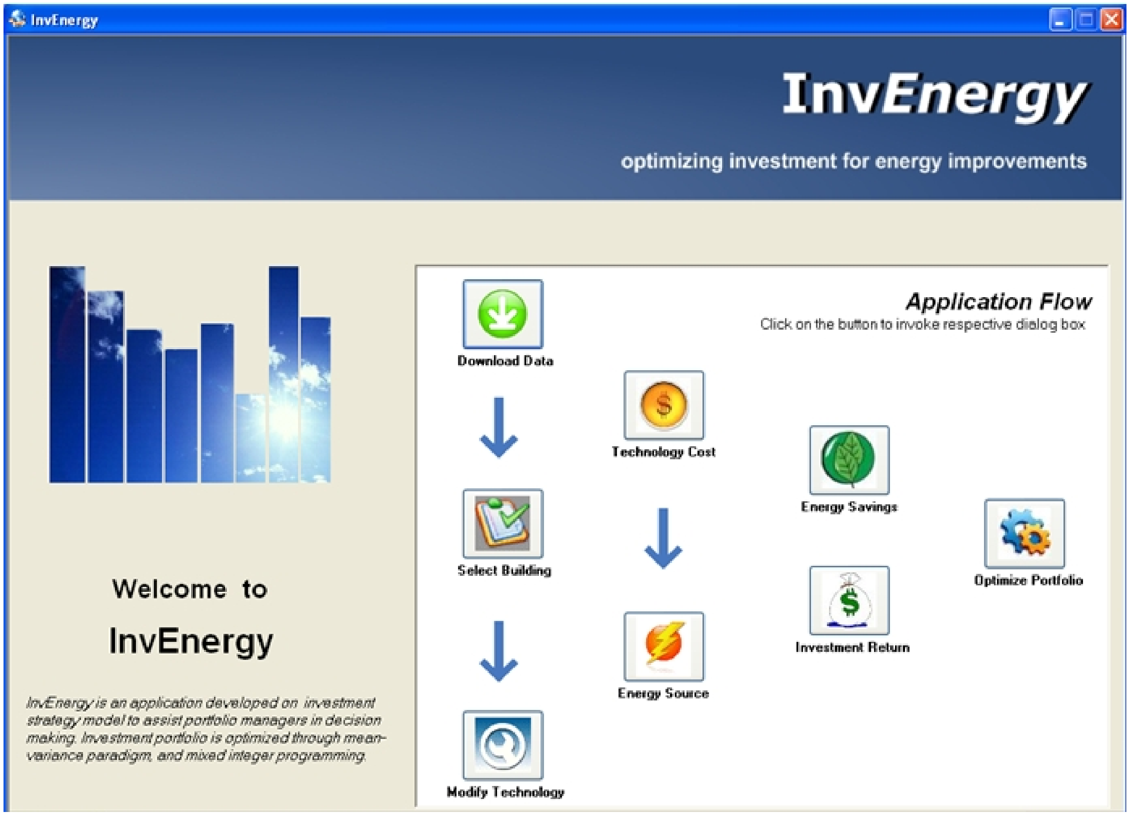

Figure 5.7: InvEnergy Gateway page

This prototype application should be operated in a designated way as shown by the application flow in the Gateway page, refer Figure 5.7. Application flow region has interactive buttons depicting the operational procedure. Each of those buttons when clicked invokes their respective dialog box.

