Department of Mechanical Engineering

Smart Control of Residential Buildings

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Abstract

"Intelligent Control is a process that drives an intelligent machine to attain its goal automatically. In other words, intelligent control is a kind of automatic control that can drive autonomous intelligent machines to reach their goals without their interaction or with least human interaction. Intelligent Control systems are systems that can perform the task of intelligent control"…………*Zi-Xing-Cai*

The project is intended to work on the concept of such control and carry out the research on further development of the concept of simulated-assisted control. The impact on the living style of the people of Glasgow could be visualized directly along with its impact on the environment.

Assessing the potential of smart controls by the self-created profile and carrying out simulation, taking into account the field study [questionnaire] enabled to build up a set of recommendations for the project. This will also be a guide for future research work. Thus the outcome of this investigation will certainly comprehend influencing smart controls in the UK.

In order to give a taste to the project, the study was carried out to design such controller. A list of hardware components together with a logic diagram is discussed in the later part of the project.

Therefore combining the entire feasibility study, it would suggest the future development and gain a good amount of global attention.

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My family, who stood by me always and believed in me and thanking all my course mates. *To end with* I would like to be grateful to all those friends that in fact I don't need to list, as they know who they are. Thank you all.

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CHAPTER-1

INTRODUCTION

This thesis is aimed at investigating the option of smart control in the residential buildings. Smart Control is one of the energy conservation measures. It will be one of the feasibility studies, which will help in making Glasgow, a sustainable city. The thesis will elucidate the related terms such as Smart Control, Smart Homes, and its requirement in the modern world. In order to investigate the effects of smart controls in energy efficient buildings, a conceptual profile was created simulating a typical lifestyle for a two bedroom flat in Glasgow and a detailed study was carried on the generated profile. In addition, a simulation was carried out with the help of university programme. Later adding to the study, a set of recommendations are put forward based on the results obtained, along with the designing of the control system. Combining the technical study, a conclusion is made, on the potential of smart control in the residential buildings.

1.1. Project Background

This project will assist in making Glasgow green as it was bid by Glasgow City Council to become one of Europe's most environmentally friendly cities within these five to ten years. To attain this objective, the council had set up 'a high level consortium' with the University of Strathclyde to examine every aspect of life in the city. This approach will enable to change Glasgow's image from polluted, wasteful and road obsessed in Scotland to a sustainable city. Several ideas like new city wide district heating scheme, more energy efficient homes, and light rail transport and a 'state of the art' telecommunications network will reduce the green house gas emission, contributing in reduction of the green gases emissions. As there are many opportunities for Glasgow in developing low carbon energy technologies, efficient homes and above all creation of sustainable communities and transport, it could easily attain its objective. [24]

Since feasibility study is one of the steps towards making a change in the reality, the proposed study will however focus on potential of the Smart Controls in the residential buildings by infusing some ambitious but achievable goals, contributing to the council's idea of energy efficient homes. It will help making Glasgow Sustainable by taking into account the use of electricity at homes. This investigation will make efforts to develop a new thinking of using energy efficiently and also focus on concept of 'simulated-assisted control'.

Based on the findings of the study, a set of recommendations will be prepared along with the suggestions related to the future work in the field under investigation.

1.2. Scope of the Present Work

The present study will cover the electrical energy consumption by various appliances (heating, lighting, equipment process etc) and look into as where control can be installed to reduce the use of electricity and also minimizing the wastage and also in saving electricity bill. It will be a feasibility study of 'simulated-assisted control' [SAC], to be installed in the houses to cut down monthly electricity bills. This study will depict the enhancement of SAC at homes. It is rather a concept to show, how simulated-assisted control can help us in saving a significant amount of electricity by reducing the electricity bills. To begin with, a conceptual profile of electricity consumption was created for a typical two-bedroom flat in Glasgow, for typical winter and summer seasons. The profile was then split in two profiles, i.e., without control and with control. The monthly consumption was estimated for both the cases. Simulation was carried out with the ESP-r, a university building simulation programme in order to estimate the energy losses in case of electricity usage without control. Considering the results, a set of guidelines was generated for 'Smart Control of Residential Buildings'.

1.3. Objectives and Methodology of the present study

The objectives of the present study are:

- To evaluate different smart control options available for residential buildings.
- To carry out the case study on present electrical load and suggest further steps to be taken to reduce electrical load and wastage of energy.
- To develop a demand profile for different electrical appliances used in home.
- To analyse the profile using smart control with the help of university programme ESP-r.
- To prepare a report based on the research and findings and develop the recommendations for subject under investigation.

1.4. Dissertation Outline

The present section of the thesis is aimed to provide a very brief summary of each chapters of the thesis.

Chapter 1 introduces the issue of energy management and its significance in attaining the sustainable city status. It also outlines the major areas t be investigated in the present study and outlines the objectives of the present work.

Chapter 2 discusses the concept of building energy management systems and demand side management, and explains the terms such as smart control, smart homes, its requirements, in addition to the overview of the research carried out in this field. It attempts to create the main body of this research in sufficient details. It also covers the details of the case studies, which will direct the future work in this field.

Chapter 3 investigates the feasibility options of smart control in the residential buildings by creating a case study for the research. It attempts to demonstrate the impact of smart controls in the residential buildings by elaborating the methods adapted. It assists in assessing the potential of smart controls in residential buildings together with a brief discussion about the environmental implications complementing to the area under study.

Chapter 4 will explain modelling with the help of the simulation software tool, ESP-r. Simulation is carried out in order to assess the capability of smart controls installed in residential buildings. Passive solar and Day lighting control simulations are carried out to analyse their effect on energy demand, which is a supplement to the impact of the smart controls, facilitating in drawing appropriate guidelines for the residences in Glasgow.

Based on the overall results obtained in Chapter 3 and Chapter 4, a set of *Recommendations* are produced on smart controls at homes.

Chapter 5 deals with the designing of the smart control. It includes the details of the hardware components required for the smart controls in addition to a brief discussion about the type of control loop required to build smart controls based on the concept of simulated-assisted control.

Finally in *Chapter 6,* the conclusions of the present investigation are discussed along with the future work, which can be carried out based on the present work.

The last section of the thesis contains the *References* and the *Appendices* relevant to the present work.

CHAPTER-2

LITERATURE REVIEW

This section of the report will explain elaborately the project background by elucidating the terms smart control or intelligent control systems, then discussing the demand side management [DSM] its deficiency, requirement of smart controls at homes. This section will also throw some light on the work done in the related fields with the help of case study, enabling to show the reason behind the study.

To begin with, the concept of Building Energy Management Systems [BEMS] is discussed briefly as intelligent control is embedded within. Demand Side Management [DSM] is just a pathway to the main objectives of the project. Both DSM and BEMS are explained to understand the background of the study and ultimately ending up with the requirement of this study.

2.1. Building Energy Management Systems

Building Energy Management Systems [BEMS] have a considerable impact on the control of building services. This concept was developed in recent twenty years but it came into focus only after introduction of electronic devices that are capable of retaining data for the purpose of managing services such as power, lighting and heating. “There are many terms used for BEMS, such as building management systems (BMS), energy management systems (EMS) and building automation systems (BAS). All these refer to the same equipment”-BEMS. [2]

To define, the BEMS is a computer aided program installed in the buildings in order to control the mechanical and electrical equipments such as ventilation, lighting, power systems, fire systems and security systems. Thus BEMS have a great impact on the control of the building services plant and energy efficiency. [2]

The ancestor of BEMS was the electromechanical systems, but the micro electronics and computing revolution in recent years have changed the outlook of BEMS. [1]

"The distributed intelligence BEMS is particularly appropriate for UK and Europe with their predominantly smaller, heated only buildings. Consequently UK has been in forefront of the development of distributed intelligence BEMS."[2]

Benefit of BEMS: One of the benefits of BEMS will be constant monitoring of the plant and the ability to recall the monitored data at a later time. This enables the technicians and the engineers to develop a better understanding of the buildings. As a result, it leads to improvement of plant and energy saving. [3]

In addition to the benefit of BEMS, there are few *drawbacks* with BEMS. As BEMS is computer aided program, the problems are also associated with the computer themselves. They are:

- Large user manual, explaining many functions and operations.
- User manuals are not 'user-friendly' as it is not properly written. This in turn compels the beginners to rely on manufacturer's training course.
- Training courses are expensive, therefore only few get the opportunity to master BEMS.
- Inexperienced programming of BEMS can spews out data and alarms as if it was suffering from 'data-diarrhoea'. [2,3]

2.1.1. BEMS Case Study: Building Energy Management Systems at UCD Belfield [25]

BEMS case study is one of the good practice case studies of the UK, which was carried out by University of Dublin [UCD]. It emphasized on the use of BEMS and involved in continuous development which eventually resulted in energy cost savings by reducing the university electricity bill.

Background: UCD is one of the largest third level institutions in Ireland consisting about 20,000 students. The total building floor area is 200,000 square metres excluding students' halls of residence. It was estimated the total energy bill is £1.4

million/year, without BEMS. Before practically installing BEMS in the campus, a number of feasibility studies, by the post-graduate students, were carried out looking into the different aspects of it. The project was handled by mechanical and electrical services division of the buildings. A significant number of buildings in Belfield are supplied with heat from the central boiler house which in 1986 got converted to natural gas. Calorifiers, feeding radiators and fan convertors help in supplying heat.

Large area of the rooms were heated and mechanically ventilated, which accounted to the huge energy consumption. The other appliances which added to the electrical load of the building consisted of lighting and general services, motive power, laboratory and workshop equipment, catering equipment and some water heating.

