Energy Performance Gap in Energy Efficient Buildings: A Study of Occupant Behavior

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This thesis is dedicated to my parents, respected teachers, batch fellows and to my friends.

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List of Abbreviations:

LEC = Low Energy Consumers

MEC = Medium Energy Consumers

HEC = High Energy Consumers

ABM = Agent Based Modeling

SD = System Dynamics

DE = Discreet Events

AC = Air Conditioning

HVAC = Heating Ventilation and Air Conditioning

TSS = Time Saver Standards

POE = Post Occupancy Evaluation

kWh = Kilo Watt Hours

Sq. ft. = Square foot

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ABSTRACT

With the continuous increase in demand and cost of electricity, and decrease in production and supply, awareness of energy use is on the rise. This has led to a global demand for construction of energy efficient buildings due to their potential of energy saving and other economic benefits to clients and building operators. The construction industry is facing challenges to ensure that the performance of energy efficient buildings is at par with their design expectations. However enough evidence is available which reveals that these buildings are not performing as per the expectations, resulting into energy performance gap. There could be many reasons for this gap: occupant behavior is one such factor. The divergence between the predicted and actual energy consumption can be linked with the negligence of behavioral influences of occupants during design phase. Occupant behavior is dynamic; it modifies with time under formal and informal influences but energy simulation software assume it as a static entity during energy estimation. It has a lot of potential to save energy; if the behavior is positively reinforced, it can bring very good results in the reduction of the energy usage. In this research the existing behavior classification from literature is used to categorize users as per Low Energy Consumers (LEC), Medium Energy Consumers (MEC) and High Energy Consumers (HEC). Building and occupant data is collected from three office buildings in the major cities of Pakistan. Further, an agent based model is developed based on the behavior modification techniques using the AnyLogic 7® software. The model simulates the number of occupants in different categories and time required by them to change their consumption behavior. Finally, to put the findings into perspective, the effect caused by behavior modification is quantified. Conclusions are drawn and modifications for further work are proposed.

Chapter 1

INTRODUCTION

1.1 General

Climate change is problem of the day. During the past few decades the energy consumption, exacerbated by changes in climate, has become a topic of interest and a lot of research effort has been redirected towards it (De Wilde, 2014). This has resulted into numerous tools and techniques to solve these problems (Lee et al., 2013).Buildings are attributed to large amount of energy consumption. United Nations energy program reports that the buildings consume 30%-40% of the total energy from the global energy use (Jeon et al., 2010; UNEP, 2007). Let alone in the United States, the commercial buildings consume about 19% of the total energy (EIA, 2010). Throughout their lifecycle buildings consume about 80% of the energy when occupied (Azar et al., 2011). To reduce the energy usage the energy efficient buildings are designed and built. Many features such as building automation systems (BAS), building management system (BMS), intelligent controls, rating procedures, etc. are incorporated to reduce the energy usage as far as possible and to make the building energy efficient (JKW Wong et al., 2005).

Currently Pakistan is facing a lot of energy issues; downtime of the energy is very large. The registered shortfall in 2009 was 40% (Asif, 2009) which has probably gone up. Since the buildings consume a large amount of energy from the total production, this points to the fact that the buildings are not performing as they are expected. There is a gap between the predicted and the actual usage of the energy. This gap is due to the lack of feedback from the building administration to the designers, faults in the design or its assumptions, improper modelling tools, built quality of the building, over usage of the equipment installed in the buildings, poor facility management, or the behavior of the occupants (Bordass, 2004; Bordass et al., 2001; Demanuele et al., 2010). These are the causal factors by which the performance is effected (Menezes et al., 2012). In order to achieve energy efficiency, these factors need to be addressed. However, not all of them can be dealt with easily and economically; some of them demand financial inputs, whereas others would require physical changes. The 'occupant behavior' is a *soft* factor which offers promising results when it comes to achieving energy efficiency (Azar & Menassa, 2011); it may facilitate serious savings against low cost and effort. This paper emphasizes on the factor occupants behavior and how occupants can play their part in energy savings.

Several studies show that the occupants affect the energy performance of the buildings with their interactions and activities inside the building environment. Activities such as usage of lighting systems, equipment and their schedules in the buildings translate into watt-hour or other consumption unit (Bourgeois et al., 2006). If the occupant behavior is so modified that they adopt energy saving practices, a significant amount of energy can be saved (Staats et al., 2000).To address occupancy issues many tools and techniques are available to minimize the energy usage levels. Some software tools such as eQuest®, Energy-Plus®, Energy-10®, etc. are available to calculate the energy usage in the early design phase. But the problem with these tools is that they only allow variations in occupancy loads and they assume that all the occupants will consume same amount of energy over the period of the time they use this facility (EnergyPlus, 2009; eQuest, 2009). However, human behavior is dynamic; occupants change their behavior over the period of time they spend in the same place either due to inspirations from others or by the effect of their environment. Research reveals that the predicted energy consumption can be improved if the effect of occupants with the different energy consumption rates is considered (Clevenger et al., 2006; Hoes et al., 2009; Yu et al., 2011).

It is very important to incorporate the behavior of the occupants in the design so that the results and actual performance of the buildings and the accuracy of the estimations can be improved. From the literature and analysis of the available software for energy estimation, it is found that no commercially available software or tool is capable of accounting for the dynamic energy use patterns, which can simulate the behavioral changes caused by the interactions of the occupants with each other and their environment. Technological measures like simulation of behavior can predict the energy usage over the given period of time or over the life of the building (Azar & Menassa, 2011; Hoes et al., 2009; Turner et al., 2008).

With the increasing interest for more energy efficient buildings, the construction industry is confronted with the challenge to guarantee that the designed energy performance level should be achieved when the building is in actual use. However, the gap between designed and actual consumption has become an alarming source for the underperformance of buildings. This paper aims at identifying the said gap and proposing an agent based model to simulate the occupants` behavior over time. The model informs about the change in occupants behavior due to their interaction with each other and their environment. . It is expected that this work will not only help designers to predict the actual energy usage but also facilitate the building managers to see the effect of different parameters on the occupants and how they behave over changes in their environment.

This might be the weakest part of energy conservation effort that occupants' behavior towards thermal comfort and illumination levels is different than expected. Occupants' feel is different that is assumed in the design stage, they behave differently according to their needs initially but in future they may evolve new characteristics in their behavior(Lindelöf et al., 2006; Mahdavi et al., 2008).

1.2 Problem statement:

Presently Pakistan is facing a lot of energy issues, downtime of the energy is very large (Asif, 2009). So many reasons are behind these crises; one of them could be that people are unaware of proper use of energy. Therefore, energy efficient buildings are designed to overcome this problem but in our region these buildings are very few in number.

Are these energy efficient buildings performing as they are expected and playing a positive role towards the consumption of energy? May be or may be not. But if not then what are the factors or hurdles which influence their performance. Moreover, the studies show that the one factor could be the behavior of the people who are using that facility(Azar & Menassa, 2011).

With the increasing interest for more energy efficient buildings, the construction industry is confronted with the challenge to guarantee that the designed energy performance level should be achieved when the building is in actual use. However, the gap between designed and actual consumption has become an alarming source for the underperformance of buildings. This paper aims at identifying the said gap and proposing an agent based model to simulate the occupants` behavior over time. The model informs about the change in occupants behavior due to their interaction with each other and their environment. . It is expected that this work will not only help designers to predict the actual energy usage but also facilitate the building managers to see the effect of different parameters on the occupants and how they behave over changes in their environment.

1.3 Relevance to National Needs:

This research will be a beneficial contribution to the construction industry of Pakistan. This research will help the Government and Private organizations involved in construction industry to design and manage their buildings with an idea to tackle those factors which causes the loss of energy.

There are so many issues Pakistan is facing: the energy needs once the issues have been addressed in the industry it will help a lot in energy savings which can contribute towards the main issues of down fall of the energy. Moreover, this research will open new avenues of research in the future and encourage the future researchers. This area of research has a huge potential and todays need in Pakistan.

1.4 Advantages:

This research will help the construction industry to design and operate buildings with an idea to tackle those factors which causes the loss of energy. It will also help in the design as well as in facility management of low energy consumption buildings.

Once the issue will be addressed it will help a lot to the management of the facility for optimal use and strategies. It will also help the occupants to make full use of the facility at a very low cost of energy use. This research will help out in design and facility management keeping a view of occupant’s behavior towards the energy use.

1.5 Research Questions:

- What is the performance of Energy Efficient building with respect to their function?
- How the performance of Energy Efficient buildings is affected by occupants' behavior.
- How the behavior evolves over time due to formal and informal influences.
- How much energy is affected by the change of occupants' behavior?

1.6 Research objectives:

Following objectives are set forth for this research:

- To find out the gap between the proposed energy efficiency in contrast with the actual performance of the energy efficient buildings.
- To quantify the number of occupants in each category according to their behavior.
- To develop an agent based model to improve the prediction of energy consumption.
- To find out the change in energy consumption due to modified behavior.

LITERATURE REVIEW

2.1 What Is Energy Efficiency?

In general terms, the energy efficiency refers to using less amount of energy to give equal amount of services or useful outputs.

According to Patterson (1996) it can be expressed mathematically as:

$$\text{Energy efficiency} = \frac{\text{Useful output of a process}}{\text{Energy input in a process}} \qquad \text{Eq. 1.1}$$

2.2 Energy Efficient Buildings

According to Meier et al. (2002) energy efficient building is that which can be considered average in all three aspects given below:

1. Building must be built with suitable materials according to the location and its climatic conditions, also energy efficient equipment installed in it to give maximum efficiency in operation.
2. The building should serve its purpose for what it is designed for and it should provide its occupants a comfortable environment to work.
3. The building must be operated in such a way that it uses very low amount of energy as compared with other buildings of its type.

Energy efficient building provides an optimal environment for the occupants who live and work there. The building is energy efficient in terms of energy and its efficiency is a result of some intelligent features like automatically controlled heating and cooling system, ventilation, blind control, fire protection, water provisions in the toilets, efficient plumbing, etc.

There is a need to understand that the building automation is not just the only key factor to make a building energy efficient or intelligent, it is the involvement of all other systems that make up the very fabric of the building as well as the occupants who are going to use that facility. All these subsystems combine together to make a building energy efficient (Chen et al., 2006).

An energy efficient building should adapt itself according to the environment and the requirements of the users and respond accordingly by using its intelligent features and results in conservation of energy. With the passage of time the building systems should learn the patterns of the users, update the processes and then act according to the need of the users and the environment (JKW Wong et al., 2005).

According to Johnny Wong et al. (2008) energy efficient building offers cost effectiveness and productive environment by the utilization of its four basic elements and those are:

1. Places (e.g. fabric, structure, facilities, material, etc.)
2. Process (e.g. control system, automation, etc.)
3. People (e.g. service providers, occupants, etc.)
4. Management (e.g. performance, maintenance, their interrelations, etc.)

2.3 Trias Energetica Concept:

In (1996) Lysen gave this concept of sustainability, named as “Trias Energetica Concept”. This concept refers to three categories of measurement; this can bring sustainable solutions for the buildings. And those are:

1. Prevention
2. Renewable
3. Proficiency

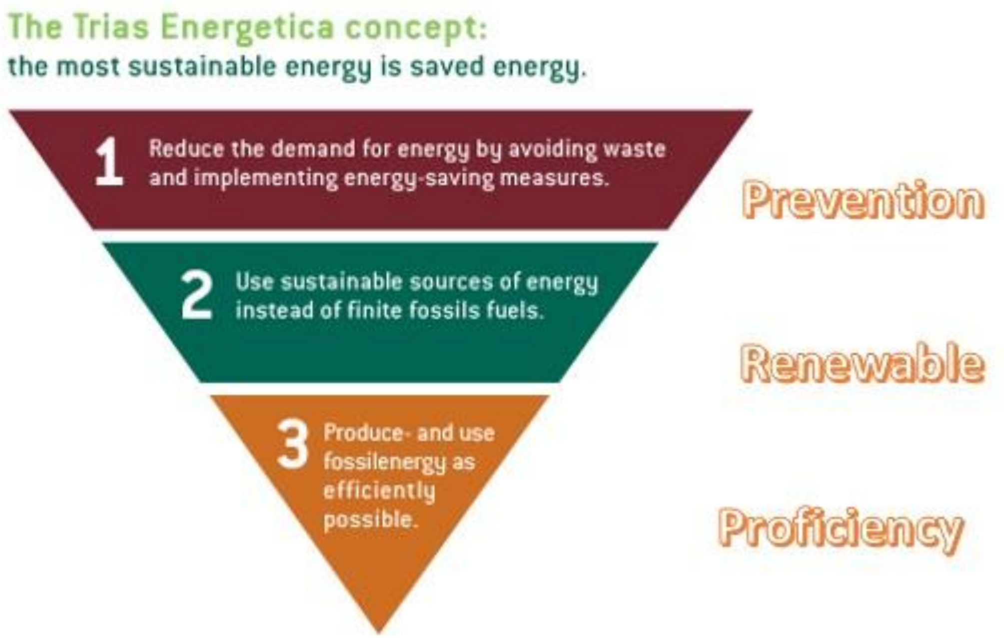

Figure 2.1: Trias Energetica Concept (Lysen, 1996)

2.3.1 Prevention:

First step is to take measures that reduce the demand of energy in buildings as much as possible. This can be achieved by proper design of the buildings, by incorporating design solutions like: providing insulation and natural ventilation, carefully placing the building in proper orientation are the examples in this case.

By using above mentioned strategies and the good use of knowledge energy demand can be reduced to the maximum level in this phase.

2.3.2 Use of renewable sources:

The next step is to use as much as renewable sources of energy as possible. This can be done by using solar panels on the roofs, facades or at any proper place where it is feasible and can give maximum output. Use every active and passive technique for the use of solar energy. The use of wind energy can also be incorporated in this category.

2.3.3 Proficiency:

In this step we try to produce and use fossil energy as efficiently as possible if there are no sustainable sources available. The non-availability of the sustainable sources only leaves a choice to use fossil fuels, and then we have to use them in a very efficient manner in order to reduce the expenses and fossil fuels demand.

One example of this is to use boiler system efficiently by combining multi-purpose like heat the building spaces and heat the water as well (Lysen, 1996).