5.2.1 Data download form

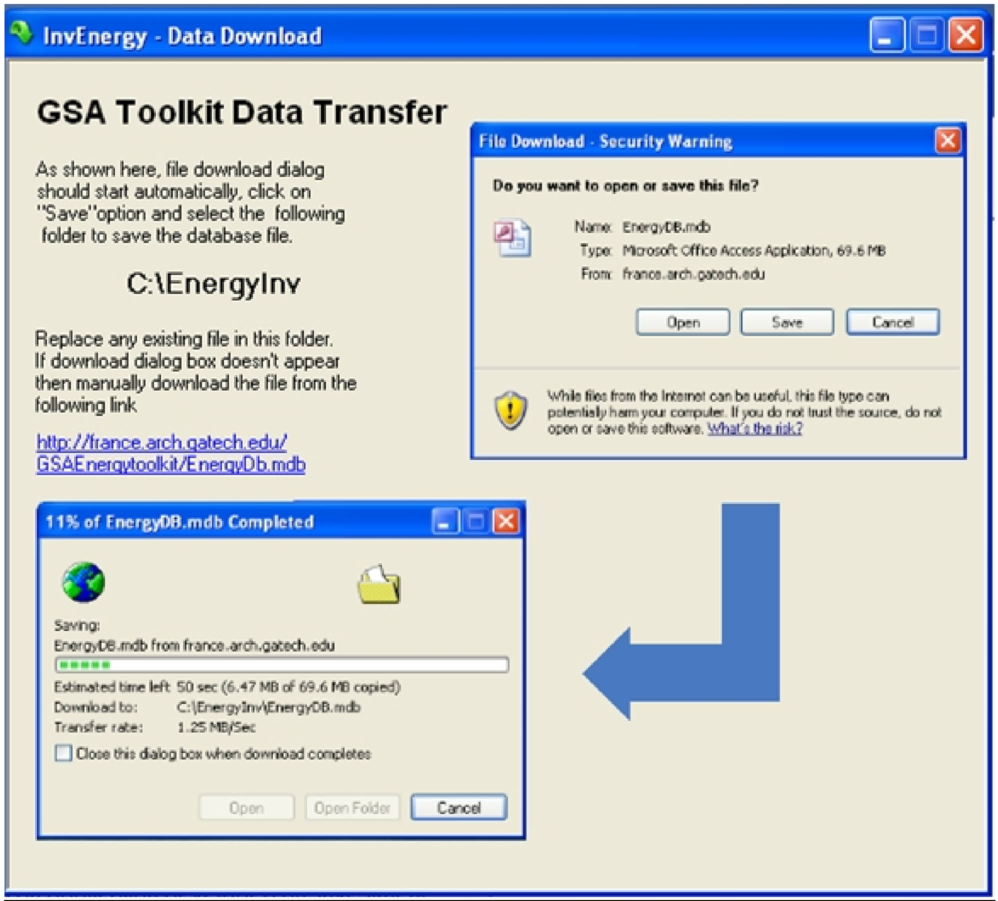

Figure 5.8: Download data dialog box

Figure 5.8 shows the screenshot of data download form. This form is invoked when the “Download data” button is clicked on the InvEnergy gateway form. It transfers the GSA toolkit access database to the local machine. This access file has to be saved in folder C:\ EnergyInv. Allow the application to replace any previously existing database, if it pops a warning message box.

5.2.2 Building selection wizard

Figure 5.9 illustrates the screenshot of building selection wizard. This dialog box is invoked when the “Select building” button is clicked on the InvEnergy gateway form. It helps the user select buildings from the GSA toolkit database, and temporarily stores them for current optimization session. This list of available buildings is populated from the local GSA toolkit database.

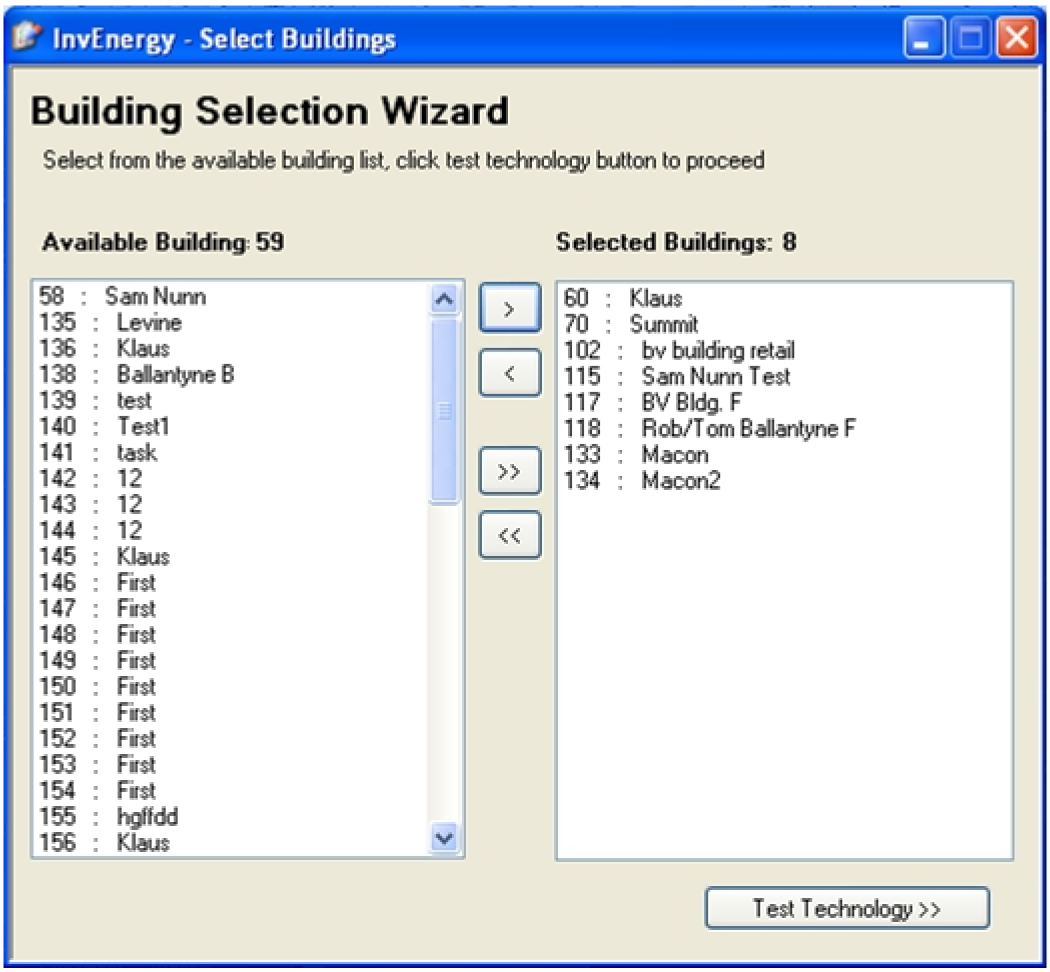

Figure 5.9: Building selection wizard

5.2.3 Technology selection wizard

Screenshot of the technology selection wizard is displayed in Figure 5.10. This dialog box controls the communication protocol; invoked when the “Test Technology” button is clicked on the InvEnergy gateway form.