The campus buildings were fitted with stand alone electrical and pneumatic controls like time clocks, thermostats and temperature controllers of different types and ages. These pneumatic controllers have many dis-advantages over the direct digital controllers as listed. It can be seen in appendix 4 of this report.

BEMS in the Building: The BEMS was decided to be installed in a small part of the huge campus, (Agricultural building) to control heating. After its success and improvement in BEMS was decide to be installed in the entire university campus to 'control and monitor' the electricity consumption of the building through check meter.

A 10% reduction in the consumption of electricity was noticed resulting in decision of installing BEMS on 'campus wide basis.' This reduction is very less as we noted from our study (as discussed in the next chapter) which accounts the monthly electricity consumption in the range of 25% to 40%.

'Event based control is probably the most powerful BEMS feature.' This feature is used in combination of time scheduling and delay timers to provide occupancy control of lecture theatre lighting and ventilation. The timers and triggers are all outdated as latest technology has come into play (as discussed in chapter 5 of the report)

At Belfield, the main buildings have been fitted with electrical check meters which provide inputs to the BEMS. After the installation, the overall performance has been measured in accordance with part 4 of CIBSE Building Energy Code in terms of total energy consumption per metre square.

There has been a continuous improvement in the rating from 1GJ square metre to 0.6 GJ square metres which made them fall into the classification of good. But due to increase in student by 40% the rating also increased to 0.7GJ square metre.

An economic analysis showed that there has been overall energy cost saving of £350,000 per annum. However there are certain benefits along with savings like improved comfort conditions centralised control and facility of remote diagnosis and solving of problems reducing the callouts for maintenance staff. Thus an investment of £100, 000 per annum in BEMS in UCD, it pays a good amount of dividends in terms of cost reductions and improved comfort and efficiency.

The case study fits in this present study as because it helps in identifying the loopholes in the project and suggests various improvements required in BEMS, especially smart controls together with use of new technology to design the controller. These when considered helps in reducing the amount of electrical energy consumption thereby reducing the monthly expenditure on electricity bills.

2.2. Demand Side Management

This is an introduction to Demand Side Management [DSM] also known as Energy Demand Management, rather a method to conserve energy in the demand side. It will help to build an overall idea as how it is related with the present study.

Background: The pattern of electrical energy consumption varies throughout the day and is mainly occupant based. It is in spotlight due to Kyoto commitments. DSM brings about the actions influencing the quantity or patterns of energy used by the consumers and target to reduce the peak demand during the periods, when the energy systems are constrained. This concept was coined just after the energy crisis, during the year 1973 and 1979. It was an approach to conserve the energy use.

Liberalization of electricity market causes every country to review its own DSM activities. Artificial DSM framework, commonly known as Integrated Resource Planning [IRP], was built up which then played a significant role in energy sector. Initially, traditional electricity expansion planning models [TES] were used for utilities planning. For TES, the main objective was to meet the required electricity demand at very low cost, ignoring the demand side options. After the energy crisis in 1973, governments introduced or rather imposed IRP planning process. The idea was to provide with the utilities at minimal societal cost to the consumer, considering both supply and demand, taking into account environmental costs. [4, 18]

The aim involved in Energy Demand management is to bring both demand and supply to best possible low value.

‘DSM in its network management programme, the following primary questions have to be answered:

- How often is the customer going to be controlled?
- What appliances is the utility going to control?
- What is the power consumption of these appliances?
- How will the utility protect the appliances on tripping and closing phases of the control time? [18]

With the help of DSM it is possible to manage the demand on the customer side of the meter. There are many such opportunities available that help us to meet this criterion. A new set of technologies and programs will offer a great potential to the demand side management. Thus introducing smart controls will aim to capture the most energy-efficient measure.

Now to strengthen the background of the study, the term ‘smart control’, ‘simulated-assisted control’ is explained along with few related terms like smart homes and its requirement and then molding all of them to give a shape to the requirement of the present study.

2.3. Smart Control

Smart control is one of the energy conservation measures and it has been rightly said "you can manage only what you can measure." [19] Thus Smart Control is installed to manage the use of energy in the consumer side. Consumption of energy is almost related with the gross national product. [27] It differs from country to country. In the developed countries it is higher, than the developing countries. The world energy consumption is steadily increasing with population. Thus it is required to put into check. It can be achieved to some extent by installing 'smart control' in the buildings.

Smart Control emphasizes the use of new technologies to make the buildings more energy efficient. Smart design, use of appropriate construction materials, compact fluorescent bulbs and above all use of sensors (regulating temperature and lights of the room) helps to minimize the wastage of energy and also trimming down the electricity bills.

It is one of the ways to bring sustainability, as technology is combined with renewable sources available to overcome wastage of energy and the extensive use of fossil fuels. This report will focus on the Smart control of the residential buildings. It will depict the amount of energy consumed by different appliances at home. Moreover consumption of energy is dominated by weather. Thus in Glasgow, maximum electricity consumption is in the use of room heaters.

There may be different ways to control the use of electricity, at homes. It may be from the smart design of the house putting stress on the use of renewable resources like sunlight, the use of appropriate construction materials, installing photo voltaic on the roof, solar water heaters, using energy efficient bulbs and also by using smart appliances. All these add to conservation of energy use but wastage of electricity can be monitored by using sensors. Thus for HVAC systems, it can adjust temperature in different zones within the building based on solar gain and internal building loads. Smart Controls can help to make regulation to the parameters like humidity, airflow, fresh air mix, and indoor air quality necessary to provide occupant comfort. [32, 33]

Movement or temperature sensors can assist in this field to a large extent. It will monitor the movement, like if someone enters a room, the lights will be switched on, and as someone leaves a room it will get switched off. In that case the lights will not remain on throughout the day. It will totally depend on the movement of the occupant in the room. These controls thus help to regulate the lighting systems. Smart controls can adjust the artificial (electric) lighting level based on available daylight, room occupancy and the functions executed in each building space. They can 'interface lighting system occupancy sensors with the building's security system to sense the intruders in unoccupied spaces'. [33]

Likewise for the temperature sensors, it will help in maintaining the ambient temperature of the room. Whenever it senses that the temperature had fallen down from the required set temperature it will start heating or cooling the room. Moreover it will also assist in holding the temperature of the room when there is no occupant, thus avoiding the room to reach the freezing temperature. This also gives immense comfort to the occupant during the seasonal changes.

Hence it can be said that smart controls are generally used for energy management, HVAC and lighting systems control. It may be computer-based or may have the necessary intelligence built into the control device. It is noticed that a significant portion of its electricity is consumed by the buildings and it contributes to atmospheric emissions. Thus it is important to minimize the overall energy consumption.

There has been no research carried out in this field thus literature review for the section was difficult. The above discussion will help to build an idea about the smart controls and give a foundation to the present study. The idea of smart control initiated and gave rise to the concept of simulated-assisted control which is put into plain words in the next segment of this section.

2.4. Simulated-Assisted Control

Smart Controls is the future-ready solution in HVAC [Heating Ventilation Air Conditioning] and lighting controls. Previously thermostats were used to control the temperature of the room. Thermostat controls were not efficient as it leaves the room either too hot or cold [28].Therefore the new technology combining simulation programs and controllers have come into play. This concept allows each room to be controlled individually for timed operation and temperature from the wall (zone controller) or from PC. Smart modules can also be used in conjunction with appropriate sensors. Basic concept with advantages along with the work of Clarke et al is discussed later in this section.

2.4.1. *Basic Concept*

A wide range of study in the field of modelling of both practical and highly conceptualised control system types is made possible by the zone level and system level controller models. This extends a big scope of extending the use of simulation programs online in BEMS to 'act in the role of an intelligent control supervisor.' Thus simulation cannot be restricted by research and design applications.

'Simulation programs' and 'Intelligent Control' are two technologies supported by BEMS multiplexing techniques providing online adjustment of control system parameters anticipated by simulation. Simulation has the capability of taking a lead, making it easier for predictions of future reality. Further this capability can be utilized by resolving it to the 'best possible control action in terms of comfort and energy levels.'[13]

Later a simulation time-step controllers are cited which facilitates simulation of the trial control actions briskly until its satisfactory performance and also reckoned, to allow the simulation to move to the next control period. 'The optimized control system parameters may then be implemented in the BEMS. Modern-day practical controllers are often based on a *controller/system model* structure. The premise implicit with the simulation-assisted control concept is that there is no need for separate system model generation (e.g. by employing identification methods), since in this case the system model is held in the form of system matrix.'[13]

The figure below explains the process briefly.