2.4 What is Energy Efficiency Gap?

Performance gap is the increasing concern in the building industry nowadays; this concern is about the difference between the predicted and the measured energy usage. This difference is referred to as the “Energy Performance gap” (Hub, 2010; Turner et al., 2008).

With the rapid growth of building automation there is variety of sophisticated equipment available that are able to give hourly or even half hourly intervals data of the consumption. With the help of these devices the energy performance gap is quite visible. In some of the cases it shows shocking results. Reports suggest that the measured gap can be 2.5 times of the predicted energy usage (Menezes et al., 2012).

There may be various causes of this mismatch between measured and predicted performance. According to De Wilde (2014) these causes can be grouped into three main stages, causes that pertain to:

1. Design stage
2. Construction stage
3. Operational stage

This should be noted that the causes of this performance gap vary from building to building, different buildings have different issues patriating to this performance gap because of many reasons like: different climatic conditions, building orientation, building envelope, etc.

2.4.1 Design stage:

In design stage the performance issues arise because of the miss-communications between the designer and the client about the performance targets of that particular building. This miss-communication can also be within the design team to set their goals towards the prediction of energy performance (De Wilde, 2014; Hub, 2010).

One more thing is that during the design phase it is very difficult to fully predict the future functions of the building, it may be possible that the building is not serving the same purpose for which it was designed (Menezes et al., 2012; Newsham et al., 2012).

It may also be possible that the building is inadequate or not designed to meet the thermal requirements as required. The reasons could be oversized HVAC system is designed or may be the lack of proper details at this stage. Even if the building is designed as energy efficient building but the lack of attention in the construction processes or sequencing of activities might be the causes of buildings not performing the same as they were designed (Hub, 2010).

2.4.2 Construction stage:

In construction stage, the performance issues arise from the lack of details available during construction; thermal insulations are not properly installed or may be they are not adequate according to required design or may be the insufficient air tightness.

There are some issues that remain unsolved during construction process, lack of details is one of the major issues in this regard. Secondly the quality of the building is often not according to the given specifications. This is might be the issue of miss-communication of site staff and the design team or may be the non-availability of the specific product to be installed. Ultimately this will result in poor performance of the buildings (Bell et al., 2010).

2.4.3 Operational stage:

When the building is completed after the construction stage it is commissioned to the client for operation. The operational stage also contributes towards the performance gap: one of the major issues is occupants' behavior. Behavior of the occupant is not the same and standard as considered in the design stage (Haldi et al., 2008; Korjenic et al., 2012).

The actual operation of the building is normally different in most of the cases, the calculations are made on the basis of idealized situations, and assumptions of the actual control settings (such as thermostat settings, operating hours, etc.) and facility management both are idealized during the design stage.

It is also very important to accept the reality that the building is a very complex system, so there is always uncertainty associated with it. It is also difficult to collect the data and totally rely on the sensors while ensuring all the sensors are working properly and giving the results in proper way (Dasgupta et al., 2012; Menezes et al., 2012).

While basic measurements such as energy consumption can easily be collected and it is less difficult from collecting the data for the whole building's portion separately (O'Sullivan et al., 2004).

2.5 Building control systems:

Building systems used in energy efficient buildings which can play their part in saving of energy. Many types of systems are available with their integration with other systems to make them more efficient. Some of them are discussed here.

2.5.1 VAV Control:

VAV or Variable Air Volume involves supply air in accordance to the setting of the thermostat. VAV is installed along with occupancy sensors which keep a record of the building occupancy details and BMS act according to this information. Hence along with this data VAV system provides the right amount of air required in that specific area. This system is considered quite efficient in energy saving. It acts intelligently in accordance to requirement of the space (Controls, 2008).

2.5.2 AHU optimization and Integration with BMS:

An air handling unit (AHU) is a device used to regulate and circulate air as part of a HVAC system. The AHU or Air Handling Unit is the heart of any HVAC system. AHU optimization means it can work to its maximum or minimum capacity depending upon the requirement of the building at a specific time. Its integration with BMS can bring a lot of savings in energy. AHU regulates the air circulation based on the commands provided by the BMS. If AHU is optimized with BMS properly then it can bring 25% of the energy savings in buildings (Ma et al., 2010).

2.5.3 Absorption type chillers:

Absorption type chillers remove the need for boilers by having a heat exchange cycle with in the chillers. In this system the evaporator allows the refrigerant to evaporate and to be absorbed by the absorbent, with this process the heat is extracted from the building (Qela et al., 2011).

2.6 Occupants' Behavior:

According to Hoes et al. (2009):

"The presence of the people in a certain area and the actions they perform (or do not perform) to implement the change in the level of energy usage, is referred as "occupants behavior or occupants' energy usage characteristics".

2.6.1 Background:

Many studies have been done so far to analyze the effect of the building occupants on the total energy consumption by observing their actions and their interactions with the environment of the building. One type of the study which is related to lighting, where the patterns of the light switching that occupant use depends upon the room and the outside conditions. Results of these type of studies shows that the occupants who tends to use day light more than artificial lights can save energy up to 40% as compared to those who use artificial light preferably (Bourgeois et al., 2006).

Second type of study depends upon the usage of equipment in commercial buildings. One of them reveals that in Unites States during off hours less than 50% of the equipment is switched off by the users of those buildings (Webber et al., 2006).

A similar type of study shows that during unoccupied hours the average turn-off rate for equipment was 59% of desktop computers, 45% of copiers and 41% for the scanners and printers (Sanchez et al., 2007).

The third type of study performed on the schedule of occupants which have an important influence on the energy usage. A study was done by developing a single room model of an office. Model was then developed to predict the daily office presence and absence of the occupants (JKW Wong et al., 2005). Another study was done on a university building where different schedules were studied by the researcher which depend upon the type of room studied and then a model was prepared to predict the behavior of users (Davis et al., 2010).

Most of the studies show the unnecessary usage of energy by the occupants'. To overcome this problem many methods, tools and equipment is incorporated to change the occupants' behavior. And if energy saving techniques are adopted by building occupants then this will result in significant reductions in energy use (Staats et al., 2000).

According to Peschiera et al. (2010) common methods to bring change in the behavior are:

1. Energy conservation trainings
2. Use of information feedback tools
3. Peer to peer information / influence

All of these techniques provide very good results in conserving the energy. The best among them is to give trainings to the occupants and aware them regarding energy issues. This will bring quite an important change in their behavior towards usage (Azar & Menassa, 2011).

Change in behavior has energy saving capabilities as compared to other cases, may be higher than the technological solutions. The best thing of behavioral change is that it requires no high tech knowledge, and very little or may be no cost and can be applicable to both existing and new buildings. Once the energy conservation culture has been developed then the occupants can transfer it to their colleagues and to new comers as well(Masoso et al., 2010).

2.7 Buildings Designed For Less Energy Consumption Are Better From Occupants' Point Of View?

Although energy efficient buildings have a potential to deliver its best in terms of energy usage, better indoor quality and occupancy satisfaction but some studies suggest that this will not always be the case. While comparing green buildings with the conventional buildings in terms of air, health, lighting, design, productivity and overall comfort, the green buildings got a higher score than the conventional buildings (Leaman et al., 2007).

Abbaszadeh et al. (2006) have compared occupants' level of satisfaction in green and conventional buildings of University of California. The occupants' of green buildings showed more satisfaction in thermal comfort and air quality but they seemed dissatisfied with the acoustics and lighting.

2.8 Factors:

Yu et al. (2011), mention the factors that affect the building consumption can be divided into seven main categories:

1. Climate (outdoor temperature, wind speed, solar radiation, etc.)
2. Building related characteristics (orientation, area, type, etc.)
3. Characteristics related to users, except for economic and social factors (user presence etc.)
4. Building operations and service system (e.g. space cooling, hot water supplying etc.).
5. Social, economic factors (education, energy costs, etc.)
6. Building occupants' behavior and activities.
7. Indoor environment quality.

These are the contributing factors that affect the energy consumption of the buildings. All of them are addressed at different stages of the project. But it is better to incorporate every factor at each stage of the project. The purpose of the above statement is to address that everything is important at each step. For example the climate in which the project will be executed should be considered at the design, construction and operation stage. So that the importance of each factor will be addressed at each phase.

2.9 Post Occupancy Evaluation (POE):

Post occupancy evaluation is a very effective tool that is being use to study user experiences (satisfaction, preferences and perceptions) and their behavior with respect to their environment where they are working and living. Post occupancy studies have different goals and can be applied on different target audience: difference in method of evaluation, people involved in evaluation and time of evaluation. There should be a good understanding of what is to be evaluated. So, all these points must be considered before conducting evaluation (Van der Voordt, 2004).

2.9.1 Aims and Objectives of Post Occupancy Evaluation:

Post occupancy evaluation is usually done to study the drawbacks of the facility which may be neglected during design phase or may be some deficiencies in operation stage of the facility. Generally POE studies can lead to improvements in project/building under study and its results to improve the quality of programming, managing, designing and implementing the facility. The main goal is to check that the facility is serving as expected or not? But if not then what are the problems. Then comparing the results of design and POE to finally address the issues or problems in that facility. Another purpose of POE studies could be some scientific goals such as contributing in developing new tools or some new theories.

According to van der Voordt et al. (2012) some of the goals and objectives of POE are listed below:

- To record unanticipated results whether they are negative or positive.
- To monitor trends and developments.
- To explore and test the theories on complex decision making process.
- To build database, including best and worst cases, foe the development of theories and benchmarking targets.
- To deliver tools, design guidelines and policy recommendations.
- To encourage improvements on upgrading the buildings.

2.10 Agent-Based Modeling (ABM):

From the viewpoint of practical applications *"agent based modeling can be defined as an essentially decentralized, individual-centric (as opposed to system level) approach to model design"* (Grigoryev, 2015).

When planning an agent based model the modeler isolates the active beings, the agents (which can be people, companies, projects, assets, vehicles, cities, animals, ships, products, etc.), defines their behavior (main drivers, reactions, memory, states, ...), puts them in a certain environment, establishes connections, and runs the simulation. The global behavior then emerges as a result of interactions of many individual behaviors (Grigoryev, 2015).

Agent based modeling is a new modeling technique and it has many practical implications in model developing after the invention of relational databases (North et al., 2007).Agent based modeling is becoming very popular from the past few years because it has potential to influence in variety of fields. Applications of agent based modeling are found in:

- Modeling of agent behavior in stock market.
- Modeling of consumer behavior in built environment.
- Predicting the spread epidemics.

2.10.1 What Is An Agent?

As there is not a single definition available for the term “Agent”, different researchers have defined it in different ways:

An agent can be used for the components and have an ability to change their behavior in response (Mellouli et al., 2004).Another definition is that agents should contain both base level rules for behavior as well as high level set of rules to change the rules. In this the base rules referred to as the environment and high level rules referred to “adoption” (Casti, 1997).

2.10.2 The Need of Agent Base Modeling:

During the design stage of the building, the most software programs only allow few input related to occupants and are limited to building schedule hours and to the number of occupants per square foot area. The behavior of occupants is considered static entity over the time (Hoes et al., 2009; Turner et al., 2008). The need of agent base modeling is to develop an approach for energy saving and its estimation in building using agent base modeling to account for different energy behavior of the occupants (Azar & Menassa, 2011).

The key benefit of ABM is that, it has ability to cover those drawbacks which are not addressed by the current simulation programs which are generally limited to the prediction of uncertainties and responding to those uncertainties dynamically. ABM represent the environment in a very natural way in context with the occupant so it has ability to act in naturally according to the behavior of the occupant (Lee & Malkawi, 2013).

According to Lee and Malkawi (2013) some of the benefits of ABM are:

1. An agent in ABM has ability to think like human, by observing its environment and adopt changes to achieve certain goals.
2. In ABM "if-then" condition is extensively used which means it allows the agent to learn and change it behavior by its experience.
3. If ABM is developed carefully which consists of agents and relationship between them, then the results will be very useful for the system as a whole.
4. ABM can capture the natural phenomena which leads to a wider acceptance of modeling approach.

2.11 Why and when we need Agent Based Modeling?

Agent based simulation can be used to see how the pattern of occupants is emerging and what changes it can bring to the whole system which are not really visible from the individual behavior of the occupant. There are some situations for which ABM offers different advantages over the traditional modeling, it reveals the new understandings and the answer of the questions which were asked before and after ABM these questions are becoming better to understand.

According to Macal et al. (2005) when we can have the benefits in terms of agents are:

1. When there is a natural representation of agents.

2. When there are certain boundaries with the decisions and behavior that can be defined.
3. When it is important that agent can change their behavior.
4. When it is important that agents can have relationship with other agents and these relationships are dynamic.
5. When final change should be the result of whole system instead of input of the model.
6. When the past is not involved in predicting the future.

2.12 Steps involved in ABM development:

According to Macal and North (2005), in addition to the typical model building methods following steps involved in ABM:

1. Identify the agents.
2. Identify the relationship of agents with the environment.
3. Get ABM software or program and ABM development plan.
4. Get agent requisite related data.
5. Validate the agent behavior model.
6. Run the model and analyze the results from micro to macro level by linking them with each other.

These are the basic steps need to follow to develop an Agent based model. At the start identification of the agents is required. Which means that there is an intense need of agents and their characteristics to be known because this is the basic need of the model and the model is totally dependent on these agents. In next step the understanding of the environment and the relationship of agents with each other and with their environment should be established at the very beginning.

In third step a tool to generate a model is selected, in this research the selected tool is AnyLogic 7, which is capable of modeling three types of systems i.e.

- System Dynamics (SD)
- Agent based modelling (ABM)
- Discrete events (DE)

After the selection of the tool the data related to the agents is gathered that, what are the actions of the agents are to be model and what actually that are doing in their routine? Data can be gathered in the form of interviews or just by observation of the modeler. The real data and the future approaches need to be model at the same time. The initial population to be studied is defined at the start. Then the agents with different behavior are defined. Population and agents are then placed in an environment.

The interaction of the agents and their relationship with environment and with each other is defined in the form of a statechart. They are linked up with the help of transitions. Transitions basically are used to build up an action which agent need to perform. Transitions are available in different types: time dependent, rate dependent, condition dependent or initiates at a particular message. After defining the actions the model is ready to run for a specific type of programing developed. The parameters can be changed and new parameters can be deleted any time.