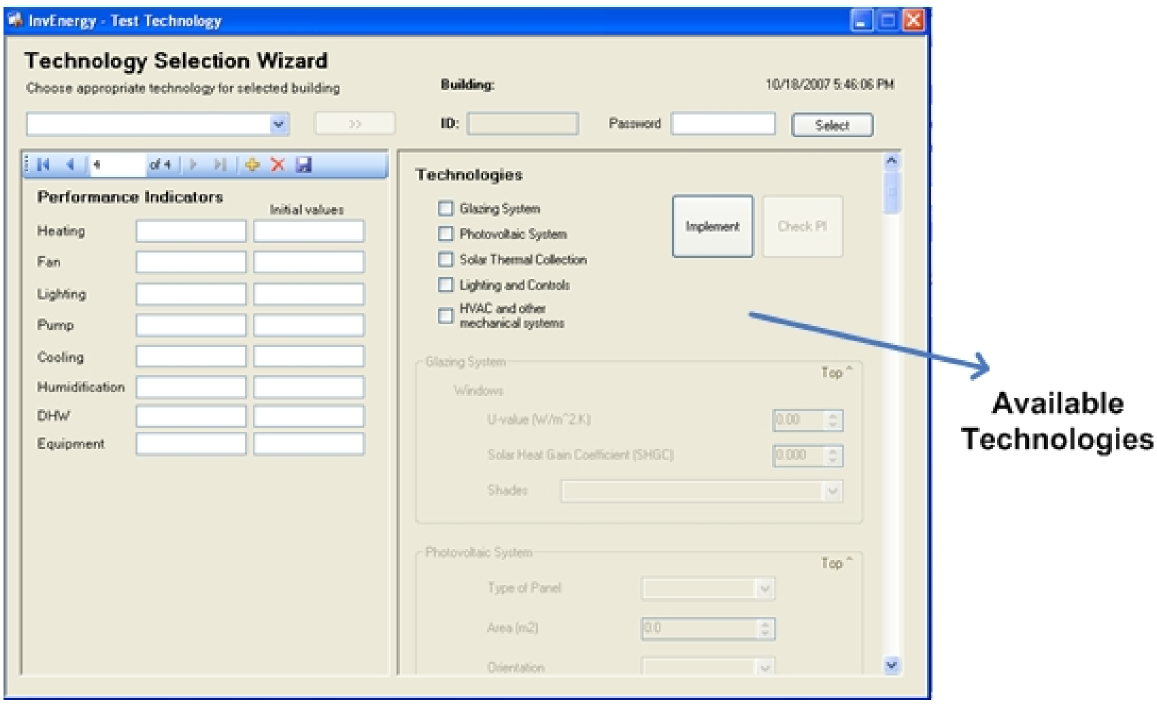

Figure 5.10: Technology selection wizard-1

The procedure followed to operate this wizard is show below:

- Choose a building from the combo box provided. The combo box list is populated from the selected buildings list box provided in the building selection wizard.
- Click on the “Select” button to trigger the communication protocol, and to display initial PIs of the selected building.
- After the values are displayed, select the technology to be modified. The technology panel will automatically navigate to respective group box to make changes in it.
- Form fields will trigger communication protocol to display current values in the GSA toolkit website. Modify these values as required.
- Click the “Implement” button to test the modified technology. To prevent the user from accidentally, controls to select new building is disabled at this stage. The implemented technology for the selected building will be displayed in a text box.
- Click the “Check PI” button to display the new PIs for the implemented technology. In the mean time the communication protocol sends original data back to the Toolkit and saves the record, as shown in Figure 5.11