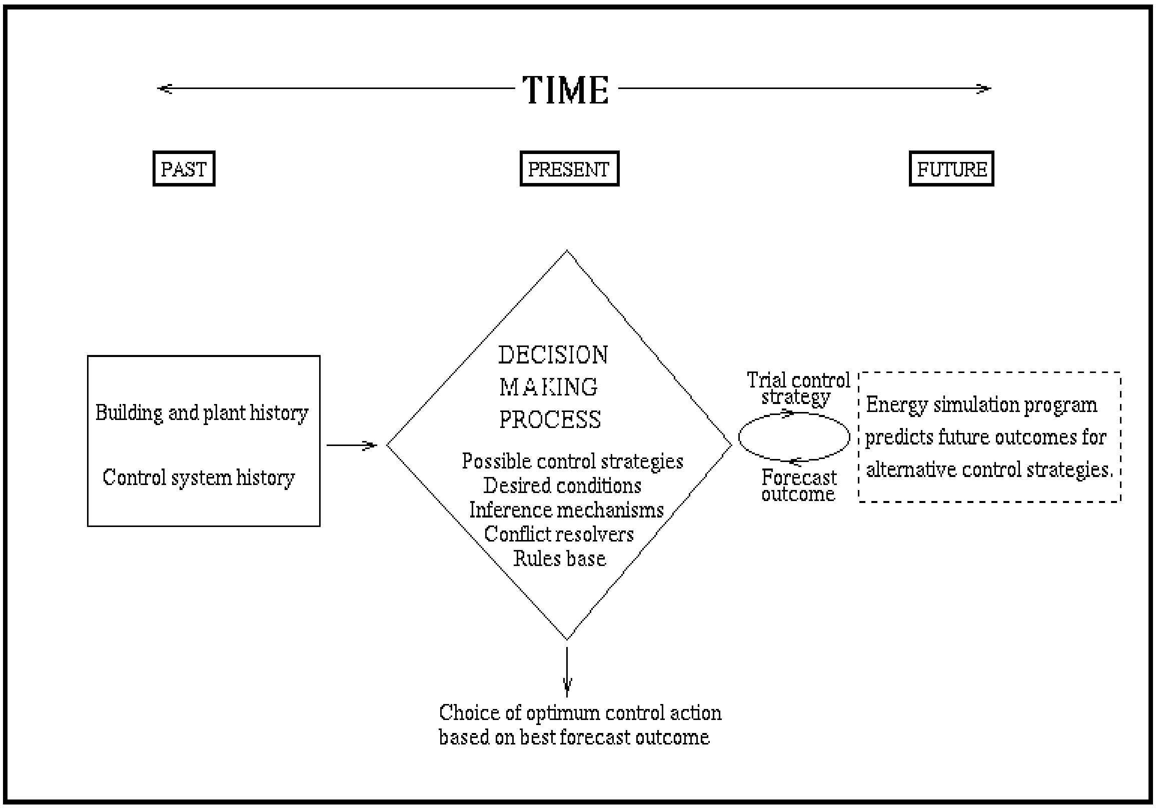

Fig: 2.1: Energy Simulated-Assisted Control [13]

The operation of the building control system and design can be achieved with the help of *objective, control actions and correct control strategy*. These three requirements are explained below:

"(1) A defined objective: control theory concerns itself with the future state of the system. The objective of any control system in every case is connected with the performance of the system over some period of time.

(2) A choice of possible control actions: if no variation of actions is possible, control is not possible since the course cannot be modified.

(3) A means of choosing the correct control strategy. Thus a model of the system is required which is capable of predicting the effect of various control actions on the system state."[13]

2.4.2. Advantages

The idea of *energy simulation assisted control decision making* (ESAC) offers a means by which the above mentioned requirements may be met, at some point in both the design and operation of BEMS.

"The main advantages of a simulation-assisted approach to control design or operation are as follows.

- Any criterion whatever can be used for the decision process, e.g. there is no need to be restricted to, say, quadratic criteria as in conventional optimal control design.
- The difficult and highly specialized problem of control synthesis is avoided.
- Control actions can first be appraised in a software environment before being applied to the real system. This feature offers tremendous potential for the next generation of intelligent buildings and BEMS."[13]

2.4.3. Simulation-assisted control in Building Energy Management Systems [12]

Clarke et al brought in focus the concept of simulated assisted control in BEMS. Their work explains the role of simulation in built environment as there had been less focus in this field.

All the recent developments in BEMS depend on the advancement of technology in telecommunications, computer and information technology. There had been a good amount of work done with done in this field like the concept of predictive control, fuzzy logic control and the use of neural networks. With these emerging concepts of controllers the drawbacks got highlighted. The predictive control used the stochastic models. Both short term and long term predictive errors were in acceptable ranges of temperature and humidity control. "Prediction errors were found to be within 1^{o}C and 1.5% relative humidity."[12] With the fuzzy logic controller, it demands for an excellent experiential knowledge and data about the controlled systems' operating characteristics. Neural network mechanism is based on the operational principles of the human brain thus it requires for extensive data training.

One common feature of the controllers mentioned, was that they did not have any physical model to be controlled. It was a non physical 'black-box model.' This approach was devoid of the external excitations like climate and occupant interaction and was also not affected with its cause and effect. These interactions can clearly be demonstrated in a physically based model where these elements interact. "Building simulation programs provide with such a model."[12]

Simulation programs play significant role in two areas: Emulators and Evaluators. As emulators help in duplicating functions, in built environment it replaces a building and its HVAC systems and then uses simulation programs to advocate their response towards BEMS commands. Fault Detection Diagnosis [FDD] is a technique to detect and locate or predict faults in energy management systems. This technique is also developed while simulating models. Evaluators are used to assess the usefulness of control strategies. [12]

"The main objective of this research was to investigate a possible third use for simulation programs: their encapsulation within the BEMS in order to provide simulation-assisted control."[12] The idea behind this study was that, potential of simulation program and BEMS flexibility are advanced satisfactorily to make simulation-assisted control to be feasible. Keeping aside the prospective of simulated assisted control, there are few difficulties coupled with it, like:

- To make and calibrate model of the system mainly when dynamic variations due to airflow and solar radiation are important.
- It helps in analyzing from complex result sets to simple actions, providing few benefits over 'black box model.'

- Simulated assisted control addresses the ‘cause and effect scenarios’, adapting to the impact to the changing building use or operation provided that the change is incorporated into the model.
- A better control is provided through the computation of interactions and identifying the factors that result in the particular building performance.
- It also provides the comparing capability of the different control approaches (by testing them on the building model).[12, 14]

“Simulation-assisted control is likely to be of most use in the following circumstances.

- When significant look-ahead times are involved (hours, rather than minutes).
- For high-level supervisory control, e.g. load shedding, where several alternatives and their implications for environmental conditions (particularly occupant comfort) may need to be evaluated.
- Where interaction is high, e.g. blinds/lighting/cooling.
- Where the building use varies or changes (e.g. large variations in occupancy) and where this variation is known in advance”.[12]

The project thus tried to investigate the opportunities involved in combining the simulation with the BEMS operation in order that it provides a prototype of the controlled decision making.

In this research, ESP-r was used as a building simulation program. Implementation of the prototype simulated assisted control required the following elements:

(i) “A calibrated model of the building and HVAC system.

(ii) Sensors to measure all critical boundary conditions (external temperature, solar radiation, etc.) and internal conditions (temperature, humidity, etc.); the data must be collated in the BEMS (i.e. within LabVIEW).

(iii) A mechanism for transferring data to the simulator.

(iv) A routine within the BEMS for initiating the simulation(s) against a predefined control strategy.

(v) A simulator to predict internal conditions and ascertain parameters (start time, plant output, etc.) to meet some user-defined criterion.

(vi) A controller to make decisions based on modeling outputs.

(vii) A mechanism for transferring control data back to the BEMS (LabVIEW).

(viii) Actuators controlled by the BEMS to initiate the control action.

(ix) A structure to allow iteration and updating of control actions."[12]

The prototype of simulated assisted control was formed together with LabVIEW and ESP-r by creating an independent software model. There were three programs for this BEMS,

(i) ESP-r

(ii) LabVIEW

(iii)BEMS to ESP-r link

The interface module is controlled by BEMS and is passed on to the file containing LabVIEW monitoring the climate and internal temperature data. This module performed the following tasks:

i. *Simulation synchronisation*: In LabVIEW there is a file containing time stamped data based on which the required start and stop dates for the simulation is determined. This data further helps in calculating the time step based on the sampling rate of the monitored data.
ii. *Climate prediction*: In LabVIEW data file the climate information is read for 24-48h. This can only be used for short-term prediction. Thus further work to develop the algorithm for the function is required.
iii. *Control Strategy Prediction*: Based on the control action file, specified control strategy is developed to use for ESP-r simulation.

iv. *Simulation commissioning*: For this, based on the start and stop dates, simulation frequency and specified control strategy, 'n' number of simulations was carried out. The control parameter is increased by fixed increment for each of the simulations.

v. *Result interpretation*: The results are interpreted for each simulation output which is then compared with the control space variable reached at the target time. The simulation is ceased when the control value is within the bounds or the results meet the control criteria.[12]

Now to describe these sections two experiments were carried out to test the real time simulation link,

(i) In the laboratory
(ii) In the full size test room environment

It is inferred from the preliminary test, that the 'prediction' of the switch on time was reasonable together with the demonstration of the practicality of the controller and accuracy of the results and in the test cell experiment, it was found that ESP-r slightly over predicts the response of the test room.

A few alterations to the model gave results which were closed to the measured data. Thus building and plant control functions open to simulated assisted control. [12, 14]

2.5. Requirement of Smart Buildings

Smart Buildings are developing into healthy buildings. For instance, companies are realizing that "*productivity and morale are increased when there is natural light as well as incandescent or fluorescent lighting*," Melby says. [33]

As one expert stated, it is simply a matter concerned with the best and the newest technology, as it emerges and whether a building is 'smart' from the blueprint stages can be ensured if it has an intelligent building design comprising of innovative, technologically advanced components, systems and resource-efficient materials, methodology to minimize waste and lastly that ensures a low impact on the environment. [33]

Thus for the present study, residential buildings were taken into account. The feasibility study for the commercial buildings can be a suggested for future research work. This report will investigate the feasibility solutions for deploying smart controls in residential buildings and thus will discuss the requirement of smart homes in the built environment.

Smart Homes is going to be the future trend. This perception has build up in these recent years to save our planet from global warming. Moreover after the Kyoto Protocol, the government in the developed countries have taken initiative to cut down pollution. Smart Homes is therefore an approach to it.