After running the model the results are in the form of graphs and tables, which can be imported to excel for further analysis. The agent based modelling describes the system in a very natural way and allows the model to learn from the previous experience and act according to need and requirement. Thus ABM is the best tool to study these kind of complex and non-linear systems which cannot be studied with other simple type of modeling techniques.

Chapter 3

RESEARCH METHODOLOGY

In this section the methodology adopted to perform this research is discussed in detail. How the research is started from identification of different behaviors. What are the factors which affect the behavior? The description of the model, its use. What are the limitations and assumptions for this proposed Agent based model. Furthermore, the provisions taken for the survey sample size is also described in this section.

Following is the methodology followed in this research. First of all the primary studies has been done in order to choose the research area i.e. Energy efficient buildings. Extensive literature has been carried out for the better understanding of the chosen area. Identification of behavior and behavior modification factors are extracted from the literature. With the help of these two an Agent based model is prepared. Data is then collected from the occupants, building management and from designers. This data and the simulation model is used in further analysis. And based of this analysis results and conclusions are obtained.

Figure 3.1 explains the entire procedure briefly.

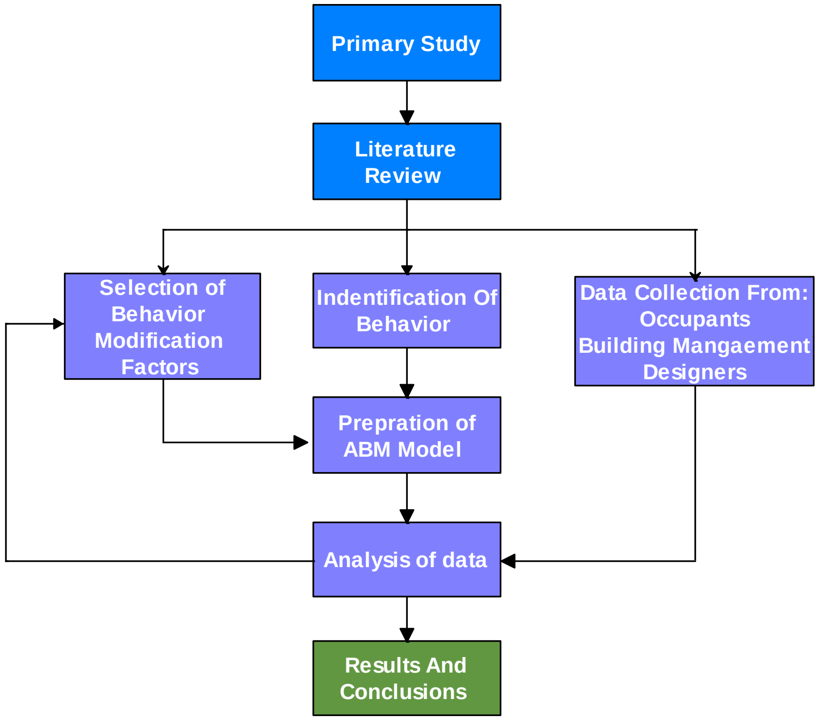

Figure 3.1: Research Methodology

Steps followed in carrying out this research and the tools used from where they are perceived are shown in Table 3.1.

Table 3.1: Steps involved in methodology.

Sr #	Step	Tool
1.	Identification of different energy behaviors.	Literature Review
2.	Identification / selection of factors that cause change in behavior.	Literature Review
3.	Simulation model.	AnyLogic
4.	Data collection.	Interview/Questionnaire
5.	Model validation.	AnyLogic

3.1 Identification of Different Energy Behaviors:

There is always an uncertainty related to the behavior of the occupants towards the use of energy in buildings. Despite using currently available software for the calculation of energy, it is still very hard to predict the future of the energy usage by taking account of occupant's behavior. The reason behind this is energy consumption can vary in a very large amount when occupants with different energy use patterns are taken into consideration (Yu et al., 2011).The different behaviors can be used to make calculations for energy models to get more accurate and reliable results. In calculations if behavioral models are considered then the results differ significantly from traditional methods of calculations.

Based on the study of Guthridge (2010), and Azar and Menassa (2011), the energy consumption behavior can be categorized as High energy consumers (HEC), Medium energy consumers (MEC) and Low energy consumers (LEC). Here HEC represents those occupants who over consume energy. MEC are those who make very little efforts towards energy savings or they are in the stage in making up their mind that they should save energy. And LEC are those occupants who use energy very efficiently. The major difference between these three classes is the pattern of energy usage in the buildings. To understand the difference in these classes it is important to have an understanding of the usage of energy in terms of building systems such as air conditioning, lighting, use of equipment, natural ventilation, etc.

Different studies are available to understand these building energy systems for example the study of Bourgeois et al. (2006) explains the lighting systems, that how the switching patterns and requirements of lights can be varied in commercial buildings and what could be their possible results. It also explains effect of manual and automatic lighting. Sanchez et al. (2007) and Webber et al. (2006) studied the effect computers and equipment that how they are used and plugged in offices. Also the status during working and non-working hours. Davis and Nutter (2010), and JKW Wong et al. (2005) studied the effect of presence of the occupants in offices and how they act towards energy usage. All the above mentioned research has been conducted for better understanding of the system which ultimately helps in understanding the behavior and the difference between the assumptions made for occupants' behavior.

So, the assumptions made are: HEC are those occupants who do not take any care about energy consumption e.g. leave their computers turned on during non-working hours, lights are turned on without their need and no care has been taken about HVAC systems for cooling the spaces. MEC are those occupants who turn their computers off before they leave office but do not turn it off during break, less lighting is being used but no day light usage. HVAC systems are used by keeping thermostat at low level. LEC turn off their computers when they leave office as well as during break as well. They utilize day light properly and HVAC system when there is a need of it. The Table 3.2 summarizes all these assumptions in terms of their usage:

Table 3.2: Behavior assumptions according to the use of Energy Systems.

Sr #	Behavior	Artificial Light	Day light	Equipment	HVAC
1	HEC	High	No use	High	High
2	MEC	Medium	No use	Medium	Medium

3	LEC	Low	High	Low	Low

The behavior of the occupant is studied on the above mentioned parameters. The criteria is set for the categorization of the occupants. Based on the questionnaire survey the occupants are divided into these three categories. This process will be discussed in the preceding sections in detail.

3.2 Identification / Selection of Factors that Cause Change in Behavior:

Behavioral change occurs due to several factors such as environment where people live or work, routines, working patterns, peer to peer influence, trainings, workshops, etc. According to Jackson (2005) if we talk about the energy conservation the factors which have maximum level of influence are:

- Peer to peer influence
- Energy conservation events (trainings or workshops)

In this research the factors used to determine the change in behavior towards energy consumption are divided into two major categories which are further subdivided:

- **Formal category**
    1. Energy events
    2. Sign boards
    3. Advertisements
- **Informal category**
    1. Peer to peer influence
    2. Act of senior management

3.2.1 Formal Category:

3.2.1.1 Energy events:

First thing to be considered in energy conservation in formal category is Energy Conservation Events which include trainings or workshops. These trainings or workshops could be in the form of a seminar which are considered to be an informational event which should have objectives such as sharing information about good consumption practices or informing regarding ways to save energy without compromising the comfort. This type of events could be arranged by the building administration at least once in a year.

It is opportune that these events are attended by all the building occupants because studies show that the amount of influence on occupants to change their behavior towards the usage of energy due to such events is substantial. As a result some subscribers of HEC convert to MEC and some of MEC into LEC (Azar & Menassa, 2011).

3.2.1.2 Sign Boards:

The second factor in formal category is sign boards placed at some selected points of the building. These sign boards include statements about energy savings along with the necessary pictures. The influence of sign boards may not be very large but with little influence it has the potential to modify the behavior of the occupants.

3.2.2 Advertisements:

The advertisement in the form of commercials over electronic media or boards placed at the prominent points also affects the behavior of the people. Different advertisements by government or by any equipment maker can bring benefits in energy savings. Because these advertisements help in developing awareness and energy saving habits, investing in them is warranted.

3.2.3 Informal Category:

3.2.3.1 Peer to Peer Influence:

Peer to peer effect represents the influence of people that interact with each other; while sitting in the same room/hall each one of them influences the others by their habits. For example in an office room there are 4 persons, 2 of them are energy savers (LEC) and 2 of them consume large amount of energy (HEC). There is a possibility that the LEC influence HEC, which helps HEC to adopt energy saving habits. Or the case may be vice versa in which LEC may convert in HEC.

Initially this kind of interaction is studied in the field of marketing, when a product is launched in the market. This particular study shows that the buyer of a particular product converted into adopters and these adopters influence the others to it (Lane, 1995). The same assumption is applied here in this research to model the behavior. It is assumed that three classes of users (HEC, MEC and LEC) are influenced by each other in context of energy consumption. They are assumed to be adopters which adopts the behavior of others while working in the same environment.

3.2.3.2 Act of senior management:

The act of any senior may influence the other members of the team to develop their energy saving habits. The leadership role vested into senior personnel allows them to influence others to adopt energy saving behavior they display routinely. For example a senior person turns off his computer and task lights before leaving his table may motivate other members to learn this habit and soon adopt it. It encourages the other members to develop their habits of consuming less amount of energy which ultimately helps them to become a low energy consumer.

3.3 Simulation Model:

Up till now the different behavior and factor that cause change in behavior has been defined. To build up a simulation model AnyLogic software is selected. AnyLogic is extensively used in the market to build agent based models (Borshchev et al., 2004). AnyLogic supports three types of modeling approaches.

- System Dynamics (SD)
- Discrete Events (DE)
- Agent Based Modeling (ABM)

Above mentioned approaches are mutually compatible, for example if we want to model a hybrid system we might go for System dynamics approach and to model just events we go for Discrete event approach of modeling. The System dynamics approach allows us to insert differential equations directly into the models which are later on solved in AnyLogic. Agent based models are capable of capturing complex behavior of the system. Such as external and internal events, communication within the system, interaction with other agents, etc. A system consisting of different units can be modeled and its effect can easily be analyzed at the system level. But in System dynamics the model is comprised of physical and mathematical models of the devices.

Agent based model is the best tool to study complex non-linear systems in which large amount of interactions of agents and their feedback are involved. Therefore, in this research on agent based modeling approach is chosen because it has the capability to combine other complex systems like System dynamics and Discrete event simulations. The beauty of the Agent based models is that even if a simple behavior is added in the system it provides capability to improve the behavior at any stage. This allows Agent based modeling to add ability to develop intelligent control (Dikba et al., 2004).

The selected energy behavior has some level of influence on each other. In one of the cases HEC influence the MEC and LEC to convert to HEC. In second case the MEC influence LEC and HEC to convert to MEC. And final case is LEC influence MEC and HEC to convert to LEC. All of these three cases are summarized in Figure 3.2.

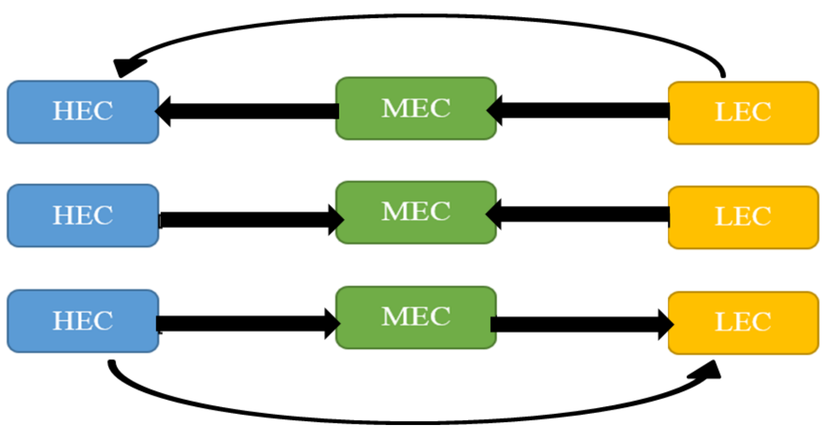

Figure 3.2: Occupant conversion chart

In this Agent based model the occupants of the building are represented by the agents. These agents are defined by different characteristics which describe the ways to interact with their environment and each other and allow them to bring change in their characteristics. This is an iterative process in which the agents keep on interacting with each other and changing their characteristics but if the change is from HEC to LEC then it is considered to be a positive change which ultimately leads to low energy consumption.

The model flowchart is shown in the Figure 3.3 below which the picture of the model which simulates the change of behavior from one category to another e.g. MEC to LEC.

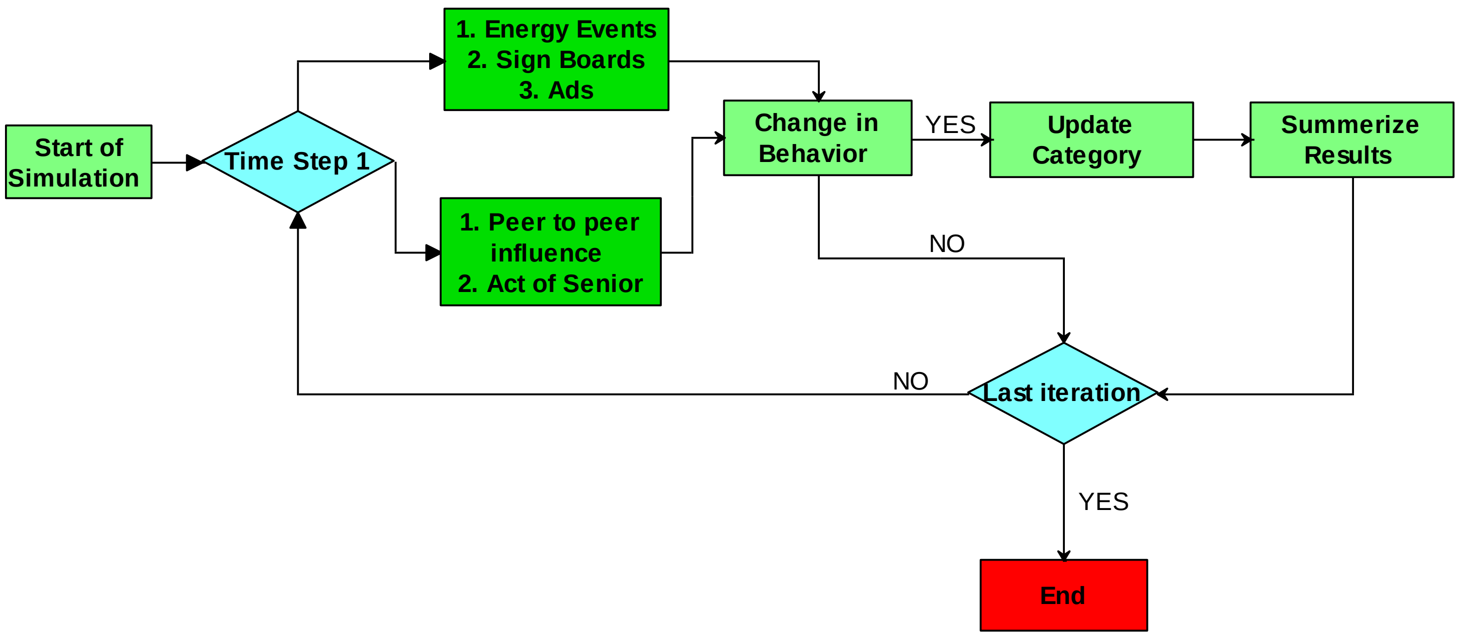

Figure 3.3: Simulation Model Flowchart

The model simulates the interactions of the agents and their behavior. The behavior change depends upon the two things: the number of occupants in each category and the level of influence of each other. By level of influence of each other it means how much each category of occupants say LEC effects other category say MEC to change their behavior while sharing the same environment e.g. same office. For now level of influence is taken as 2%/person/month which means that LEC has a capacity to convert any other occupant to change its category by 2%. If the value of level of influence of one category is higher, it means that category exerts more pressure on others to change their category.