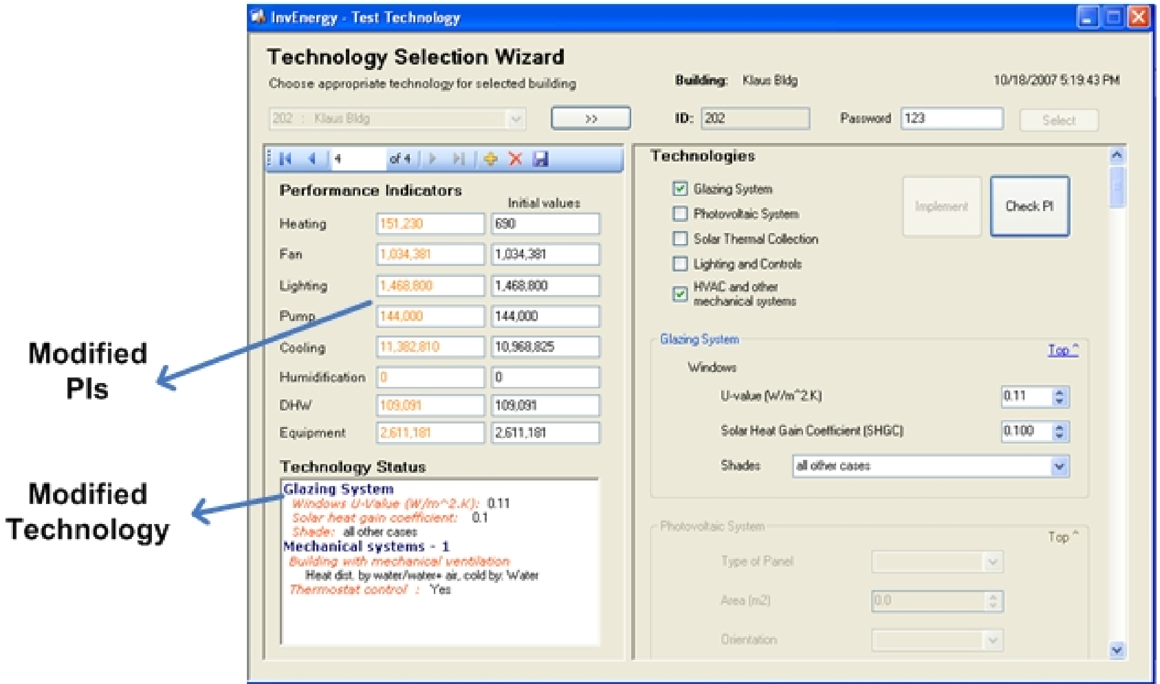

Figure 5.11: Technology selection wizard-2

5.2.4 Investment cost wizard

Figure 5.12, illustrates the screenshot of the investment cost wizard. This wizard allows user to assign investment cost to the modified technology. This is invoked when the "Technology Cost" button is clicked on the InvEnergy gateway form.

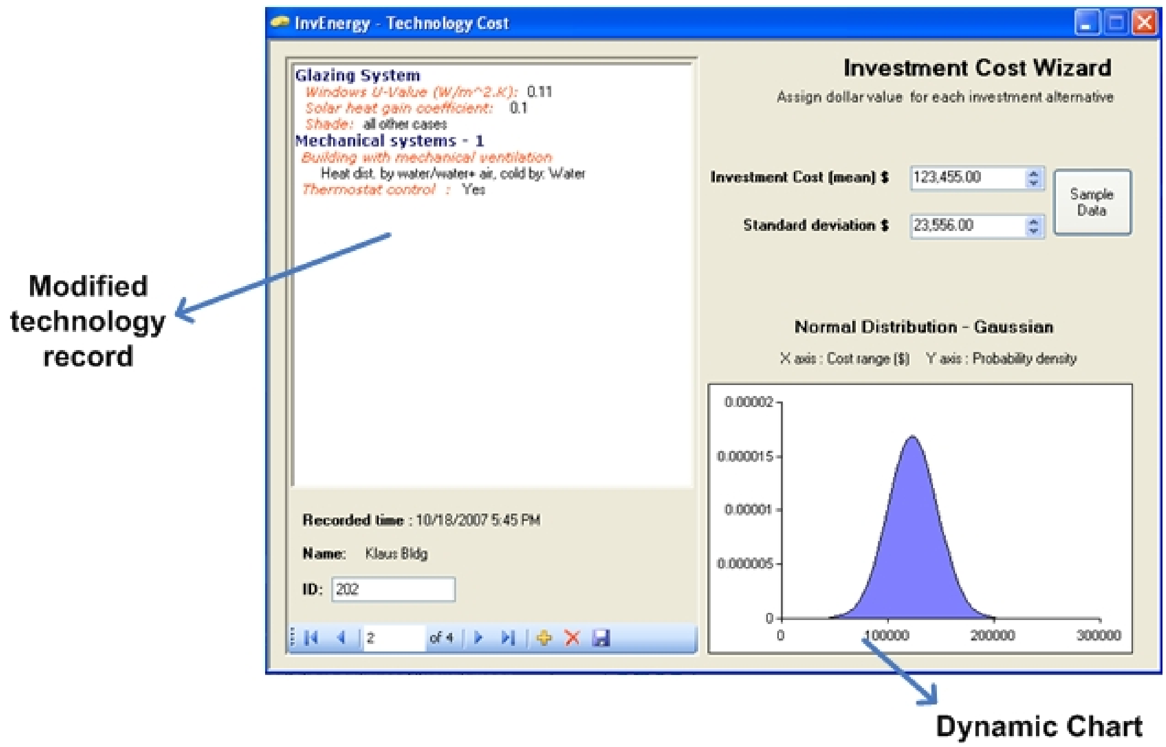

Figure 5.12: Investment cost wizard

The procedure followed to operate this wizard is show below:

- Provide a suitable investment cost mean and a suitable standard deviation. Click on the "sample data" button to calculate mean and standard deviation for a given sample of values. A maximum of 20 samples can be provided.
- A dynamic normal distribution chart is generated when values in the Investment /Standard deviation box are changed.
- Click the "Save button", when cost values have been assigned to every investment option.

5.2.5 Energy source selection wizard

Figure 5.13 shows the screenshot of energy source selection wizard. This dialog box provides an interface to provide energy source mix at campus, energy supply efficiency, and energy price. It is invoked when the “Energy Source” button is clicked on the InvEnergy gateway form.