In building environment keeping all the occupants comfortable while also striving to save energy is a difficult task. A control strategy on heating the coolest room to bring to a comfortable temperature will cause excessive energy use. However if the range of temperature throughout the building can be minimised then it is less likely that any home will be too far from the desired temperature set point.[5]

Smart Control or home automation is an up-coming trend. There are various techniques applied to the residential buildings like light control, temperature control of the doors and window shutters etc. Smart homes can be for everyone, from the person on rent or already have a home or building it. Smart Homes are generally well designed, well insulated staying warm and dry all year round.

Smart Control also implies to smart design which also helps to control the noise and glare of the sun. Reducing damp of the home will decrease moisture damage. This will decrease the amount of maintenance required, saving both time and money. [29]

2.6. Requirement of Present Research Work

This section of this report have enabled in building in the concept of simulated-assisted control at homes. BEMS is a path to guide us to the proper method in order to consume electricity more efficiently.

Integrating BEMS, DSM and Smart Controls is an art. DSM will help in drawing the attention towards the amount of electricity consumed by the utilities. The scope of BEMS is required to be increased. BEMS should be able to simulate and then send a control signal to the utilities thus enabling to manage the load in the demand side. The advancement in technologies cannot restrict the growth of BEMS. Therefore with the new technologies, innovative ideas should be appreciated and incorporated in BEMS. The concept of simulated-assisted control is new together with its introduction in residential buildings. The present study will investigate the feasibility of smart controls in residential buildings by assessing its potential through quantitative analysis and simulation.

This study thus focuses in creating the load profile, to see the amount of electricity consumed by the appliances and trying to control its use by applying the concept of simulated-assisted control to manage BEMS more efficiently. It is generally noticed that in a typical house in Glasgow, maximum electricity is consumed in space heating and water heating, then in lighting.

Thus ‘intelligent control’ will control the use of electricity and will also keep a check on wastage of energy. Therefore, implementing controls in houses restricts the misuse of electricity, thus trying to meet one of the objectives of DSM and also increasing the scope of BEMS.

IMPACT OF SMART CONTROLS

This section will examine the utility of smart controls in the residential buildings by introducing the case study developed for the research. It will elaborate on the techniques followed to illustrate the impact of smart controls by assessing its potential and then conclude by a brief discussion about environmental implications of the smart homes by focussing on the amount of carbon reduction.

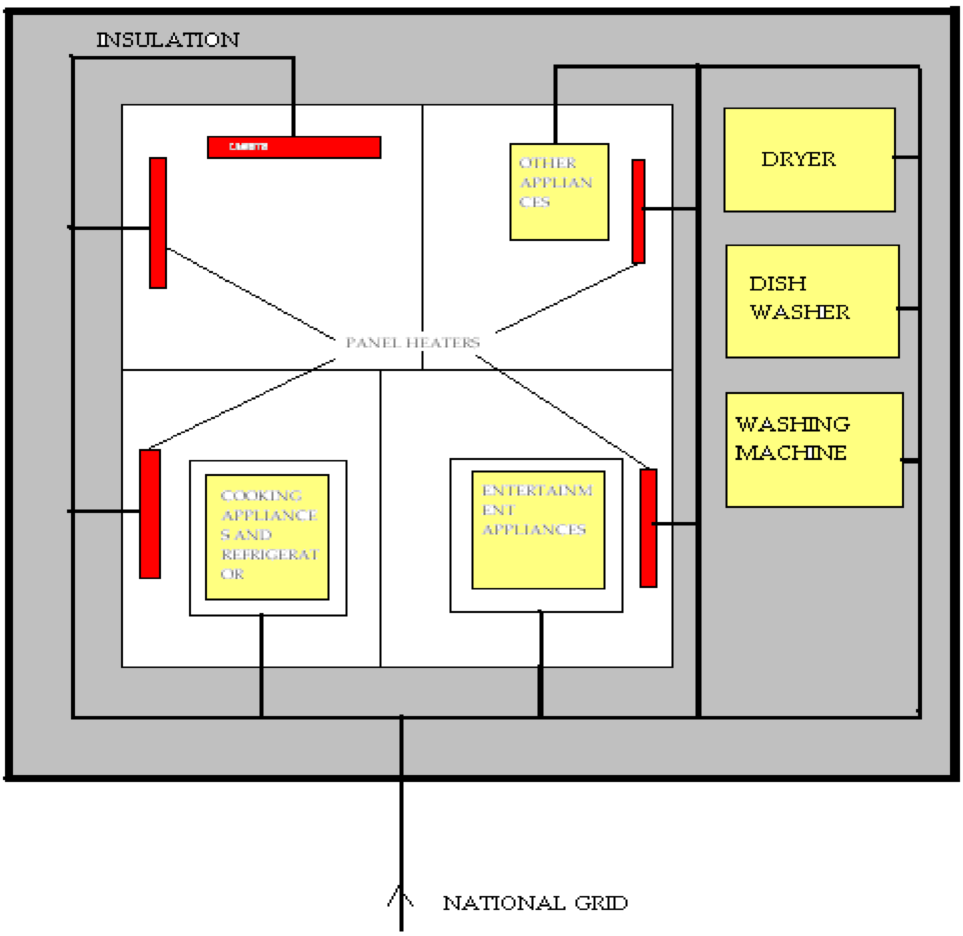

Fig 3.1: An electrically heated house

Fig. 3.1 gives an idea behind the case study developed for the research. In the above figure a house is considered which is electrically heated. It also shows the essential appliances available in each house in Glasgow. The appliances marked in red can be controlled by the concept of simulated-assisted control, which is also explained later in this section. This is a conceptual study carried out, by developing a hypothetical situation where deploying smart controls would enable to save electricity consumption and bill.

3.1. Methodology Adapted

In this part, the methods are discussed elaborately. The methods undertaken are

1. The Questionnaire
2. Creating the profile
3. Assessing the potential of Smart Controls

The discussion is as follows:

3.2. The Questionnaire

In order to carry out with the further study, a consumption profile was created taking into consideration the flats in Glasgow. To begin with, a questionnaire was prepared to get an overall idea of the consumption at homes (appendix-1). It was distributed among sixteen families, six residing in the two bedrooms flat and five each in the three and four bedrooms flat. It was prepared to generate the inputs required for creation of the electricity consumption profile.

The questions were based on the monthly expenditure on electricity bills, duration of the room heaters being switched on, number of luminaries at their homes and their rating.

The results of the questionnaire facilitated the profile creation and justification and further consideration of the two bed room flats. The outcome of it enabled a proper profile to be created for summer and winter periods. It was noticed that, winter expenditure was more than summer, and it was just due to the room heaters. The expenditure during the transition period was a bit less than winter period as few days during that period the room heaters were switched on.

The wattage rating of the luminaries were around 60W and among the sixteen people energy efficient lights were used among six people. Energy efficient bulbs can also contribute in saving electricity.

Next, we noticed that many people are not aware of smart controls. This statement can be made, as out of the sixteen people, only four of them had some idea of intelligent control systems. The common man is not aware of the fact. This is to give the holistic approach to the project and could be a part of future study.

The overall result of the questionnaire facilitated in making justification to the profile built for the case study. The main difference in the two or three or four bedroom flats is the consumption pattern due to the increase in electrical load. The control strategy remains the same. With smart control, lighting, heating can be controlled due to the maximum consumption of electricity is noticed in those areas at homes.

Moreover the questionnaire carried out gave an idea that a profile for a two bedroom flat would be sufficient to investigate the influence of the controls at homes. Thus two bedrooms flat were considered. This facilitated the creation of the profile for a two bedroom flat in Glasgow as discussed below.

3.3. Creating the Profile

The main aim of the case study was to show that installing smart controls at homes can save electricity and money. A daily electrical consumption profile was built for a two bedroom flat in Glasgow, taking into account all the electrical appliances used at homes on daily basis. A spread sheet was prepared with the different entities, its rating, and number of items per flat. The questionnaire as well as a field survey assisted while making up the daily electrical consumption profile for a typical winter, summer and transition period.

Utilization of energy was noted down for every five minutes, throughout the day. Binary method (0/1) was followed. If there was consumption it was marked 1, and for no consumption, it was marked 0. In the following manner, total consumption profile of a two bedroom flat for electricity for all the entities listed.

For example, during the summer period the heaters remained off, therefore while crafting the profile, 0 was placed, whereas during the winter period when ever the heaters were switched on 1 was placed in it. A snapshot of the profile for one hour is shown below:

1	2 BED ROOM FLAT				0:00:00	0:05:00	0:10:00	0:15:00	0:20:00	0:25:00	0:30:00	0:35:00	0:40:00	0:45:00	0:50:00	0:55:00	1:00:00
2	ENTITY																
3	Lights		Rating	No. of items/flat													
4	1	Corridor	0.06	2	1	1	1	1	1	1	1	1	1	1	1	1	1
5	2	Bedroom 1	0.06	2	0	0	0	0	0	0	0	0	0	0	0	0	0
6	3	Bedroom 2	0.06	2	0	0	0	0	0	0	0	0	0	0	0	0	0
7	4	Living Room	0.06	3	0	0	0	0	0	0	0	0	0	0	0	0	0
8	5	Kitchen	0.06	3	0	0	0	0	0	0	0	0	0	0	0	0	0
9	6	Bathroom	0.06	2	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Kettle		2.2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Electric Cooker		4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Oven		2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Fridge		1.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	Washing Machine		1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Others: Toileteries & Iron		1.015	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Television		0.2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Others Cooking App		1.6	1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Vaccum Cleaner		1.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Tumbler Drier		1.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Room Heaters (bed-rooms)		1.5	2	1	1	1	1	1	1	1	1	1	1	1	1	1
21	Room Heaters (living room)		1.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Room Heater (kitchen)		1.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	*-includes other kitchen items used during cooking such as microwave, toaster and rice cooker, mixer																

Fig. 3.2: The Daily Electrical Consumption Profile [for one hour]

To build the profile, following assumptions were made:

i. The house is assumed to be electrically heated.

ii. During the winter season, the room heaters in

- Bed rooms are assumed to be switched on for about thirteen hours per day.
- Living room is assumed to be switched on for about six hours per day.
- Kitchen is switched on for five hours per day.