Thus, at the start of simulation the model analyzes the results of formal and informal category simultaneously. In formal category the values of influence of energy events, sign boards and advertisements are given to the model. These values combine with the values of LI of each category to be analyzed by the model. If the change in behavior occurs and some of the occupants change their category, the model updates the occupants' categories and stores the new number of HEC, MEC and LEC for the next iteration.

In the next step the model summarizes the results and checks out the category of occupants. After this the results are displayed showing how many occupants have changed their behavior and converted to other category. This process keeps on repeating till the total simulation time has reached. The results are in the form of graphs and time state charts which show how much of the occupants have changed their category and what influence it will bring over the total consumption.

3.4 Agent based Model:

As mentioned earlier, the AnyLogic is used in this research to develop an Agent based model. AnyLogic is widely used simulation software and can produce very reliable results. The model type is Agent based model. Agent based modeling is selected because it has an ability to look deep inside the system. In this different types of agents can be defined within an environment.

For this research the model is developed using 3 behavior categories i.e. HEC, MEC and LEC. The total population of the sample is divided in these categories. The hierarchy of communication and the way the occupants change their behavior is defined while developing the model. Figure 3.4 illustrates the model statechart. The behavior categories are joined together with the help of transitions. Transitions are path on which the behavior changing parameters are defined. These transitions are also used to express the path to add or subtract the number of occupants in each category for every single time event when simulation is performed.

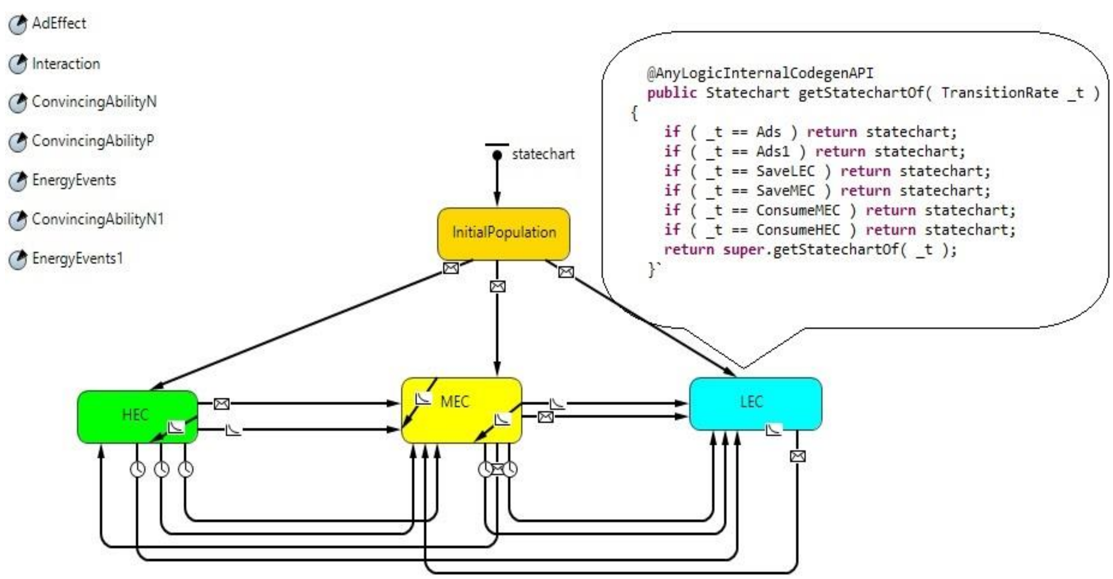

Figure 3.4: Model Statechart

The model is prepared with java coding in the transitions as well as in the behavior categories in the statechart. The parameters which affect the behavior are defined with the values taken from different studies. For example the effect of ads is taken as 0.01 which exhibit that the 1% of the total population can be affected by the Ads per day (Bhatt et al., 2010).

Interaction parameter has its default value 1 per month, which means that the occupants interact with one another once in a month and talk about the energy issues. The beauty of this model is that it can simulate the positive as well as negative effects of a certain parameter. For example, in this interaction parameter the occupant may be a random agent in the model and it can be a HEC which effects any other MEC or LEC to adopt bad energy consumption habits. This is only possible when this HEC has a high level of influence on other occupants. In the same MEC can influence HEC to reduce its bad energy consumption habits and influence LEC to adopt bad consumption habits.

So, at the start of the simulation the value of the interaction parameter can be changed and the user can define the value according to its requirement depending upon the nature of the environment under study.

3.5 Data Collection:

First of all three Energy efficient buildings were selected in three big cities of Pakistan.

Following are the buildings selected for this research:

- **FFC Headquarters, Rawalpindi**

  12 storey + 3 storey Office space and Data Center

  Architect: Meinhardt

- **Center Point Office Tower, Karachi**

A 28 storey state-of the-art Office Tower with a Tier 3 Data Center , swimming pool, gym, executive restaurant.

***Architect**:* Arcop Associates

- **MCB Data Center, Lahore**

  Purpose built IT building with a Tier 3 Data Center

  ***Architect**:* Arshad Shahid Abdullah

The operational data of building energy consumption is collected from the building management team. Other than that the designed energy consumption data is also collected from designers of the buildings the details of designers is mentioned in Appendix II. Both of these energy consumption values use to determine the energy gap between the designed and actual energy consumption of the building.

To study the behavior of the occupants' data is collected in the form of questionnaire survey and interviews from the building users. The questionnaire is to find out the pattern of activities which are being performed by the occupants in their daily routine.

3.5.1 Survey sample:

The focused population in this research is the building users. The data is collected by distributing the questionnaire to the occupants. The questionnaire technique is considered suitable for collecting data from the building users because of its ease. The respondents need to answer the question as per their daily routine, what they actually do during their office timings.

While choosing an appropriate means for research, it is compulsory to think through the connections between information selection and the required issues to be resolved through research, as well as the main concerns to be resolved and the results. Therefore, when continuing on a research, it is very important that the link among research questions, the kind of information obtained and the technique of information research approach should be considered.

3.5.2 Sample size:

A typical objective of survey research is to gather data representative of a population. The researcher utilizes data assembled from the survey to sum up findings from a sample back to a population, inside of the limits of a random error. It is very convenient for the researchers to gather a small sample and inference about the larger population. To collect data for the whole population is very hectic and time consuming (Holton, 1997). The researcher should decide first that which variables should be considered in determining the sample size.

Following are the factors which should be considered before determining the suitable sample size (Dillman 2007),

- Error in sampling
- The size of the population
- Differences in responses
- The level of confidence

This infers that for keeping the specimen size advantageous and sensible, a little number of sub-classes ought to be considered, potentially lessening the scope. Additionally, for diverse population, there are distinctive pointers to be used. Indicators specific to the project involve number of projects as the population, indicators specifically to the firm comprise on number of firms as the population, and pointers specific to the business oblige number of sub-classifications as the population.

Table 3.3: Minimum Sample Size .(Kotrlik et al., 2001).

	Sample size					
	Continuous data (margin of error= .03)			Categorical data (margin of error= .05)		
Population size	alpha= .10 t= 1.65	alpha= .05 t= 1.96	alpha= .01 t= 2.58	p= .50 t= 1.65	p= .50 t= 1.96	p= .50 t= 2.58
100	46	55	68	74	80	87
200	59	75	102	116	132	154
300	65	85	123	143	169	207
400	69	92	137	162	196	250
500	72	96	147	176	218	286
600	73	100	155	187	235	316
700	75	102	161	196	249	341
800	76	104	166	203	260	363
900	76	105	170	209	270	382
1,000	77	106	173	213	278	399
1,500	79	110	183	230	306	461
2,000	83	112	189	239	323	499
4,000	83	119	198	254	351	570
6,000	83	119	209	259	362	598
8,000	83	119	209	262	367	613
10,000	83	119	209	264	370	623

3.5.3 Sections of questionnaire:

The questionnaire is primarily designed to differentiate between the category of the occupants and pattern of their daily routine. This will lead us to the category of occupants in which the respondent lies, either the respondent lies in HEC, MEC or LEC category of the energy consumers. For this purpose very simple questions were included in the questionnaire. All questions were related to the daily routine of the users. The questionnaire can be seen in Appendix I.

The questionnaire is divided into six sections, section 1 is related to the personal information in which the respondent required to give information about their work space either it is located in a large hall or they have private enclosed offices. Also the time they spent on their work place which helps in determining the time of contact with the equipment and appliances.

Section 2 is the equipment category, in this section the respondents asked to give information about the equipment or appliances they use during their stay in their office, for how much time they use their computer, printers, etc. In this section also they are required to give information about what they usually do with computer when they leave their office for home or a short break, they switch it off or put it on sleep mode and when they turn on their printers and scanners. This section helps to determine the usage pattern of the respondents towards the equipment.

Section 3 is the day light category, in this section the respondents asked to give the information about the sources of daylight they have in their work place, they have enough daylight through that source or not. And for how much amount of time they utilize daylight. In this way this section helps to determine either the respondent has knowledge about utilizing day light or not and if they know about it how they are employing their knowledge on it.

Section 4 is comprised of the questions about the artificial light. This section gives the information about how many lights are present in the office and how many lights usually switched on. Either the users control the lights or they are automatic. And also they turn the lights of or not when they leave office for home or a short break. This section gives the results about the pattern towards the artificial lighting system.

Section 5 is related to HVAC system, in this section the information regarding the type of air conditioning system is provided by the respondent. Air conditioning systems consumes a large amount of electricity in buildings so it is very important to know about the pattern of usage of HVAC systems in buildings by the occupants.

Finally the last section is about the energy efficiency. In this section the respondents asked about the level of awareness they have energy efficiency and sustainability. And also it is important to know that how much an individual urge to put his own efforts in energy saving, this is done by asking the question regarding their approach towards energy savings and how much they know about the individuals who adopt energy saving habits around them. All that information together helps to categorize the occupants and ultimately it will become the input of the model which is proposed in this research.

Chapter 4

RESULTS

In this chapter the findings of this research will be discussed. It explains the methods of analysis that are performed on the collected data and the results obtained. The chapter also reports findings from the model proposed in this research. A total of 3 energy efficient buildings from three major cities of Pakistan are surveyed to gather the data from occupants as well as the building managers for the operational data of the building. In order to get the design data the designers of these buildings, 3 architectural and 3 MEP designer were visited. A total of 101 building occupants were surveyed for data collection.

4.1 Survey data:

In this section the details of data collection is provided. How many response have been collected and from which sources other data about building is gathered. Mainly the results of data collection have been discussed here.

4.1.1 Data from Building Occupants:

Based on the data collected with survey questionnaire form building occupants. Total 101 responses from the occupants were gathered. And building wise details is given in Table 4.1.

Table 4.1: Frequency of the respondents.

Sr #	Building name	Number of Respondents
1	FFC Headquarters, Rawalpindi	32
2	Center Point Office Tower, Karachi	25
3	MCB Center, Lahore	44
	Total	**101**

4.1.2 Data from the designers:

Designers of these selected buildings were interviewed regarding the design aspects of the buildings. Questions were asked regarding the design features and assumption during the design phase in terms of energy consumption and the building efficiency. Some information was acquired related to the feedback of the buildings either they are performing well as expected during the design phase. Because the literature shows that most of the energy efficient buildings are not performing as they are expected to perform in the design phase (Menezes et al., 2012). Some reviewed literature reports an average reduction up to 50% in efficiency (Nicol et al., 2005; Turner et al., 2008).

The assumed values of the designed consumption are taken from the designers to compare them with the values taken for the operational data of the building. Furthermore, the information regarding the tools and the standards they follow during design was also taken. Questions were also asked about the behavior of the occupants, whether it was assumed it during the design phase or not. The tools used by the designers and their capability to model and analyze the occupant behavior were also inquired. They were also asked to share their thoughts on the topic of behavior of the occupant and energy efficiency issues.

4.1.3 Comparison of the Building Data from Designers and Building Manger's interviews:

The data obtained from the interviews of building managers and the designers is briefly discussed in Table 4.2. All of the three buildings with their intelligent features are explained. What are the different features in those buildings which make them energy efficient e.g. BMS, lighting control systems, security systems and firefighting systems. All these systems work together to make a building efficient.