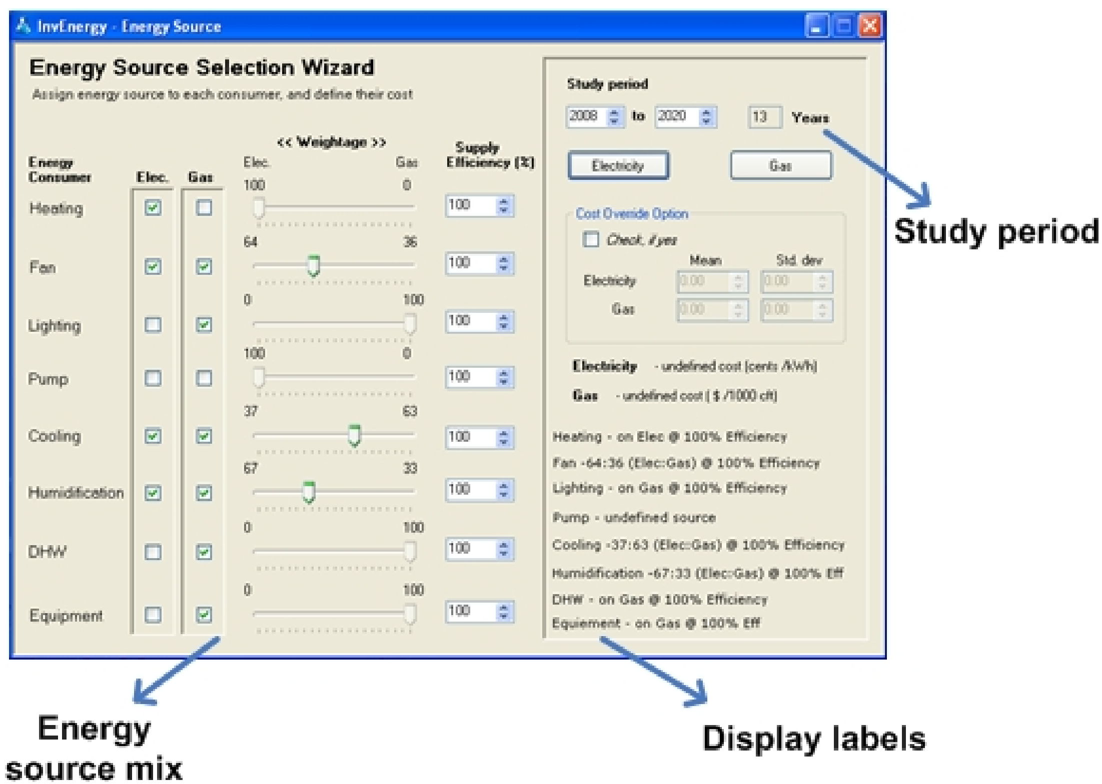

Figure 5.13: Energy source selection wizard

The procedure followed to operate this wizard is show below:

- For every energy consumer, the user can select the primary source: electricity, gas, or both. The proportion of electricity/gas can be assigned with the help of a slider. The efficiency values, if not changed, has 100% value by default.
- The study period can be assigned by changing the initial and final values in a numeric box. Click on “Electricity” or “Gas” button to load the energy price window.
- The display labels will reflect any changes made on to the form. If required, the user can override the forecasted value and assign price to energy sources.

5.2.6 Energy cost wizard

This dialog box provides an interface to alter forecasted energy cost provided by EIA. It is invoked when either the “Electricity” or “Gas” button is clicked on the Energy source selection form. Figure 5.14 displays screenshot of Electricity cost form, and magnified view of corrected energy cost. The user can assign a confidence interval to the given energy cost to introduce uncertainty.

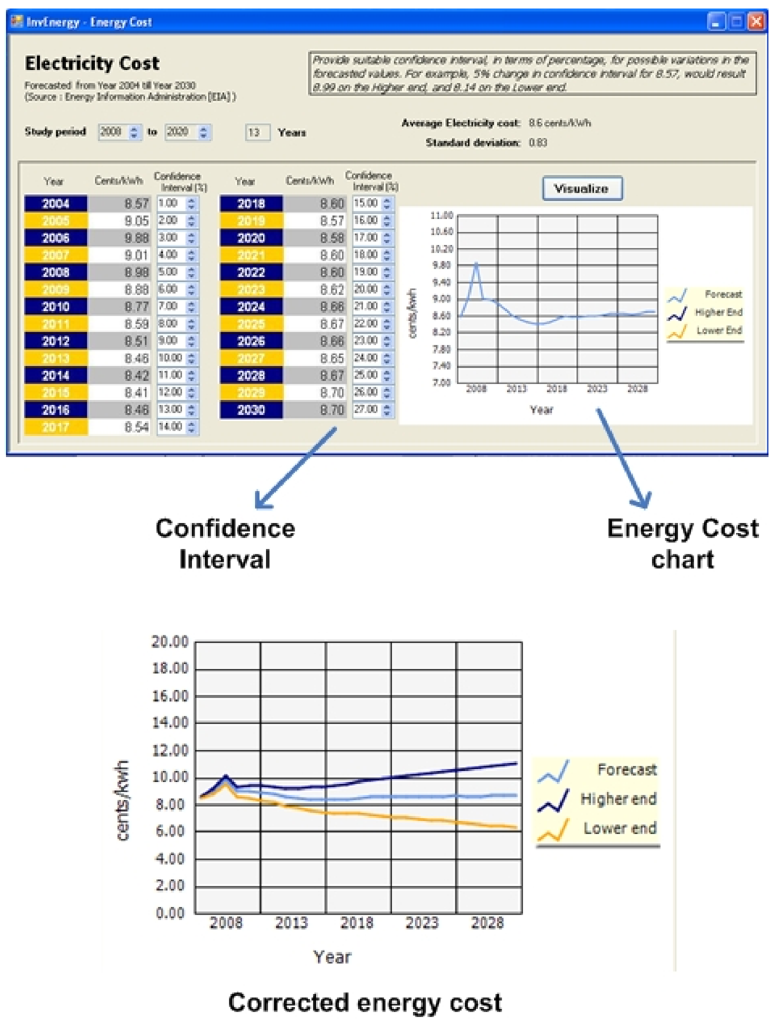

Figure 5.14: Energy cost wizard

5.2.7 Investment return/Energy saving wizard

This dialog box provides an interface to calculate IRF/Energy Saving values for each investment option. Screenshot of IRF wizard and ESF wizard is shown in Figure 5.15 and Figure 5.16 respectively. It is invoked when the “Investment return” or “Energy saving” button is clicked on the InvEnergy gateway form. The user can assign a rate of return and eco-efficiency values. The rate of return value can be different for each investment option, while the eco-efficiency value generally remains the same.