These assumptions were based taking into consideration the overall outcome achieved in the questionnaire. An average is taken for this study. The rating of the appliances taken into account is based not only on the questionnaire but also from the field study carried out. Hence all the essential entities are listed which adds to total the electrical load of the house. This also gives a practical approach to the research.

A particular column is made in the spread sheet to remark on the control. This remark is made whether the particular appliance can be controlled (Y/y) or cannot be controlled (N/n). Remark made on the appliances to be controlled made easy to create scenarios for simulation and also for the section assessing the potential of smart controls.

The next step was to get the total consumption of the house considering the total electrical load together with the assumptions. Hence to obtain the total consumption, a sum was done considering all the five minute consumption, throughout the day. This was found for winter, summer and transition periods. The total consumption for a day is calculated for individual entity by the following formula:

(**SUM (Total consumption for every 5 minutes interval)/12) * (Wattage rating of the entity) * (No. of Items in the room)**

Here it is divided by 12, the data is noted for every 5 minutes.

Hence monthly consumption is calculated by multiplying daily consumption with 30. Cost of electricity is assumed to be 0.10p/kWh. Thus daily and monthly expenditure is evaluated. This led to the formation of the profile to carry out further quantitative analysis to interpret the impact of controls.

3.4. Assessing the Potential of Smart Controls

This study is carried out with the profile created. Climate dominates the energy use mainly in case of the residential buildings since due to direct conduction of heat or from infiltration/ ex filtration through building surfaces a certain amount of heat is lost or gained which ultimately accounts for a major portion of the energy consumption. Smart Controls have the potential to make a significant amount of electricity, but the amount is not specific as found in the literature review. There is no consensus about the value.

The most important end use of the domestic sector is space heating, which accounts half the energy costs. Appliances (lighting, refrigeration and other equipment) accounts for only 22% of the total costs. [5]

The questionnaire was fruitful in giving us the monthly expenditure on electricity consumption. Keeping this in mind the profile was crafted. During the winter season, it is in the range of £240 to £250 monthly. This is the case when there is no control. But during the summer season, as the room heaters are switched off, the electricity bill ranges in between £85 to £100.

The above statement is verified by doing an evaluation in the excel sheet. The total heating load is removed, to get the total electrical consumption during summer period as listed below:

Monthly consumption= 85kWh

Expenditure on electricity Bills= £85/monthly

But during the winter period the load gets increased as thus different scenarios are created to gauge the capability of smart control.

Thus to assess the capability of the smart controls at homes, different scenarios was built to see its effect and also considering a worst case scenario. Initial electrical consumption for a two bedrooms flat in Glasgow was considered, which is listed in the table below:

Heaters	Bedroom	Living room	Kitchen	Cost/day(£)	Monthly Expenditure(£)
No. of hours operated	13	6	5	8	240

Table 3.1: Initial Electrical Energy Consumption [without control]

The monthly expenditure as listed in the table is in line with the questionnaire carried out. Now, considering that the house is controlled by the smart controls the method of assessing is made easier by taking into account the heaters used for space heating and doing various combinations with the number of hours the heaters are operated to the visualize the effect it will have on the impact of smart control.

Scenario 1 was created considering the room heaters being operated for 13, 15 and 24 hours , living room heaters 7 and a half hours and kitchen heaters for 5 and half hours a day.

Scenario 2 was based keeping both the living and kitchen room heaters operating 6 and half hours in a day. The operating hours for bedroom were kept constant, 13, 15, and 24 hours.

The last *Scenario 3* was created taking into account that the room heaters will be operated for 13, 15 and 24 hours, living room heaters for 6 hours and kitchen heaters for 5 hours in a day.

This evaluation is prepared with the help of the profile created. The findings of the scenarios as stated above are listed below in tabular form:

Scenario 1					
Heaters	**Bedroom**	**Living room**	**Kitchen**	**Cost/day(£)**	**Monthly Expenditure(£)**
No. of hours heaters operated	13	7.5	5.5	6.5	195
	15	7.5	5.5	6.7	201
	24	7.5	5.5	10.8	324
Scenario 2					
No. of hours heaters operated	13	6.5	6.5	6.5	195
	15	6.5	6.5	6.7	201
	24	6.5	6.5	10.8	324
Scenario 3					
No. of hours heaters operated	**13**	**6**	**5**	**6**	**180**
	15	6	5	6.5	195
	24	6	5	10	300

Table 3.2: Results of the scenarios [considering space heating in a house]

The result obtained shows that the daily expenditure or the monthly electricity bill depends on the number of hours the heaters are being operated throughout the day.

The line marked in green is in line with the assumption made as stated earlier, while creating the profile for winter period. Controls can save about 20% of the total monthly electricity bill.

The values marked in red, shows that there is no savings if the heaters are operated for those number of hours in a day, inspite of the smart controls installed.

Similarly, if we consider operating the heaters throughout the day, (the worst case scenario) we cannot make any saving rather it amounts to a huge expenditure on the total monthly electricity bill of the house.

Worst Case Scenario					
Heaters	**Bedroom**	**Living room**	**Kitchen**	**Cost/day(£)**	**Monthly Expenditure(£)**
No. of hours heaters operated	24	24	24	17	510

Table 3.3: Worst case Scenario

Hence from the above analysis we can conclude that installing smart controls in the house can meet the useful space heating requirement of the house (as marked in green) and also assist us in saving both electricity and money.

Next a *quantitative study* is carried out. Hence this analysis study will facilitate to show the potential of the smart controls starting from the assumption of about 70%, 60%, 50%, 40%, 30%, and 20%, 10% reduction. Again from literature review, it has been found that installing controllers can make energy savings up to 40%.

With the help of the excel sheet calculation on the amount of saving was done. The calculation was carried out with the following parameters as follows:

The total monthly electrical energy consumption of the house during winter period [without control] ranges between 2400 kWh to 2550 kWh. Here it is considered 2550 kWh.

Total Expenditure based on the consumption= £250/monthly

Now based on the percent reduction, monthly and as well as daily expenditure is evaluated which is listed in the following table shown below:

% Reduction	Monthly Electrical Energy Consumed(kWh)	Monthly Expenditure(£)	Daily Expenditure(£)
10	2295	230	7.7
20	2040	204	6.8
30	1785	179	6.0
40	1530	153	5.1
50	1275	128	4.3
60	1020	102	3.4
70	765	77	2.6

Table 3.4: Quantitative Analysis [during winter]

The values in table-3.4 are evaluated by taking the electricity consumption without control (table-3.1) as the base value and the estimated % reductions are calculated as following:

Monthly Electrical Energy Consumption [MEEC] = Initial Consumption-(10% of Initial Consumption)*Cost of Electricity

For example for 10% reduction

MEEC = [2550-(10% of 2550)]* 0.1 = £230

Daily Expenditure = 230/30 = £7.7

[Number of days in a month = 30]

Similarly for 20%, 30%, 40%, 50%, 60% and 70% the MEEC was evaluated along with monthly and daily expenditure.

Further a Quantitative Analysis graph is drawn taking into account the percent reduction and monthly expenditure.

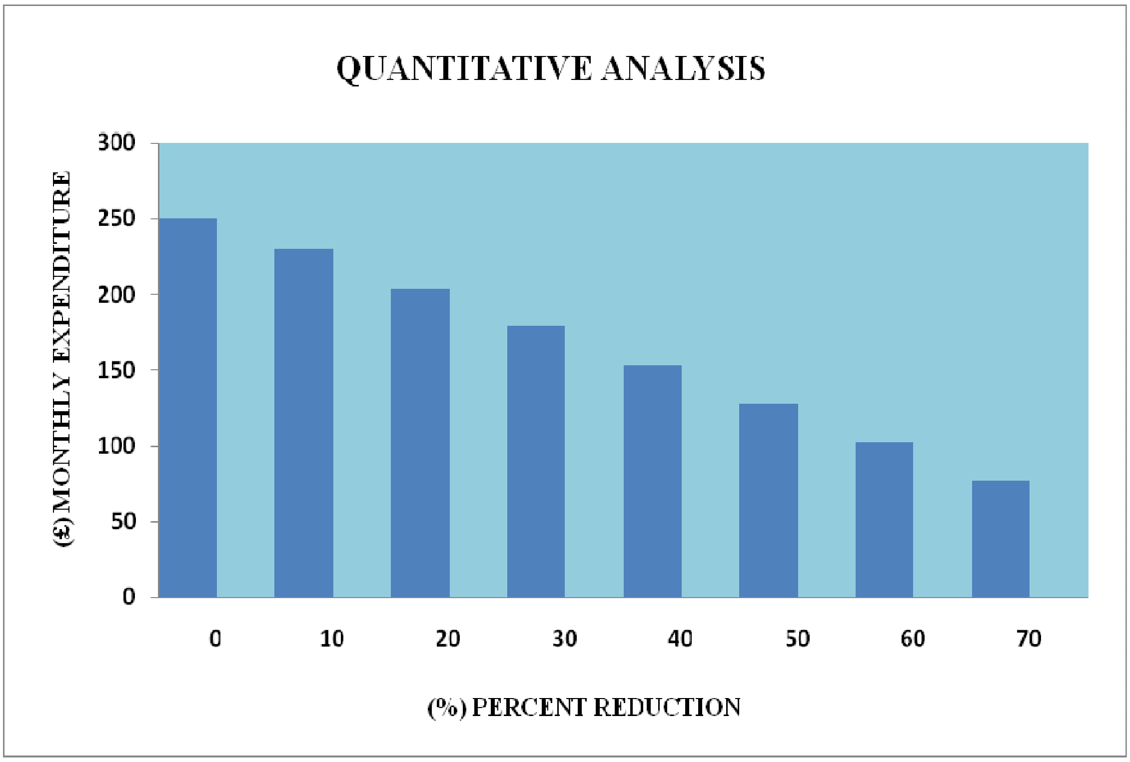

Fig. 3.3: Quantitative Analysis graph (For winter period) [with control]

The above graph represents the %age reduction in the range 10-70% along with zero percent reduction or the maximum consumption.