Table 4.2: Comparison of the building systems

Characteristics	FFC	Centre Point Tower	MCB Centre
Location	Rawalpindi Peshawar Road.	Karachi Adjacent to KPT flyover	Lahore Opp. Askari X
Year built	2012	2013	2014
Building nature	Energy Efficient	Energy Efficient	Energy Efficient
Total floor area	316,000 Sq. ft	202,732 Sq. ft	187,000 Sq. ft
Number of storeys	14 + 2 basements	GF + 27	8 + 4 basements

Total building cost	Rs. 2 billion	Rs. 2.5 billion	Rs. 1.1 billion
Energy Efficient features:			
BMS	Yes	Yes	Yes
HVAC systems	• VAV control • AHU optimization • Integrated with BMS • Manually controlled dampers to set air volume and cycle change in different areas • Temperature is manually set on each floor • Gas fired chillers for saving electricity cost • Pre-set temperatures after	• VAV control • CAV+VFD control Units • AHU optimization • Integrated with BMS • Gas fired chillers • Combined with Co-gen system • Pre-set temperatures after which AHUs automatically shut of chillers saving both resources and	• VAV control • AHU optimization • Integrated with BMS • Gas fired chillers • Combined with Co-gen system • Pre-set temperatures after which AHUs automatically shut of chillers saving both resources and energy

	which AHUs automatically shut of chillers saving both resources and energy • Absorption type chillers with heat exchanger, eliminating the need for boilers.	energy • Absorption type chillers with heat exchanger, eliminating the need for boilers	• Absorption type chillers with heat exchanger, eliminating the need for boilers
Lighting control	• Not integrated with BMS, conventional lighting system most of the control is given to users • User controlled blinds for artificial lighting	• Occupancy sensor are installed to reduce the lighting load • Management controlled blinds for artificial lighting	• Integrated with BMS not user controlled • Occupancy sensor are installed to reduce the lighting load • User controlled blinds for artificial lighting

Firefighting system	• Automated response with manual over ride • Smoke detectors • Automatic sprinklers • Smoke dampers • Integrated with the HVAC system Pressurized stairwells	• Automated response with manual over ride • Smoke detectors • Automatic sprinklers • Integrated with the building management system • Integrated with the HVAC system	• Automated response with manual over ride • Smoke detectors • Automatic sprinklers Integrated with the HVAC system
Security system	• Integrated with BMS • Personnel identification using access cards • Car parking management using RFID	• Integrated with BMS • Personnel identification using access cards • Time cards • CCTV	• Integrated with BMS • Personnel identification using access cards • Time cards

	• Time cards • CCTV		• CCTV
Temperature maintained	25 °C ± 1°C Temperature can be manually adjusted on each floor	23 °C± 1°C No user control on temperature	24°C - 25°C No user control on temperature

4.1.4 Discussion:

All of these three buildings were selected in different cities of Pakistan so that we can generalize the characteristics of the buildings constructed in this region. FFC, Rawalpindi building has the largest covered area among all of them and it is constructed in 2012. This building includes intelligent features like VAV systems, AHU optimization and gas fired chillers. All of these are integrated with BMS which automatically controls the building temperature. The most prominent feature included is that temperature control boards are installed on each floor area so that employees working there can also set the temperature according to the comfort level they need. This feature of controlling temperature and air flow can play a significant part in saving energy once the users adopted energy saving habits.

Moreover the lighting system is not automated with the help of occupancy sensors or with the BMS. The control of the lighting system is given to the users so that they can use artificial and day light according to their requirement. There are chances to consume more or less energy by the user.

Centre point tower building, Karachi is in operation since 2013 and tallest among all of the selected buildings. Here the HVAC is integrated with the BMS. Everything is controlled by the building management for HVAC systems. No control panel of any kind were sighted during the visit which was later confirmed in the interview. This implies that occupants cannot control the temperature or air flow of their work space. If they feel uncomfortable they have to inform the building manager who will change the configurations accordingly. While talking in terms of the lighting system it is not integrated with the BMS, rather a control panel is given at each floor to control the lights. Since it is not readily accessible to the users, there is very little possibility of saving energy by considering the role of the users.

MCB Centre, Lahore is in operation since 2014. In this building both HVAC and lighting system are integrated with BMS. Lighting system is integrated with the occupancy sensors which is a good step towards the energy efficiency. But the dark side of these sensors is that the users do not pay any attention towards the energy saving by their own.

So, talking only in terms of behavior of the occupants, they can play important role in energy conservation only if more control is given to the users for controlling lights, blinds and HVAC systems. The discussion can be summed up by saying that FFC building has more potential of energy saving without compromising the comfort level of the occupants if proper workshops and trainings are arranged to spread awareness in the occupants. Because in this building at users end there is a lot of control already provided. On the other hand MCB and the Centre Point Tower have less potential to save energy in terms of HVAC systems and lighting system.

4.1.5 Energy gap:

Energy efficiency is the one of the attributes of the building which is considered as the performance indicator. There may be a possibility that the energy gap exists between the predicted and the actual energy (De Wilde, 2014). To determine if this gap exists or not the data obtained from designers and building5 managers is mentioned in the Table 4.3.

Table 4.3: Gap between Predicted and Actual Energy

Sr #	Building name	Area (Sq.Ft.)	Actual Consumption (KWh/day)	Predicted Consumption (KWh/day)	Actual consumption (Kwh/month)	Expected consumption (Kwh/month)	Difference	%age Gap
1	**FFC, Rawalpindi**	316000	900	750	19800	16500	3300	16.67%
2	**CPT. Karachi**	202732	700	600	15400	13200	2200	14.29%
3	**MCB, Lahore**	187000	650	550	14300	12100	2200	15.38%

After analyzing the data it has been found that the gap exists between the predicted and the actual energy. The FFC building has 16.67% more energy consumption then its predicted energy at the design stage. Similarly, 14.29% and 15.38% for CPT and MCB respectively. The average gap found in these buildings is **15.45%.**

4.2 Survey results:

The data is obtained from the survey forms, some of the questions based on the consumption and on the behavior of the occupants are extracted. The consumption values are taken from the different sources e.g. PEPCO, Ashrae 90.1, USGBC and Energy Star. Table 4.4 shows the values of the appliance power usage and the source from where these are taken.

Table 4.4: Building energy standard information

Sr #	Appliance name	Power Usage	Source
1	HVAC / AC	1400-1600 Watts/hr	(PEPCO), USGBC
2	Computer	200 Watts/hr	(PEPCO), USGBC
3	Printer	250 Watts/hr	USGBC & Energy Star
4	Scanner	150 Watts/hr	USGBC & Energy Star
5	Fans	70 Watts/hr	(PEPCO)
6	Table Lamps	60 Watts/hr	(PEPCO), USGBC
7	Energy savers	22 Watts/hr	(PEPCO)
8	Daylight	0.98 W/ft^2	(ASHRAE_90.1, 2007)
9	Equipment loads	0.36 W/ft^2	(ASHRAE_90.1, 2007)

Some of the values for energy consumption were not directly available, so the average value of occupied space for work station in office buildings was taken from the Time Saver Standards

(TSS)[1]. The value is obtained on the basis of typical layout found in these selected buildings. Figure 4.1 illustrates the layout and the area required for this kind of spaces.

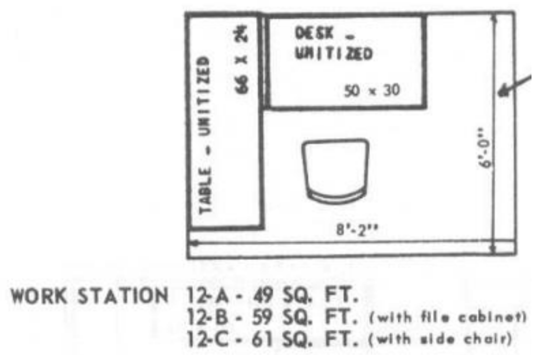

Figure 4.1: Work station area (Time Saver Standards)

And the values per square feet were taken from the ASHRAE 90.1 and then loads are calculated by the Eq 4.1:

Load = Loads (per Sq.Ft) * 61 Sq.Ft ……………………….. Eq (4.1)

e.g.:

Day light load = 0.98 * 61

= 59.7 Watts/Hour

The data is analyzed using excel, based on the answers given by the respondents each option in the question is assigned a number from 2-12.

[1] TSS is one of the most comprehensive architectural and interior design reference resources. Time-Saver Standards for Interior Design and Space Planning is an excellent source of easily accessible design criteria, planning standards, and technical guidelines. The vast array of design information, all contained in a single volume, facilitates and expedites the completion of programming, preliminary planning, design development, and working drawing service.

4.3 Ranking of the Questions:

To rank the questions in terms of its significance towards energy saving questions were sorted according to the energy use (Watts/hour) by the appliance. The values are taken from different sources like PEPCO, USGBC, Energy Star and TSS. But there was a problem in doing this as most of the questions deal with similar appliance used by the building occupants. Therefore the questions cannot be ranked based only on the usage (Watts/hour) of the appliance.

So, in order to rank this the effect of the appliance usage based on the hourly consumption is taken. The hourly usage values are based on the typical schedule followed in Pakistan. Then the questions are ranked by taking the combined effect of the appliance and the hourly usage which ultimately give the total energy consumed by a particular appliance or equipment. The result of all this procedure is shown in Table 4.5.

Table 4.5: Ranking of questions based on the Energy consumption

Sr. #	Questions	Watts/hour	Hourly usage	Energy consumed (Watts)
1	1.8 How much time you spend at your work place daily using AC?	1500	9	13500
2	2.4 What do you do with your computer when you leave your office for home?	200	15	3000
3	2.5 If you have a personal printer at your work place, then you:	250	9	2250

4	2.2 How much time you work on your computer daily?	200	9	1800
5	5.2 If you have an individual unit, what do you do when you leave office for a break/meeting?	1500	1	1500
6	5.6 If the temperature of your work place is very cold then what do you usually do?	1500	1	1500
7	2.6 If you have a personal scanner at your work place, then you:	150	9	1350
8	4.7 Do you switch lights when you leave office for home?	22	15	330
9	2.7 If you have a fan at your work place then for approximately how much time you turn it on in a day?	70	4	280
10	4.3 If you have a desk lamp at your work place, for how long you use it?	60	4	240
11	2.3 What you usually do with your computer when you leave your office for a short break or for a short meeting?	200	1	200
12	4.2 How many of the lights you usually switch on while you are in your office?	22	9	198
13	3.5 How often you change the orientation of	65	2	130

	the blinds to let day light in?			
14	3.3 If you have windows in your office, for how much time do you use day light approximately?	22	4	88
15	4.5 If you can control the lights then you turn them off when you don't need artificial light?	22	3	66
16	4.6 Do you switch lights off when you leave office for a break/meeting?	22	1	22

Depending upon the appliances and their hourly usage, their weightage in overall consumption is calculated. The HVAC systems seem to consume more energy than all other equipment, thus a weightage of 0.394 is given. Secondly the desktop computers consume a lot of amount of energy because they remain switched on throughout the day besides of their low hourly usage than other equipment. Equipment which is in the control of occupants is often left switched on during non-working hours. This is the key problem of the behavior that needs to be changed, because often enough amount of energy is consumed during the non-working time. This causes the consumption rates to get higher than expected.

On the other hand lighting system found in these buildings is BMS controlled. This implies that the lighting system operates on a certain schedule which varies from building to building and on the basis of the routine of occupants. But in case of artificial lighting system the building management ensures switching on of lights during the working hours only. So, in case of non-working hours there is almost no possibility of the lights to remain switched on. But the dark side of these automatic lighting systems is that the occupants have no control over lights, which eliminate the impact of their behavior in energy savings from the lighting system.

Use of daylighting has a potential to save a large amount of energy. Daylighting provides an appealing environment and a pleasant work space that can increase both performance and productivity (Plympton et al., 2000). Field studies and simulation analysis show that the daylighting has a potential to save energy ranging from 30% to 70% (Doulos et al., 2008; Li et al., 2006; Onaygıl et al., 2003). The data obtained from these buildings reveals that most of the occupants complain of not having enough daylight. This is because of the position of the occupant or the operating style of blinds and windows.

4.4 Weightage calculations:

Based on this calculation, the impact on energy consumption by the behavior of user is studied. The individual score of the respondents is then calculated in order to classify them in the relevant behavior category. The weightage calculation as shown in Table 4.6 is based on the Eq 4.2.

$$\textbf{Weightage} = \frac{\textbf{Individual energy consumed}}{\textbf{Total Energy consumed}} \qquad \textbf{Eq (4.2)}$$

Table 4.6: Weightages for each question.

Sr. #	**Questions**	**Energy consumed (Watts)**	**Weightage**
1	1.8 How much time you spend at your work place daily using AC?	13500	0.3941

2	2.4 What do you do with your computer when you leave your office for home?	3000	0.0876
3	2.5 If you have a personal printer at your work place, then you:	2250	0.0657
4	2.2 How much time you work on your computer daily?	1800	0.0525
5	5.2 If you have an individual unit, what do you do when you leave office for a break/meeting?	1500	0.0438
6	5.6 If the temperature of your work place is very cold then what do you usually do?	1500	0.0438
7	2.6 If you have a personal scanner at your work place, then you:	1350	0.0394
8	4.7 Do you switch lights when you leave office for home?	330	0.0096
9	2.7 If you have a fan at your work place then for approximately how much time you turn it on in a day?	280	0.0082
10	4.3 If you have a desk lamp at your work place, for how long you use it?	240	0.0070
11	2.3 What you usually do with your computer when you leave your office for a short break or for a short meeting?	200	0.0058

12	4.2 How many of the lights you usually switch on while you are in your office?	198	0.0058
13	3.5 How often you change the orientation of the blinds to let day light in?	130	0.0038
14	3.3 If you have windows in your office, for how much time do you use day light approximately?	88	0.0026
15	4.5 If you can control the lights then you turn them off when you don't need artificial light?	66	0.0019
16	4.6 Do you switch lights off when you leave office for a break/meeting?	22	0.0006

After getting the weightage of the questions, the individual score is calculated for each respondent. By multiplying the option number (assigned against each answer of the question 2-12) and the weightage against each question the individual score is calculated as shown in Eq (4.3).

$$\textbf{Individual Score} = \sum (W_i * K_i) \qquad \text{...... Eq (4.3)}$$

Where:

Wi = weightage of the question

Ki = individual score of the question answered by Users

The values of the individual score range between 2.963 to 6.7012. These values are divided into 3 parts. Table 4.7 shows the frequency of the respondents lies in the given range. The higher values show the score of HEC and the lower values represent LEC. According to this situation the occupants are categorized.