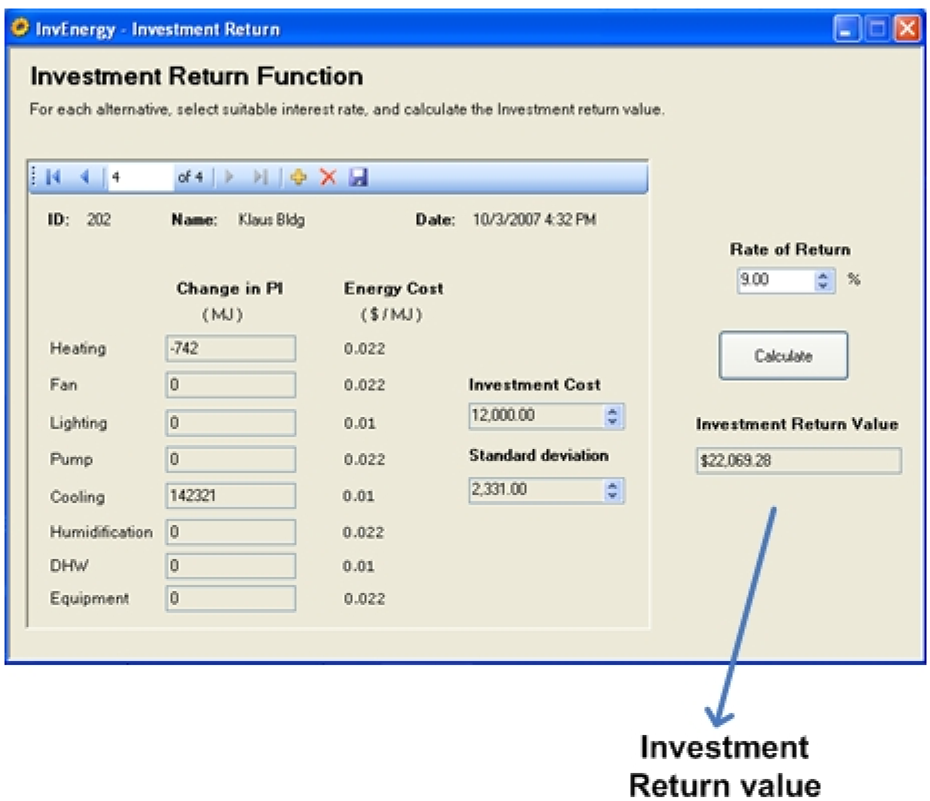

Figure 5.15: Investment return function wizard

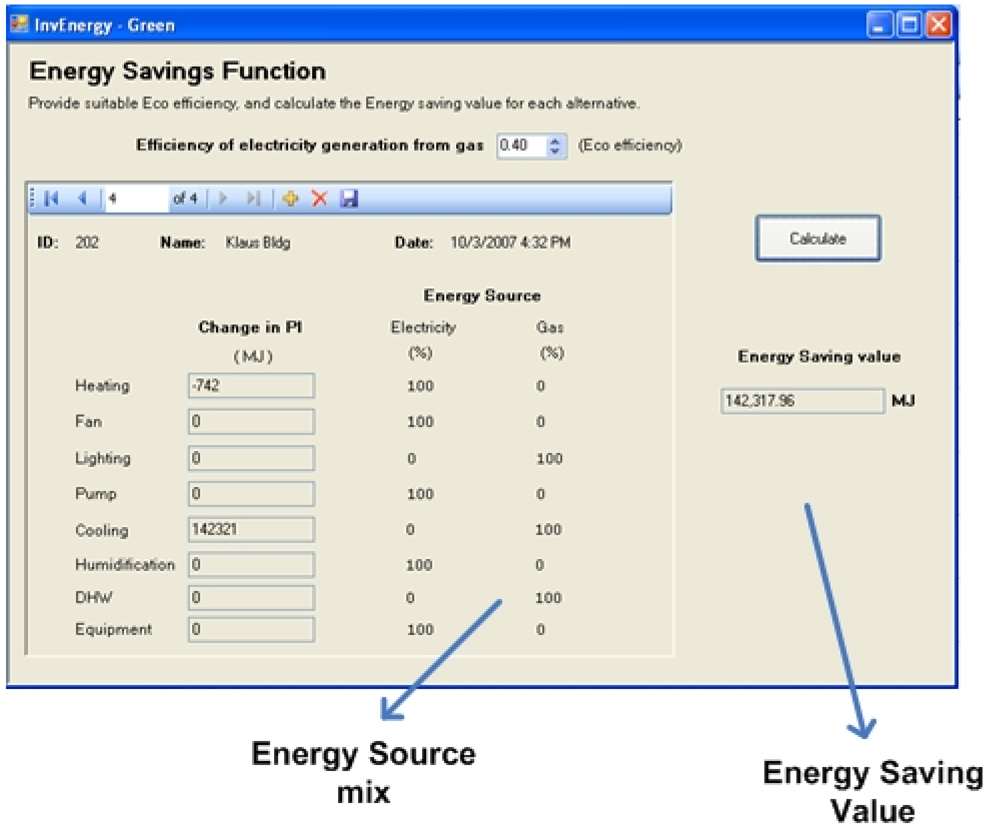

Figure 5.16: Energy saving function wizard

5.2.8 Portfolio optimization wizard

Screenshot of this wizard is shown in Figure 5.17. This dialog box provides an interface to provide a portfolio budget, and to choose optimization options for the portfolio. It has a communication channel established with a MS excel file for mixed integer programming. It is invoked when the "Optimize portfolio" button is clicked on the InvEnergy gateway form. User can either optimize Investment return/Energy saving or both of them. After selecting suitable optimization options, click on the "Solve" button to trigger the calculation in excel file. The "Result" button is enabled as soon as the solutions are obtained by the application from the Excel tool.

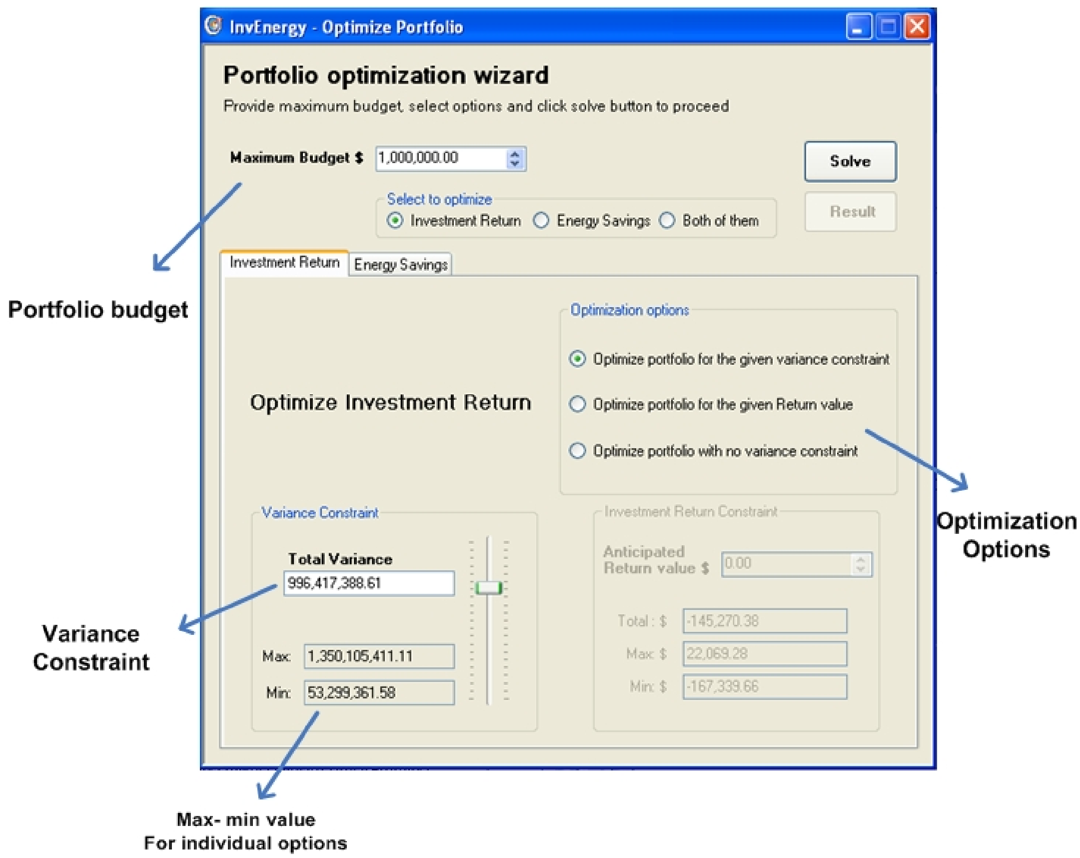

Figure 5.17: Portfolio optimization wizard

5.2.9 Results form

This form is invoked when the “Result” button is clicked on the Portfolio optimization wizard. Screenshots of combined result form is shown in Figure 5.18. The user can analyze the investment return portfolio, energy saving portfolio or both of them in the same interface. Customized reports can be made for each portfolio through MS access. After clicking on the “Print” button it will show a print preview of the report, ready to be printed!!