Zero percent reduction values are the values considered for initial electricity consumption, without control during winter period. During the transition period the monthly expenditure ranges from £170 to £200 which equals to £6 to £7 daily (approximately). The variation might arise because the room heaters are switched on when the temperature falls below 12^0C and hence the external weather plays a significant role.

Thus from this study we can conclude that weather in Glasgow can potentially affect the electricity consumption and it can be managed by installing controls which not only saves energy but also a significant amount of money.

3.5. Environmental Implications of Smart Homes

To add to the impact of the smart controls a brief note on its environmental implication is discussed below. This shows that installing smart controls helps in reducing the emission of the amount of carbon-di-oxide in the atmosphere. Since it has a wide area of research it is precisely shown how it affects the environment, starting the discussion giving a *brief background* to it and then *showing calculations* carried out in terms of reducing carbon foot print.

There are benefits of smart home, to which it is hard to put a value. The things like ambience, distinctive design, a sense of space and harmony with the site. Smart Homes help the environment by reducing the use of energy and thereby cutting the green house gas emissions.

Global warming and other environmental issues can seem too big to deal with but can make a difference by making smart decisions at home. Relevance between carbon foot print and green building design is just integrating natural environment with building environment. 'Green Building Design' and Smart Homes are synonyms. Green Building Design is regarded as a practice to increase the efficiency along with resource energy water and materials and also reducing building impacts on human health and design, construction, operation, maintenance and removal.

It is found that home electricity contributes 12% of Carbon Foot Print [CFP] in the developed world. CFP is sum of two parts, primary and secondary footprint. The domestic consumption is included in primary footprint. Carbon dioxide (CO_2) is the main gas produced by human activities, which is associated in global warming. [29]

Therefore Smart Home can significantly contribute in reducing CFP thus helping in making a sustainable environment to leave in.

The environmental implication for the smart controls was carried out keeping in mind the sustainability indicators. These indicators provide useful information to help to prevent or solve problems before they become severe. These indicators are selected on the basis of their reliability, understanding, the accessibility to data etc.

In this report measuring the amount of carbon emissions is used as the sustainability indicator.

The evaluation was carried out taking into consideration the amount of carbon emitted per kWh. Then considering the profile created, the evaluation of the carbon emission was carried out. Every house that uses electricity emits CO_2. Thus this analysis will guide us as how much CO_2 is emitted daily for both the scenarios, strengthening the study of impact of smart controls.

Assuming, 1 kWh of electricity produced from a coal powered station emits 0.97kg of CO_2 to the atmosphere, [30] the carbon emission for the profile is evaluated.

From the profile

Scenario 1: Without control

Electricity consumption= 84 kWh/day [when the room heaters are switched on, winter period]

Therefore CO_2 emitted to the atmosphere = 82 kg/day (approximately)

Therefore monthly emission of CO_2 = 2473.5kg/month.

This is indeed a bulk amount of CO_2, which is emitted to the atmosphere. Therefore the next scenario will show the reduction, while handling with the smart controls.

Scenario 2: With control

In this case, the comparative study is taken into account and according to the percent reduction in electricity consumption, the carbon emissions is analyzed and is summarized in the table as shown below:

% Reduction	Monthly Electrical Energy Consumed(kWh)	Monthly Carbon Emissions(kg/month)	Daily Carbon Emissions(kg/day)
10	2295	2226	74
20	2040	1979	66
30	1785	1731	58
40	1530	1484	49
50	1275	1237	41
60	1020	989	33
70	765	742	25

Table 3.5: Carbon emissions after installing controls

The carbon emission (kg/day) is calculated from the daily electricity consumption, keeping in mind the 10% reduction, when control is installed. The reduction percent in carbon emissions is calculated taking into consideration the carbon emissions from scenario 1 and then subtracting it and multiplying by 100.

Thus from the above analysis it is noticed that installing controllers at homes not only save money but can reduce the amount of carbon emission, thus helping in reducing the carbon foot print of the house. Moreover it has been noted that the consumption of energy in domestic sector depends mainly on the location, design and construction of a dwelling, and the specification of heating systems and their controls along with the efficiency of the appliances. It also depends on the behaviour and socio demographical characteristics of the occupants. "Total domestic energy consumption can be reduced by 10–30% by changing occupants' behaviour alone." [17]

"DEFRA's (2004) Energy Efficiency Action Plan stated: In the household sector, there are different barriers to improving energy efficiency, and three predominate: lack of information, high upfront costs, and hassle and disruption.... Even relatively well informed consumers are often more interested in renewable energy... but will not install cost effective energy efficiency measures in their home." [15]

Therefore user must be made aware of the fact of global warming and should also understand its role and contribution towards it. Misusing of energy can contribute a large amount to global warming. Building smart homes or renting smart homes can contribute to a great extent to sustainability of environment.

Smart Homes with smart control will also enable them to cut down their monthly electricity bills. Thus together with deployment of smart control at homes, it is also necessary to change the attitude of user by making them ‘aware’ of the facts while using energy for daily consumption.

The environmental implications of smart homes can be recommended for future work as it has a very big scope and a wide area for research. The idea behind this discussion is to bring forward few issues like sustainability, carbon emissions etc. It adds a flavour to the entire discussion of the impact of smart controls. Moreover it helps in assessing the smart controls as the sustainability issues are put forward enabling to understand the impact of smart controls in a better way.

CHAPTER-4

SYSTEM DESCRIPTION AND ESP-r MODELLING

This section of the project will describe the construction of the model and three different simulations. The simulation, for this project is carried out with the university developed modelling package ESP-r. A short description on ESP-r can be found in appendix 2 of this report. Both of the model descriptions are examined and an explanation about their form and structure.

Initial simulation was carried out considering without control and then with controls. For the case of with controls, the control period was changed and respective results were noted. Finally dynamic simulation for the model was carried out.

A brief background to passive solar and daylight control is discussed to understand its importance and requirement in a house. Solar energy is used all the time, directly or indirectly by all living beings in the world. In Passive Solar Energy Design, one tries to make maximum use the amount of the sun’s heat by making very careful planning of the building design, so that the requirement of the room heating can be reduced. While designing, building materials, method of construction can also help us to reduce the amount of space heating, ventilation & artificial heating. In Passive Solar houses, the design is planned in such a manner, that the main objective to let sun’s heat during winter & block the sun during summer months.

The use of daylight to illuminate a space along with integrated electric lighting system is a new and evolving concept and is particularly useful for lighting control. It can improve the energy efficiency of the building as the daylight is used for illuminating it depending upon its orientation and design

4.1. Model Description : Residence

This section, describes the model and its assumptions done to move ahead with the simulation. The simulation was carried out by building

- One zone model
- Two zone model

One zone model represented a room in the house. The two zone model was built representing the rooms (mainly living and bedrooms) in the house to visualize energy delivered in each room. Both the models are so designed for light electrical load house. The design process thus proceeds on the basis of the beliefs the design team holds. Simulation is used to test the beliefs of the design team.

There were few assumptions made while carrying out simulations.

The following assumptions were:

i. Glasgow climate was considered for the respective year.

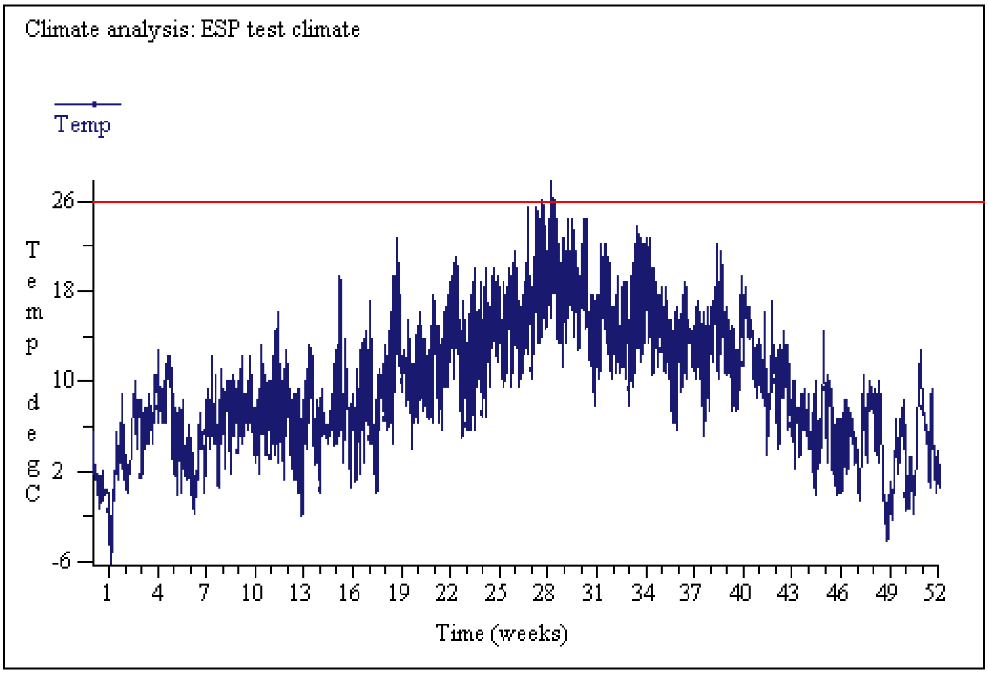

Fig.4.1: The Climate Analysis of the year.