Table 4.7: Number of occupants in each category

Sr #	Occupant Category	Range	Frequency
1	LEC	2.963-4.209	24
2	MEC	4.209-5.455	54
3	HEC	5.455-6.7012	23

Figure 4.2 shows the number of occupants in each category according to the answer they gave in the questionnaire. Questionnaire was designed to capture the behavior of the occupants, that how they are performing in their daily routine towards the energy consumption.

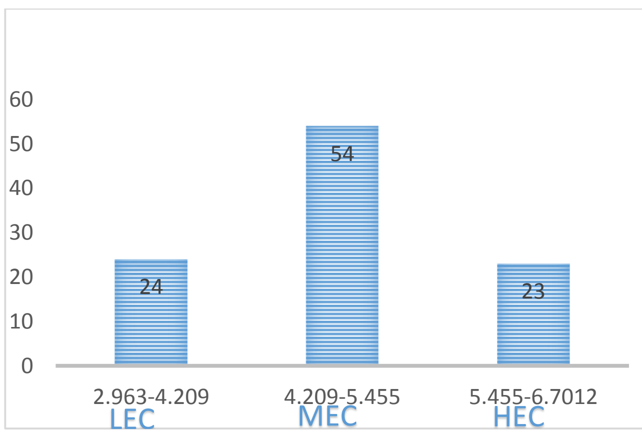

Figure 4.2: Distribution of Respondents in behavior category

The distribution of behavior is almost a normal distribution. Most of the respondents lie in MEC category and the remaining in HEC and LEC category. This is mostly the case when certain population fall in the medium or average category (Montgomery et al., 2009).

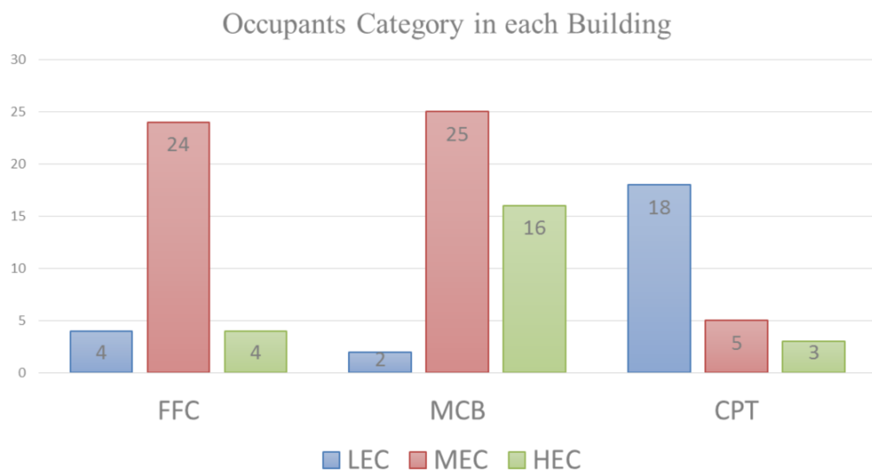

Figure 4.3: Building wise occupant category chart.

Further breakdown of the occupant category in each building is shown in the figure 4.3. it can be seen that in case of FFC and MCB building majority falls in the category of medium energy consumers. While in CPT building most of the occupants lie in the category of Low energy consumers.

4.5 Model Results:

An agent based model which is proposed in this research has an ability to perform simulations of an environment in which agents are placed and tend to behave naturally. By a little modification the model can be transformed into other shapes to study different behavior parameters and variables. In this model new agents and new parameters can easily be added and also the values and conditions can be changed with few easy steps.

4.5.1 Model validation:

This model is validated by using the survey data from the building users, in this model the effect of 5 different parameters is analyzed. Based on these parameters, the model divides the total population in three different behavior categories i.e. HEC, MEC and LEC. And then on these behavior categories the model applies the effect of all the parameters.

Initially at the start of the model the user must provide the details about the size of the population and the total number of occupants in each category. When initial number of occupants in each category is defined then the next step is to define the values of the parameters. In this model the values of parameters are set as default, but that can be changed at the start of the simulation. For example the Effect of Ads is taken as 0.01 which means that the 1% of the total population can be affected by the ads per day.

Similarly the interaction parameter has its default value 1 per month, which means that the occupants interact with one another once in a month and talk about the energy issues. The beauty of this model is that it can simulate the positive as well as negative effects of a certain parameter. For example, in this interaction parameter the occupant may be a random agent in the model and it can be a HEC which effects any other MEC or LEC to adopt bad energy consumption habits. This is only possible when this HEC has a high level of influence on other occupants. In the same MEC can influence HEC to reduce its bad energy consumption habits and influence LEC to adopt bad consumption habits.

So, at the start of the simulation the value of the interaction parameter can be changed and the user can define the value according to its requirement depending upon the nature of the environment under study.

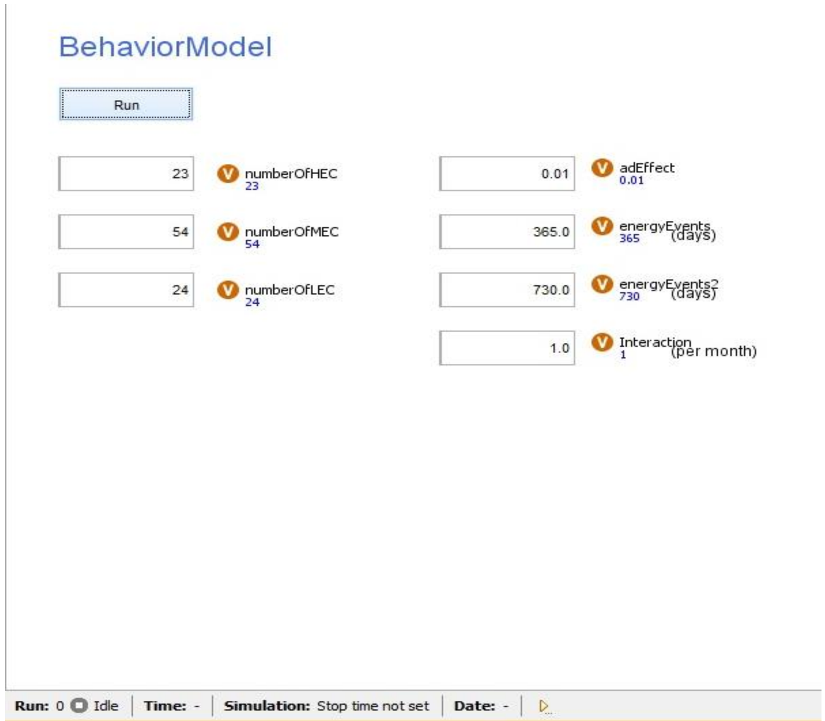

Figure 4.4: Simulation model window

The next step is to define when you want to arrange energy events, the energy events are added in that model, at the start of the model the energy events should be define in days. By default their values are defined at 365 days and 730 days. This totally depends upon the user that how they want study the behavior and if they want the results at the earlier stage then these can be changed to earlier dates. Say if the study includes the energy events to be held after 6 months instead of annually. Then the values can be changed to 180 and 365 days for energy events or at any other day.

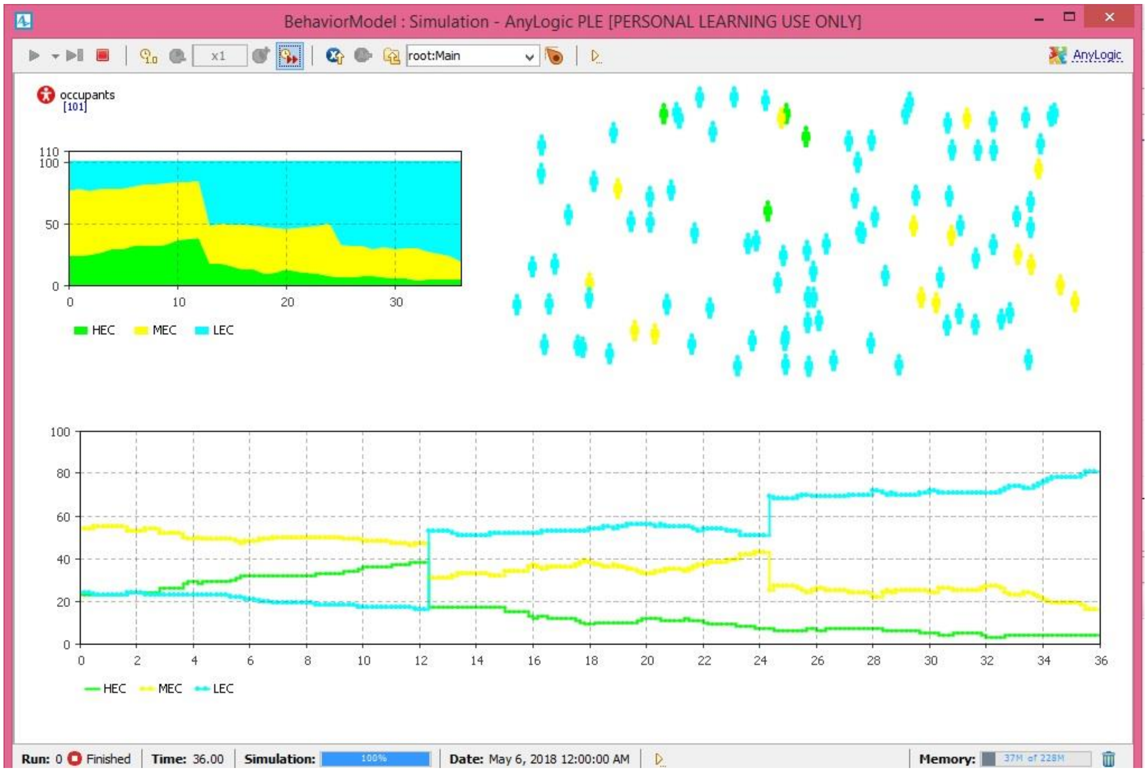

Figure 4.5: Simulation model result window.

Once all these values are set then you just have to start the simulation. The period for the simulation must be defined by the user that for how much time the behavior should be studied. In this research the model time for simulation set for 3 year time. The result of this model is in terms of then number of occupants in a category at the end of simulation time. The simulations can be stopped at any time to see the effect at desired time period.

When the simulation starts, its start showing the effect of all the parameters on the occupants and if there is a change in the category, it updates the occupant category and jumps to other time interval for next iteration. Figure 4.4 shows the results of simulation over a 3 year period of time.

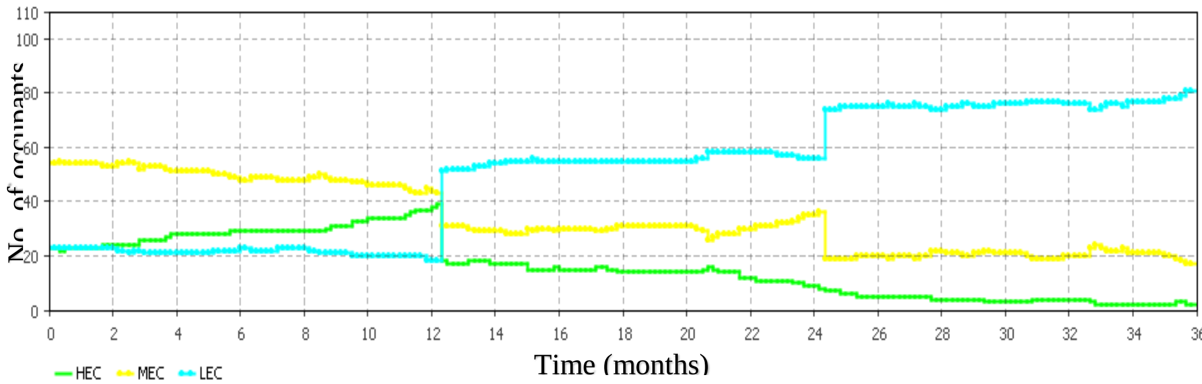

Figure 4.6: Occupants behavior change

First energy event is arranged after 12 months from the simulation time, initially the effect of Ads and interaction is visible. It seems without an energy event or any training the people are influenced by the HEC. The effect is highly noticeable in MEC who are influenced by the HEC to adopt bad consumption habits. This might be possible that the occupants are unaware of the energy saving techniques or too busy to consider it becoming careless towards the energy conservation as a result. Therefore, the number of MEC is decreasing and HEC are increasing. This could also be a case that the occupants who are less aware of the energy saving and lie in the MEC category will start moving to HEC by ignoring their previous activities.

But there is one significant finding that the occupants who lie in the category of LEC sustain their behavior over a longer period of time because they have adequate knowledge of energy saving and sustainability. When the first energy event has been organized a major change in the category is witnessed. The number of LEC has been increased because more people become aware after this energy event. Therefore, the most of the occupants are converted to LEC which are either from MEC or HEC. HEC are converted to MEC or LEC that is why their number has decreased. Now MEC are in the middle which was in abundant at the start. So, after the first energy event the number of HEC are now 19, MEC are 32 and LEC are 50. Between 12 to 24 months the behavior sustaining capability of the occupants is quite considerable. Purpose of energy events is to give an ample amount of information and the benefits of energy saving. This does not impose anything on the occupants that they have to save energy. Because when something is imposed rather than making the individuals to think on their own, this will results in long term behavior sustaining ability (RAYMOND, 2004). The next energy event occurred at the end of 24 months there is again a high change in the number of occupants. Most of the MEC are now converted into LEC. Figure 4.5 displays the density of the occupants who changed their category from the start to the end of the 36 months period.

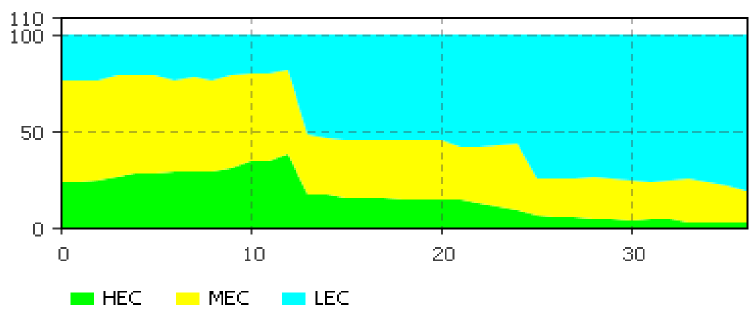

Figure 4.7: Density of the occupants in each category

After 36 months most of the occupants have changed their category and converted into LEC. At the end of the simulation time the number of LEC are 82, MEC are 16 and the HEC are only 5.