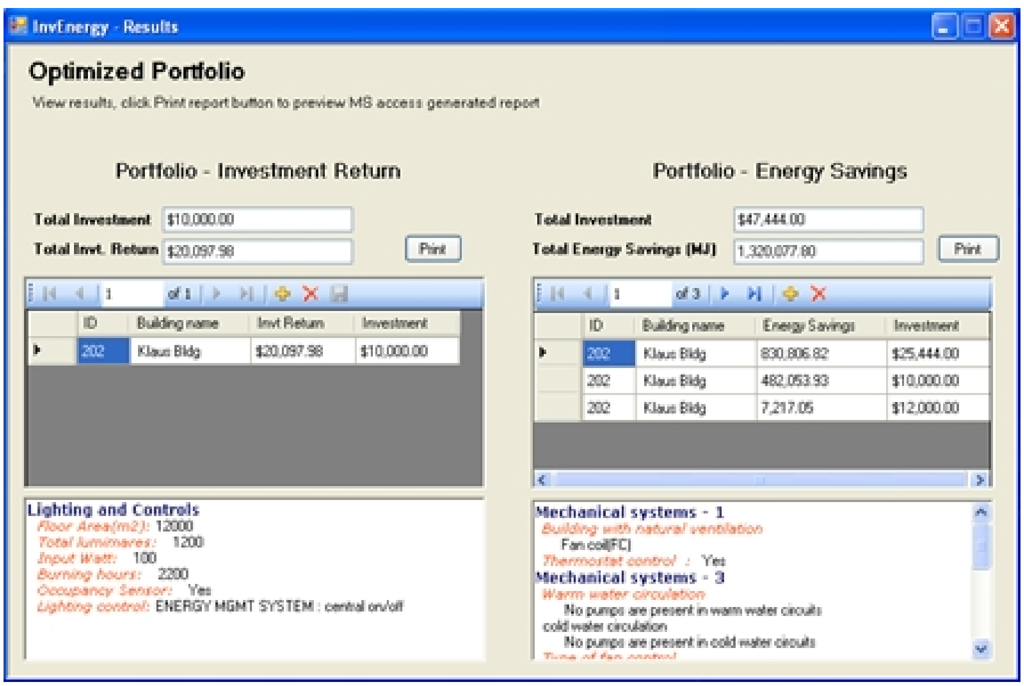

Figure 5.18: Optimized portfolio form

5.3 Issues and workarounds

This section describes the issues that were faced while developing the prototype and feasible workaround solutions that were obtained.

- Technology Selection: Our approach requires that every technology which is paired with the building should have specific input parameter associated with it. This is required to automate the automatic invocation of the toolkit to calculate the modified PIs after installing the new technologies. To do this, every technology should be predefined in terms of the toolkit-input parameters that it affects. Collection, classification and mapping of all technologies that are potentially applicable, to a toolkit input parameter set is not feasible. Therefore the current set of technologies is limited to those for which the associative toolkit input parameters could be readily defined.
- Lighting & controls Issue: In the GSA toolkit, there are four major aspects, i.e. Energy, Lighting, Thermal comfort, and Maintenance. They are dealt with in four different parts of the toolkit. In our approach, we only use the energy part. In the lighting & controls, the choice of lighting fixture/wattage is has an important impact on energy costs; however in the Energy part of toolkit, it is currently not an input parameter (standard values based on building usage are used to determine Lighting energy (MJ/ sq ft)). We have solved this problem by using the Lighting part of the toolkit in the energy calculations. This means that any technology modification in lighting & controls is now performed in the lighting part, to determine total energy (kWh/sq ft) and converted to (MJ/ sq ft).

- Energy Source Mix: Determining the electricity/gas mix of the energy source for every building and every specific building consumer would have been possible but in many cases impractical. This is therefore currently not supported in our tool. The current solution is that the expert user (facility manager/portfolio manager) is supposed to know or guess the proportion of electricity/gas utilized on campus as a whole and we assume that the same mix applies to all consumers. As a result, the software application has a slider to allocate proportion source of energy for every consumer for the whole campus irrespective of the building. This may lead to the wrong portfolio if there is a wide spread in how different buildings use gas versus electricity. If this proves to be the case, future versions of the tool will allow the user to specify the energy mix per consumer.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This study was designed to investigate the possibility of developing an optimal investment strategy model to determine the best retro-commissioning portfolio for campus buildings which suits decision maker's risk attitude and also his/her commitment to "Greenness". To rapidly deploy this investment strategy, a prototype application named "InvEnergy" was also developed.

This investment tool can provide an essential instrument for the decision makers who are faced with the task to refurbish their portfolio, if it is tested and validated with real building data. In the current business culture, the question of investment in energy savings becomes more relevant in the early stages of decision making as new initiatives to the green campus are being launched. This tool also provides an answer to the question of what can be achieved, if we put a line item of $10 million dollars to improve energy of building portfolio.

In the initial phase of research development, expected utility function was considered to be a method to map risk behavior of the decision maker, and also to select an optimal investment option. As all investment options were independent of any event, there was no feasible way to assign probability to their success, thus leading to inconsistencies in the formulation of indifference curve, and eventually utility function was compromised to the "Mean – Variance" paradigm to handle risk behavior of the decision maker. The idea to compare and integrate utility function for "Green" and "Investment return" decision was abandoned. This would have been an ideal approach to understand the minimum monetary value for which the decision maker would cease to go for "Green" or "Energy saving" technologies. Nevertheless, in mean variance paradigm it was possible to develop independent "Green" and "Investment return" portfolio, which the decision maker can review and select investment options. As the conclusion, this investment tool with its normative approach proves to be very efficient substrate to make investment decisions.

As recommendation for further scope, this research work could be continued in the following aspects:

- Testing and validation of developed investment tool on a real scale with real building data on campus, to identify possible improvements.
- As stated in the limitations, "Investment returns" and "commitment to greenness" are just two elements considered in the broader decision making framework. Other elements that impact portfolio decision making can be identified and integrated in the investment tool.
- Varied energy sources apart from electricity and gas should also be considered in the savings generated due to performance improvement.
- Provide an additional capability in the instrument to determine retro-commissioning investment cost for the building.
- Integrating utility function in the investment tool to generate optimized portfolio for decision maker's risk nature.

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