The space-heating in a house is mainly dominated by climate; the above graph gives an idea of the climate throughout the year, enabling to take the design assumptions correctly to run simulation for different period of the year.

ii. A standard UK norm for housing was considered, i.e. it is insulated, with no cavity walls. This regards mainly to the solid wall insulation, either internal or external. This is a light electrical load house.

iii. Windows are double glazed. This feature in the house helps to reduce the heat lost and also the transmission of noise. It is a type of insulation.

iv. The casual gain for bedroom and living room for occupants, lights and equipments were adopted from the ESRU report, *Development of a Methodology for the Evaluation of Domestic Heating Controls,* Phase 2 of a DEFRA Market Transformation Programme project, carried out under the contract to BRE environment. [23] Casual gain charts for the rooms are also attached in the appendix 5(A) and 5(B).

v. Heating set points are 21^{o}C in the living zone and 18^{o}C in other zones (bedrooms).

Two heating schedules are used, according to the ESRU report, [23] following assumptions are made:

- Intermittent, for weekdays: 07:00 to 09:00 and 16:00 to 23:00
- Continuous operation at weekends 07:00 to 23:00.

Considering these assumptions, the models were built. For the first instance the simulation was carried out. Then a basic heating and cooling control was installed and a complete simulation was carried out for summer, winter and transition period. This simulation when carried out fulfilled the condition without control.

Next step was to add controller and run simulation fulfilling the condition with control.

vi. The control period was divided into three periods: 00:00-08:00, 08:00-17:00 and 17:00-23:00.

The operation of the controllers was throughout the day. During the period 08:00-17:00, a controller is placed because to hold the temperature to 15^{o}C to 18^{o}C so that when the occupant enters the room at 17:00 hours, does not feel uncomfortable due to low temperature. In the period from 08:00-17:00, it is assumed there are no occupants in the house.

Changing the control period and the temperature had an effect on the energy delivered to the house. Thus it was analyzed and the results are discussed in the later part of the report.

A ‘result analysis’ was carried out. The ambient and dry-bulb temperatures were recorded keeping in mind the scenarios with and without control. As Glasgow climate is unpredictable, the ambient temperature is taken into account before carrying out with simulation. This also resulted in easier interpretation of the impact of controls in the homes. The results for the simulation carried out for the two-zone model representing the two-bedroom flat in Glasgow is represented are discussed in this section.

The ambient temperature and the climate data for assist in taking decisions for the heaters to be switched on and also enabling to answer different questions based on it. The software provides the facility to browse the climate data yearly, monthly or seasonally. Exploring this data can give clues which can be used while designing the model.

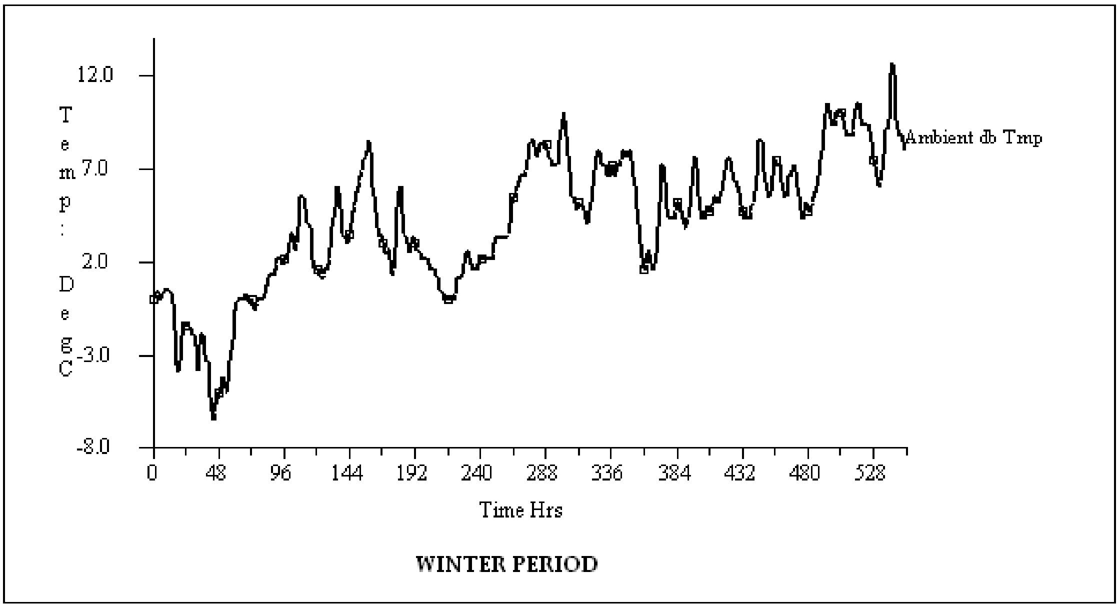

Fig. 4.2: Ambient Temperature for winter period

For example, the graph of the ambient temperature for winter period enables us to predict concisely that at certain point of the day, it will be below freezing point. This may give a support to the heating and cooling demands and capacity.

Next step was to monitor the dry bulb temperatures of the rooms during summer and winter periods. The winter period considered for simulation is: Sunday 7th January to Monday 29th January. Figure 4.3 shows the temperature of the room when there is no control installed in the house. The room temperature along with the ambient temperature may reach the freezing point leaving the occupant uncomfortable. This is achieved by switching on the room-heaters, which are to be manually operated and take about 30-45mins to increase the temperature of the room. But when it is switched off, after a certain time lag the temperature falls down. The comfortable temperature cannot be retained for a long period of time.

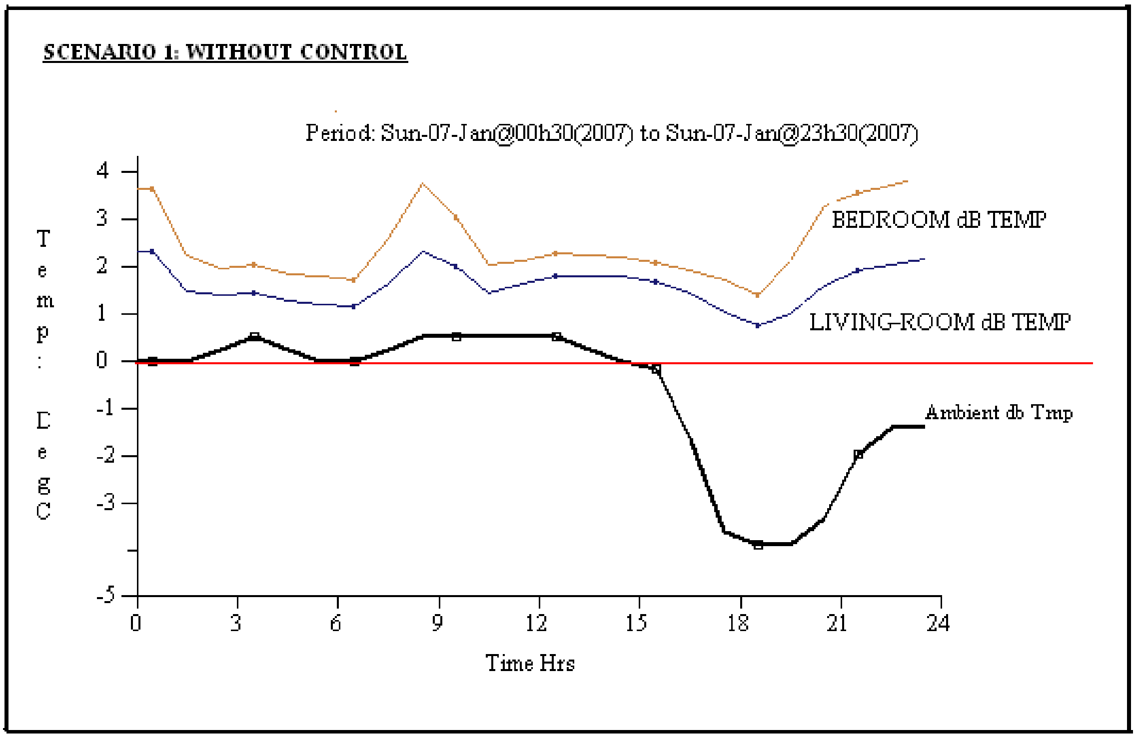

Fig 4.3: Simulation for Scenario 1: Without Control

If the room-heaters are switched on for a long time, there is a possibility of the room getting over-heated. Thus it is necessary to manually monitor the room-heaters so that neither the temperature of the room falls down nor the room gets over-heated. This makes uncomfortable stay in the house for the occupant. Here the smart-controls come into play.

Simulated-assisted control will help to retain the temperature, so that it does not reach the freezing point. A basic controller with control period was selected to carry with the simulation.

Generally the temperature of the room is programmed to be about 2-3^{0}C less than the condition when there are no occupants. If the temperature is allowed to fall to a greater extent, the waste heat production is more, which is marked in red as shown in figure-4.4.