In order to show the significance of the results obtained from simulation model and put them in perspectives, the possible overall energy saving must be estimated. For that, the amount of energy consumed by an occupant should be known. Usually the published consumption is an average per capita and may only be attributed to MEC. In order to know the hypothesized non-linear difference between MEC and other consumption behaviors, data support is very restricted. Therefore, heuristics are applied to get the upper (HEC) and lower (LEC) ranges of an average consumer (MEC). To establish these values two most commonly used electricity consumption sources are considered i.e. lighting and air conditioning (AC) systems. Now a days three different type of categories as per the consumption are found for each of them in the market. For example in case of lights, fluorescent, compact fluorescent and LED lights are available. Similarly window AC, split units and inverters are available for air conditioning. So based on their electricity usage all of them are categorized as high, medium and low consumers. Comparison of these systems and their percentage increase in consumption is given in Table 4.8.

Table 4.8: Comparison of equipment based on the electricity usage

Equipment	**Low**	**Medium**	**High**	**Percentage increase from low to medium**	**Percentage increase from Medium to High**
Lights	10	14	60	28.57	76.67
AC	1490	1566	1676	4.85	6.56
			Average	**16.71%**	**41.61%**

Medium value is considered as the base value and the rest of the calculations are made. In case of lighting system the percentage increase form low to medium and medium to high is quite extraordinary. Reason being the technology is very much improved from fluorescent tube lights to LED lamps. In contrast with the case of air conditioners, despite the improvement in technology the difference is low. This is because the fact that electricity usage is already too high and the improvement in technology can reduce it by 100 watts/hr only. Estimations based on these statistics can be challenged owing to smaller sample, larger standard deviation and major difference between the consumption of each system.

Further, three scenarios have been considered in order to decide about the category of the occupant. Based on these, the consumption rates are calculated in Table 4.9.

Table 4.9: Behavior-wise energy consumption

Equipment	**LEC**			**MEC**			**HEC**		
Computer	8	200	1600	9	200	1800	15	200	3000
HVAC	4	1500	6000	6	1500	9000	9	1500	13500
Lights	1	22	22	2	22	44	2	22	44
		Total	7622		Total	10844		Total	16544
Consumption			1524.4			2168.8			3308.8

In 2015, per capita energy consumption in Pakistan is estimated at 800 kWh annually (NTDC, 2011). Thus, 800 kWh is considered as a standard value for MEC because it reflects national average. Compared to developed countries such as USA 6,721 kWh (CEC, 2010), UK 5,072 kWh, Australia 9,486 kWh (CIA, 2014), etc., the average consumption in Pakistan is lower due to power shortage and lower economic conditions of its people. Thus it falls with countries such as Indonesia 858 kWh, India 910 kWh (WDI, 2015), etc. As per the findings reproduced in Table 4.9, it is evident that average percentage increase from low to medium and medium to high is different from LEC to MEC and MEC to HEC as shown in Figure. 4.7.

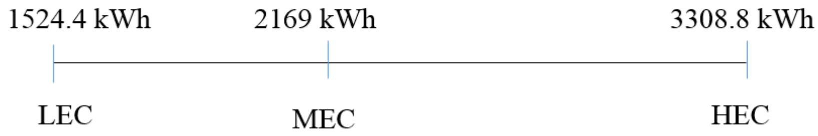

Figure 4.8: Difference between the Electricity Consumption of occupants.

This implies that HEC are consuming far more amount of energy than the LEC are saving. Thus a change of behavior from MEC to LEC will need lesser efforts as needed for changing from HEC to MEC. This is empirically established by looking at the trend of behavior adoption in simulation; at the end of year 1, the LEC have increased by 40% as opposed to a mere decrease of 17.4% in HEC as shown in Table 4.10.

Once the consumption rates are obtained, energy consumed by occupants in each category is calculated. Difference in the total electricity consumption by 101 occupants who were selected for the survey is shown in Table 4.10.

Table 4.10: Difference in electricity consumption before and after simulations.

Occupant Category	Per capita consumption/ Year (kWh)	t=0 months		t=12 months		t=24 months		t=36 months	
LEC	1524.4	24	36585.6	51	60976	73	83842	81	123476.4
MEC	2169	54	117126	31	91098	19	80253	16	34704
HEC	3308.8	23	76102.4	19	62867.2	9	29779.2	4	13235.2
Total (kWh/year)			229814		214941.2		193874.2		171415.6
Annual savings					**6.47%**		**9.16%**		**9.77%**
Cumulative Savings					**6.47%**		**15.64%**		**25.41%**

Readings from the model are obtained at three different time intervals and then compared with the consumption rates obtained from Table 4.10. At the end of year 1 i.e. t=12, the total savings of energy are 6.47%. Similarly, t=24 and t=36 the savings are 15.64% and 25.41% respectively; thus energy saved in year 1 is 6.47%, year 2 is 9.16% and year 3 is 9.77%. At the end of year 1 the first energy event is organized causing a decrease in number of HEC and MEC and increase in LEC. Increasing number of LEC is the sign of change in behavior in a positive direction which causes reduction in the total energy consumption. At the end of simulation i.e. year 3 a very large number of occupants are converted to LEC, MEC are now in a very small amount which were in abundance at the start, and only a few HEC are left. Hence at this stage 25.41% savings are realized. Referring to Table 4.3 the average energy gap due to buildings is 15.45%. Thus by only changing the behavior of the occupants by employing the above mentioned techniques average electricity saving of 8.47% can be achieved every year.

Summary:

The results obtained have couple of key implications:

1. Occupants with different energy consumption behavior affect the building's total energy significantly.
2. If the behavior is considered during the design phase of the buildings then the gap can be reduced.
3. Behavior of the occupants can be changed if information regarding energy savings is spread among them.
4. A total of 25.41% of energy can be saved only by employing behavioral changes in the occupants. These savings can be significantly higher if these measures are applied on the usage of gas and water in buildings. And if these savings are considered on global level then this can incorporate a very high amount of savings.

Conclusion:

By analyzing the results of surveyed data a normal distribution of the occupants' behavior is obtained. Most of the occupants lie in the category of MEC, which is a good sign that most of the occupants are aware of consuming less amount of energy and playing their part towards energy savings. There are more chances to convert MEC to LEC if trainings and informatory sessions are kept on arranging. The number of LEC and HEC are almost equal which implies that LEC are saving a significant amount of energy but at the same time the HEC consuming more energy which nullify the effect of saving energy which is conserved by LEC. So, the total energy usage comes at an average value which is same as the MEC is consuming.

HEC can be converted easily with a little effort to other category. When occupants of HEC category interact with other occupants of MEC or LEC they may notice the activities performed by them. In another case if the benefits of energy conservation is shared with HEC then there is a very high possibility of changing behavior by the HEC. If the behavior is changed by the occupants with their own awareness instead of asking them to change it forcefully or imposing it to them, then this change will have more long lasting effects. Research shows that if the behavior change occurs by imposing certain conditions on the occupants, this change will lasts only for 3-10 weeks while the change occurs by their on awareness lasts for a longer period of time (RAYMOND, 2004). So, interaction of occupants and the advertisement found to be a more useful tool instead of feedback and other imposed techniques to change the behavior.

At the start of the simulation most of the occupants' lies in MEC category, these occupants are already saving energy and applying their energy saving habits in their daily routine. They have adopted this behavior by their own. Because there were no seminars or any other training programs on energy savings in the surveyed buildings, the MEC might have more capability of sustaining their behavior as it is developed by their own knowledge (Bodenheimer et al., 2009). Thus, more effort is required to convert them into LEC category. This conversion is difficult because to convince MEC to change their routine requires more level of effort as they consider their knowledge sufficient for energy conservation. This may be a dark side of sustaining behavior as it become difficult sometimes to bring a positive change (Masoso & Grobler, 2010).

Further, the energy saved by applying behavior modification techniques 25.41% of the energy can be saved in 3 years. This means that at a very little cost of employing the modification techniques 8.47% of the energy can be saved. This definitely saves a lot of cost as compared with proposing technical changes in the buildings. Which may saves more energy but at a very high capital cost and low rate of return

However, incorporation of this model with any of the commercially available energy estimation programs could significantly improve the estimation of building's energy consumption. As a result it will help to overcome the existing limitations of the simulation programs. The model can be used by the facility management team to further improve the energy savings. Finally, this model can also be used as decision making mechanism which evaluates several method of changing behavior (e.g., seminars on energy conservation, peer to peer influence, feedback tools etc.) and helps the designers and owners to choose the best method to invest in reducing the energy demand.

Recommendations and Limitations:

Recommendations:

1. To minimize the gap energy events should be arranged by building administration.
2. Behavior modification is cost effective and must be tried before making any technical changes for energy saving.

Limitations:

1. Developed only for office type Commercial Buildings.
2. Only applicable on subjected population.

Future work:

1. More parameters should be included in the model to extend it for further sophistication in results.
2. Real time data of the occupant after applying behavior modification techniques should be collected and the model be tested on it.

References:

Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C. (2006). Occupant satisfaction with indoor environmental quality in green buildings. *Center for the Built Environment*.

ASHRAE_90.1. (2007). Energy Standard for Buildings Except Low-Rise Residential

Buildings.

Asif, M. (2009). Sustainable energy options for Pakistan. *Renewable and Sustainable Energy Reviews, 13*(4), 903-909.

Azar, E., & Menassa, C. C. (2011). Agent-based modeling of occupants and their impact on energy use in commercial buildings. *Journal of Computing in Civil Engineering, 26*(4), 506-518.

Bell, M., Wingfield, J., Miles-Shenton, D., & Seavers, J. (2010). Low carbon housing: lessons from Elm Tree Mews.

Bhatt, R., Chaoji, V., & Parekh, R. (2010). *Predicting product adoption in large-scale social networks.* Paper presented at the Proceedings of the 19th ACM international conference on Information and knowledge management.

Bodenheimer, T., & Handley, M. A. (2009). Goal-setting for behavior change in primary care: an exploration and status report. *Patient education and counseling, 76*(2), 174-180.

Bordass, B. (2004). *Energy performance of non-domestic buildings: closing the credibility gap.* Paper presented at the in Proceedings of the 2004 Improving Energy Efficiency of Commercial Buildings Conference.

Bordass, B., Cohen, R., Standeven, M., & Leaman, A. (2001). Assessing building performance in use 3: energy performance of the Probe buildings. *Building Research & Information, 29*(2), 114-128.

Borshchev, A., & Filippov, A. (2004). *From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools.* Paper presented at the Proceedings of the 22nd international conference of the system dynamics society.

Bourgeois, D., Reinhart, C., & Macdonald, I. (2006). Adding advanced behavioural models in whole building energy simulation: a study on the total energy impact of manual and automated lighting control. *Energy and Buildings, 38*(7), 814-823.

Casti, J. (1997). Would-be worlds: how simulation is changing the world of science: New York: Wiley.

CEC. (2010). U.S. Per Capita Electricity Use By State In 2010. Retrieved from http://energyalmanac.ca.gov/electricity/us_per_capita_electricity-2010.html

Chen, Z., Clements-Croome, D., Hong, J., Li, H., & Xu, Q. (2006). A multicriteria lifespan energy efficiency approach to intelligent building assessment. *Energy and Buildings, 38*(5), 393-409.

CIA, F. (2014). Retrieved from https://www.cia.gov/library/publications/the-world-factbook/, http://www.indexmundi.com/map/?v=81000

Clevenger, C. M., & Haymaker, J. (2006). *The impact of the building occupant on energy modeling simulations.* Paper presented at the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal, Canada.

Controls, C. a. J. (2008) Building Automation System over IP (BAS/IP) Design and Implementation Guide.

Dasgupta, A., Prodromou, A., & Mumovic, D. (2012). Operational versus designed performance of low carbon schools in England: Bridging a credibility gap. *HVAC&R Research, 18*(1-2), 37-50.

Davis, J. A., & Nutter, D. W. (2010). Occupancy diversity factors for common university building types. *Energy and Buildings, 42*(9), 1543-1551.

De Wilde, P. (2014). The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction, 41*, 40-49.

Demanuele, C., Tweddell, T., & Davies, M. (2010). *Bridging the gap between predicted and actual energy performance in schools.* Paper presented at the World renewable energy congress XI.

Dikba, A., & Dikbas, A. (2004). *eWork and eBusiness in Architecture, Engineering and Construction*: Taylor & Francis.

Doulos, L., Tsangrassoulis, A., & Topalis, F. (2008). Quantifying energy savings in daylight responsive systems: The role of dimming electronic ballasts. *Energy and Buildings, 40*(1), 36-50.

EIA. (2010). Energy Information Adminisitration (http://www.eia.doe.gov/aer/pdf/aer.pdf). Retrieved from http://www.eia.doe.gov/aer/pdf/aer.pdf

EnergyPlus. (2009). "Input/output reference: The encyclopedic reference to EnergyPlus input and output." The Board of Trustees of the Univ. of Illinois and the Regents of the Univ. of California through the Ernest Orlando Lawrence Berkeley National Laboratory, ⟨http://apps1.eere.energy.gov/buildings/energyplus/pdfs/inputoutputreference.pdf⟩.

eQuest. (2009). "Introductory tutorial, version 3.63." ⟨http://doe2.com/download/equest/eQ-v3-63_Introductory-Tutorial.pdf⟩.

Grigoryev, I. (2015). AnyLogic 7 in three days.

Guthridge, G. (2010). Understanding consumer preferences in energy efficiency: Accenture end-consumer observatory on electricity management. *Accenture, Dublin, Ireland, Tech. Rep. ACC10-0229*.

Haldi, F., & Robinson, D. (2008). On the behaviour and adaptation of office occupants. *Building and Environment, 43*(12), 2163-2177.

Hoes, P., Hensen, J., Loomans, M., De Vries, B., & Bourgeois, D. (2009). User behavior in whole building simulation. *Energy and Buildings, 41*(3), 295-302.

Holton, E. B. (1997). M.. Quantitative Research Methods. *Human Resource Development: Lingking Research and Practice*.

Hub, Z. C. (2010). Carbon compliance for tomorrow‟ s new homes: A review of the modelling tool and assumptions, topic 4-closing the gap between designed and built performance [online]. London: Zero Carbon Hub and NHBC Foundation. *NHBC Foundation, Milton Keynes*.

Jackson, P. T. (2005). Motivating Sustainable consumption :a review of evidence on consumer behaviour and behavioural change. Retrieved from www.surrey.ac.uk/CES

Jeon, J., Lee, S., Hong, D., & Kim, Y. (2010). Performance evaluation and modeling of a hybrid cooling system combining a screw water chiller with a ground source heat pump in a building. *Energy, 35*(5), 2006-2012.

Korjenic, A., & Bednar, T. (2012). Validation and evaluation of total energy use in office buildings: A case study. *Automation in Construction, 23*, 64-70.

Kotrlik, J., & Higgins, C. (2001). Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. *Information technology, learning, and performance journal, 19*(1), 43.

Lane, D. C. (1995). Modeling for learning organizations. *Journal of the Operational Research Society, 46*(6), 793-795.

Leaman, A., & Bordass, B. (2007). Are users more tolerant of 'green'buildings? *Building Research & Information, 35*(6), 662-673.

Lee, Y. S., & Malkawi, A. (2013). *Simulating human behavior: an agent-based modeling approach.* Paper presented at the Proceedings of the 13th IBPSA Conference, Chambéry.
Li, D. H., Lam, T. N., & Wong, S. (2006). Lighting and energy performance for an office using high frequency dimming controls. *Energy Conversion and Management, 47*(9), 1133-1145.
Lindelöf, D., & Morel, N. (2006). A field investigation of the intermediate light switching by users. *Energy and Buildings, 38*(7), 790-801.
Lysen, E. H. (1996). *The Trias Energica: solar energy strategies for developing countries.* Paper presented at the Proceedings of the Eurosun Conference.
Ma, X., Cui, R., Sun, Y., Peng, C., & Wu, Z. (2010). *Supervisory and Energy Management System of large public buildings.* Paper presented at the Mechatronics and Automation (ICMA), 2010 International Conference on.
Macal, C. M., & North, M. J. (2005). *Tutorial on agent-based modeling and simulation.* Paper presented at the Proceedings of the 37th conference on Winter simulation.
Mahdavi, A., Mohammadi, A., Kabir, E., & Lambeva, L. (2008). Occupants' operation of lighting and shading systems in office buildings. *Journal of Building Performance Simulation, 1*(1), 57-65.
Masoso, O., & Grobler, L. J. (2010). The dark side of occupants' behaviour on building energy use. *Energy and Buildings, 42*(2), 173-177.
Meier, A., Olofsson, T., & Lamberts, R. (2002). *What is an energy-efficient building.* Paper presented at the Proceedings of the ENTAC 2002-IX Meeting of Technology in the Built Environment.
Mellouli, S., Moulin, B., & Mineau, G. (2004). Laying down the foundations of an agent modelling methodology for fault-tolerant multi-agent systems *Engineering Societies in the Agents World IV* (pp. 275-293): Springer.
Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy, 97*, 355-364.
Montgomery, D. C., Runger, G. C., & Hubele, N. F. (2009). *Engineering statistics*: John Wiley & Sons.
Newsham, G., Birt, B., Arsenault, C., Thompson, L., Veitch, J., Mancini, S., . . . Burns, G. (2012). Do green buildings outperform conventional buildings? Indoor environment and energy performance in North American offices.
Nicol, F., & Roaf, S. (2005). Post-occupancy evaluation and field studies of thermal comfort. *Building Research & Information, 33*(4), 338-346.
North, M. J., & Macal, C. M. (2007). *Managing business complexity: discovering strategic solutions with agent-based modeling and simulation*: Oxford University Press.
NTDC, P. R. (2011). Electricity Demand Forecast Based on the Multiple Regression Analysis.
O'Sullivan, D., Keane, M., Kelliher, D., & Hitchcock, R. J. (2004). Improving building operation by tracking performance metrics throughout the building lifecycle (BLC). *Energy and Buildings, 36*(11), 1075-1090.
Onaygıl, S., & Güler, Ö. (2003). Determination of the energy saving by daylight responsive lighting control systems with an example from Istanbul. *Building and Environment, 38*(7), 973-977.
Patterson, M. G. (1996). What is energy efficiency?: Concepts, indicators and methodological issues. *Energy policy, 24*(5), 377-390.
PEPCO. www.pepco.gov.pk. Retrieved from www.pepco.gov.pk

Peschiera, G., Taylor, J. E., & Siegel, J. A. (2010). Response–relapse patterns of building occupant electricity consumption following exposure to personal, contextualized and occupant peer network utilization data. *Energy and Buildings, 42*(8), 1329-1336.
Plympton, P., Conway, S., & Epstein, K. (2000). Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford.
Qela, B., & Mouftah, H. (2011). *An adaptable system for energy management in intelligent buildings.* Paper presented at the Computational Intelligence for Measurement Systems and Applications (CIMSA), 2011 IEEE International Conference on.
RAYMOND, D. (2004). CHANGING BEHAVIOR AND MAKING IT STICK.
Sanchez, M., Webber, C., Brown, R., Busch, J., Pinckard, M., & Roberson, J. (2007). Space heaters, computers, cell phone chargers: How plugged in are commercial buildings? *Lawrence Berkeley National Laboratory*.
Staats, H., Leeuwen, E., & Wit, A. (2000). A longitudinal study of informational interventions to save energy in an office building. *Journal of Applied Behavior Analysis, 33*(1), 101-104.
Turner, C., Frankel, M., & Council, U. G. B. (2008). *Energy performance of LEED for new construction buildings*: New Buildings Institute Vancouver.
UNEP. (2007). "Buildings can play key role in combating climate change.". *United Nations Energy Program (http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=502&ArticleID=5545&l=en)*. Retrieved from http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=502&ArticleID=5545&l=en
Van der Voordt, T. J. (2004). Productivity and employee satisfaction in flexible workplaces. *Journal of Corporate Real Estate, 6*(2), 133-148.
van der Voordt, T. J., de Been, I., & Maarleveld, M. (2012). 10 Post-occupancy Evaluation of Facilities Change. *Facilities Change Management*, 137.
WDI. (2015). Retrieved from http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC
Webber, C. A., Roberson, J. A., McWhinney, M. C., Brown, R. E., Pinckard, M. J., & Busch, J. F. (2006). After-hours power status of office equipment in the USA. *Energy, 31*(14), 2823-2838.
Wong, J., Li, H., & Lai, J. (2008). Evaluating the system intelligence of the intelligent building systems: part 2: construction and validation of analytical models. *Automation in Construction, 17*(3), 303-321.
Wong, J., Li, H., & Wang, S. (2005). Intelligent building research: a review. *Automation in Construction, 14*(1), 143-159.
Yu, Z., Fung, B. C., Haghighat, F., Yoshino, H., & Morofsky, E. (2011). A systematic procedure to study the influence of occupant behavior on building energy consumption. *Energy and Buildings, 43*(6), 1409-1417.

Appendix I

QUESTIONNAIRE

Research Topic: Expectations And Realities From The Energy Efficient Buildings: An Investigation Of Occupants' Behavior

Energy crisis is a major issue now a days and a lot of efforts has been going on to overcome this problem. To put some of our efforts a Master level research has been conducted at NUST, Islamabad in the department of Construction Engineering and Management. This questionnaire is design to study the pattern of the occupant's behavior in energy efficient buildings and their energy usage. You are requested to give your feedback on this questionnaire.

Regards,

Qadeer Ali

Student MS-CEM

NUST, H-12 Islamabad.

Personal information:

1. Gender:
   - Male
   - Female

2. Age:
   - 20 years or under
   - 21-30 years
   - 31-40 years
   - 41-50 years
   - 51-60 years
   - Above 60

3. The level of qualification you have?
   - Matriculation
   - Intermediate
   - Graduation
   - Post-graduation
   - Doctoral

4. Where is your workspace located?

- Specify floor number ________

5. Do you have a permanent workspace in your building?
- Yes
- No

6. How long have you been working at your present workspace?

______ Years

______ Months

7. Which of the following best describes your personal workspace or the type of space you usually work at?

- Enclosed office, private
- Enclosed office, shared with other people
- Cubicles with partition wall 5' or higher
- Cubicles with partition wall lower than 5'

8. How much time you spend at your work place daily?
- 1-3 hours
- 3-6 hours
- 6-9 hours
- Or more

Equipment:

1. Which of the following electronics, including personally owned, are in your workspace? Check all that apply.

- laptop
- desktop computer
- desk phone
- fan
- space heater
- smart phone docking station

- personal desk lamp
- electric clock
- other (please describe) ____________________

2. How much time you work on your computer daily?
   - 1-3 hours
   - 3-6 hours
   - 6-9 hours
   - Or more

3. What you usually do with your computer when you leave your office for a short break or for a short meeting?
   - Shut down
   - Put it on sleep mode
   - Put it on hibernate mode
   - Just turn off the LCD/Monitor

4. What do you do with your computer when you leave your office for home?
   - Shut down
   - Put it on sleep mode
   - Put it on hibernate mode
   - Just turn off the LCD/Monitor

5. If you have a personal printer at your work place, then you:
   - Switch it on when you need it
   - Switch it off when you remember
   - Switch it off right after use
   - Or it remains switched on every time

6. If you have a personal scanner at your work place, then you:
   - Switch it on when you need it
   - Switch it off when you remember
   - Switch it off right after use
   - Or it remain switched on every time

7. If you have a fan at your work place then for approximately how much time you turn it on in a day?
   - 1-3 hours
   - 3-6 hours
   - 6-9 hours
   - Or more

3. Day light

1. Within the proximity of 15 feet, what do you have for natural lighting? Check all that apply.

- Window
- Ventilator
- Skylight
- Nothing

2. Please indicate why you are dissatisfied with visual comfort by checking all the reasons that apply:

- Not enough daylight most of the day
- Too much daylight most of the day
- Not enough overhead light in my workspace
- Too much overhead light in my workspace
- Not enough overhead light in the office overall
- Too much overhead light in the office overall
- No task lighting
- Reflections in/glare on the computer screen
- Daylight glare from windows
- Other (please describe) __________________

3. If you have windows in your office, for how much time do you use day light approximately?

- 1-2 hours
- 2-4 hours
- 4-6 hours
- Or more

4. If you feel discomfort from day light then what do you do?

- Adjust the blinds/shades
- Complain your manager/supervisor
- Talk with others in your group about the problem
- Change your position in your workspace
- Other please specify__________

5. How often you change the orientation of the blinds to let day light in?

- Regularly
- Often
- Never
- Can't adjust

6. In summers for how long you use daylight without feeling hot?

- 1-2 hours
- 2-4 hours
- 4-6 hours
- Or more
-

4. Artificial light:

1. If you have an individual office, how many lights do you have in your room?

- 1-2 lights
- 2-3 lights
- 3-4 lights
- Or more

2. How many of the lights you usually switch on while you are in your office?

- 1-2 lights
- 2-3 lights
- 3-4 lights
- Or more

3. If you have a desk lamp at your work place, for how long you use it?

- 1-2 hours
- 2-4 hours
- 4-6 hours
- Or more

4. If you have a shared office, then can you control its lights?

- Yes
- No

5. If you can control the lights then you turn them off when you don't need artificial light?

- Very often
- Often
- Not often
- Never

6. Do you switch lights off when you leave office for a break/meeting?

- Yes
- No
- No need because they are automatic

7. Do you switch lights when you leave office for home?

- Yes
- No
- No need because they are automatic

5. HVAC

1. What type of HVAC system do you have in your office?

- Individual unit
- Centrally controlled system

2. If you have an individual unit, what do you do when you leave office for a break/meeting?

- Switch it off
- Put it on Economy Mode

- Set its temperature between 24-26°C
- Leave office without doing anything

3. If you have an individual unit, what do you do when you leave office for home?

- Switch it off
- Leave office without doing anything
- Timer is set which switch it off automatically

4. If centrally controlled system is installed in your office then is there any control panel to manage your surrounding temperature?

- Yes
- No

5. Please indicate why you are dissatisfied with the temperature of your workspace by checking all the reasons that apply:

- Too hot much of the time
- Too hot in the summer
- Too hot in the winter
- Too cold much of the time
- Too cold in the summer
- Too cold in the winter
- Other (please describe) ____________________

6. If the temperature of your work place is very cold then what do you usually do?

- Adjust thermostat
- Open or close the window shades
- Complain your Supervisor
- Complain your Building manager
- Change your location
- Talk with others in your group

6. Energy Efficiency:

1. How well you are aware of energy efficiency and sustainability?

1	2	3	4	5
☐	☐	☐	☐	☐
Not well				Very well

informed				informed

2. How well informed do you feel about using the energy saving design features in your building?

1	2	3	4	5
☐	☐	☐	☐	☐
Not well informed				Very well informed

3. Have you attended any course, workshop, training session, etc. about energy efficiency and sustainability?

- o Yes
- o No

4. If yes, how well informed do you feel about energy efficiency and conservation after taking the course/seminar/workshop?

1	2	3	4	5
☐	☐	☐	☐	☐
Not well				Very well

5. How would you describe your approach to reducing energy in your building? Check all that apply.

- o Follow policies/practices in energy conservation workshop/training
- o I act as role model for others
- o I have accepted/taken on a formal lead role in the group/department/floor
- o Other (please describe) ____________________

6. Have you or any members in your group been recognized by your management or chain of command for efficient energy use?

- o Yes
- o No
- o Don't know

7. How many people you know who adopt energy saving habits?

- o 1-4 persons
- o 4-8 persons

- 8-12 persons
- Or more

Thank you so much for your participation.

Appendix II

Table: Designer interviewed for design related data.

Sr #	Building name	Designer name	Name/Designation of the Person interviewed
1	FFC Headquarters, Rawalpindi	Meinhardt. Pvt Ltd., Karachi	Engr. Muhmmad Mobeen-ul-Haq
2	Center Point Office Tower, Karachi	Arcop Associates, Karachi	Arch. Naseema
3	MCB Center, Lahore	Arshad Shahid Abdulla, Karachi	Arch. Naheed