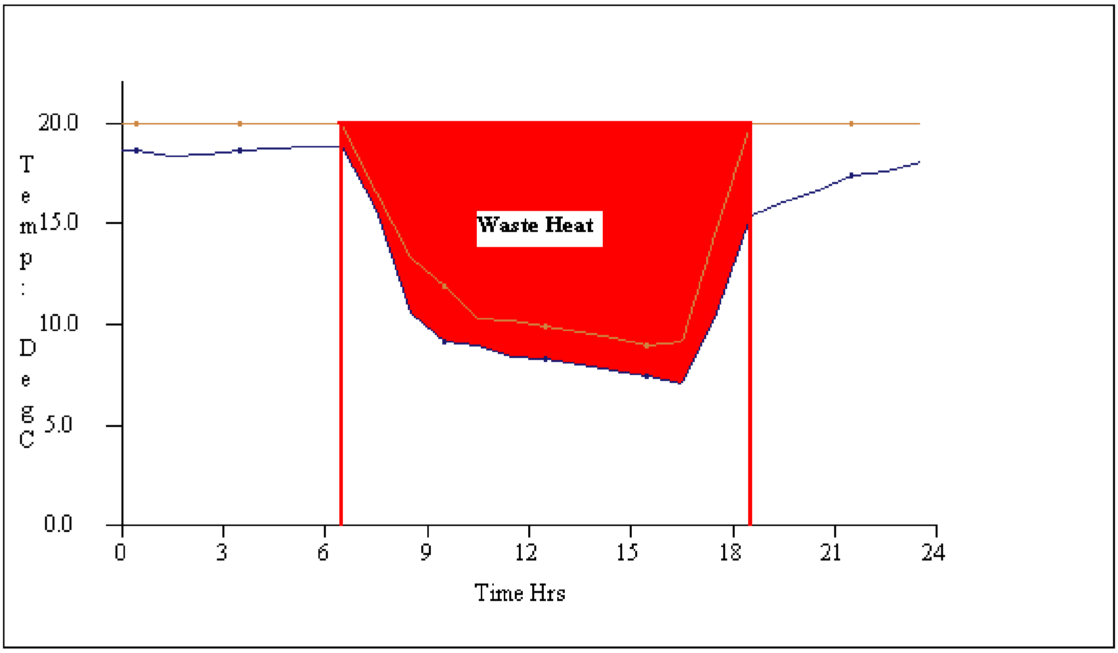

Fig. 4.4: The waste heat production for the period from 07:00-17:00 (without control).

The above graph shows that there is immense amount of waste heat produced for the period 07:00 to 17:00. This is the period when there is no control. After 17:00 hours, extra amount of energy is required to reach the desired temperature of 20^{o}C.

Figure-4.5 is a continued simulation carried out by introducing a control simulation for the similar time-period, i.e., 07:00-17:00. It is noticed that the waste heat production is less as compared to the condition, when there is no control on the heating targets. Thus keeping this in mind the control period is so set that there is minimum waste heat produced and hence the further simulation is continued with varying control periods.

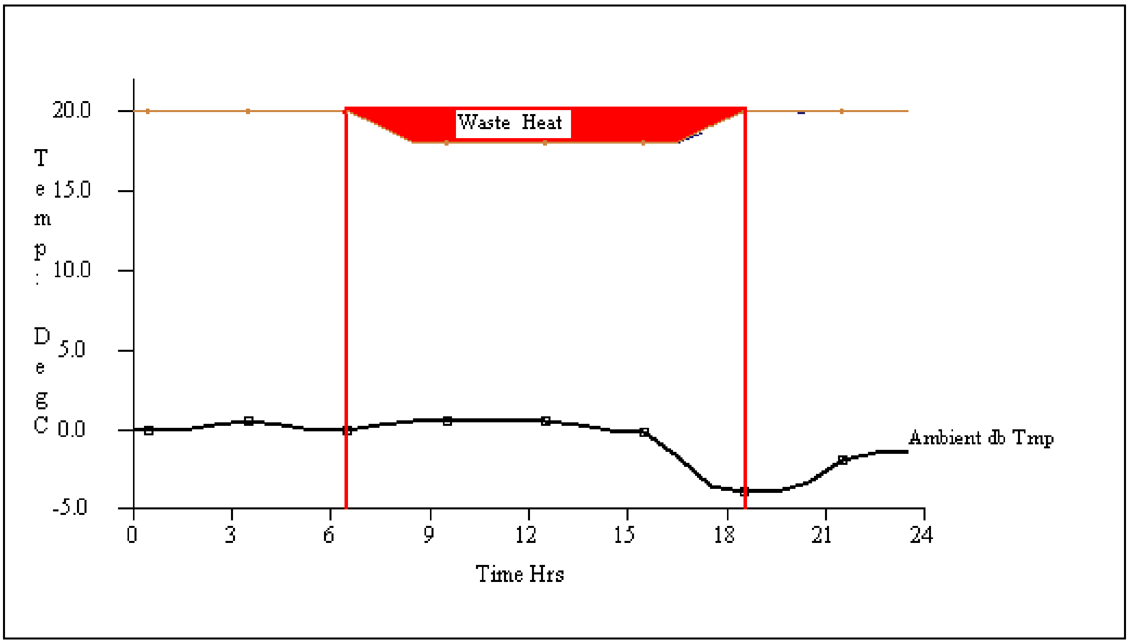

Fig: 4.5. The waste heat production for the period from 07:00-17:00 (with control)

The simulation for scenario 2 with control (figure-4.6) shows that the temperature of the room can be maintained to about 15°C as occupancy of the room is time-based.

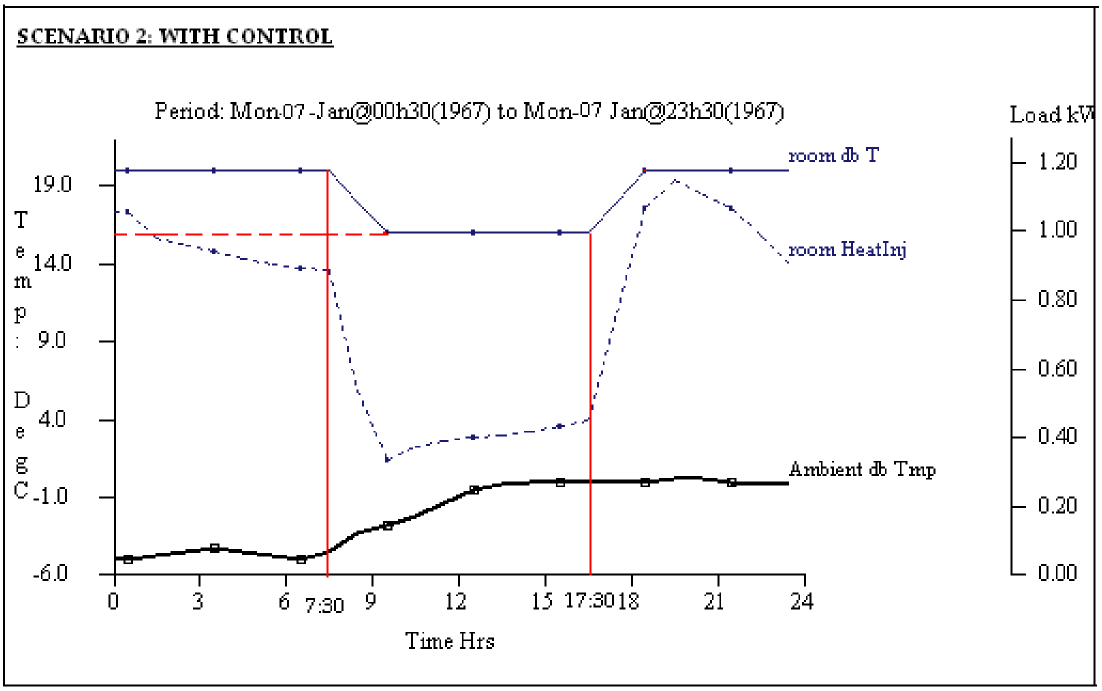

Fig: 4.6: Simulation for Scenario 2: With Control

The room heaters start to raise the temperature of the room to 15°C at 07:30 hours, as the occupants leave the room by 08:30 hours.

Again at 17:30 hours, the heaters get activated to raise the room temperature to 20°C. This results in avoiding the huge loss of heat and also ensures the comfort stay in the house.

The control period is divided into three periods and simulation is carried out during winter period. The control period was changed it was noted that operating the heaters for 24 hours will make no saving compared to13 and 16 hours of operations. The result of this simulation is listed in a tabular form below. These results are found to be in line with the results obtained from the quantitative analysis as carried out in chapter-3, which gives about 20% to 40% reduction in electrical consumption upon using the controllers.

FOR SCENARIO 2: WITH CONTROL		
No. OF HOURS HEATERS OPERATED	**ENERGY DELIVERED (kWh)**	**(%) PERCENT SAVING**
24	56	No Saving
16	25	22
13	20	38

Table 4.1: Simulation Results for Scenario 2 (with control).

The calculations for changing control period are explained further. If the room heaters are switched on throughout the day, there is absolutely no saving. From the profile we noted that the room heaters of bedroom deliver 32 kWh. Thus taking this assumption we evaluated the percent saving. The calculation is shown below for 24 hours of operating room heaters:

Percent Saving= ((32-56)/32)*100= No saving

Similarly for 16 hours and 13 hours is evaluated. Hence the saving of electricity is in line with the saving noted in quantitative and literature review.

4.2. Dynamic Simulation

Dynamic Simulation is carried out in order to note the changes if these techniques are incorporated in a house. This is a type of integrating renewables in the house by passive solar and day lighting control. The overall energy delivered by the room gets decreased thus helping the occupants of the house to save some more money and also energy.

Thus simulation was carried out creating scenarios as explained together with the results obtained for each scenario.

(i) Passive Solar

With the aim of understanding the importance of passive solar gain in building this simulation is carried out. This simulation is carried out to determine the impact on heating or cooling requirements and overall thermal comfort. The simulation was carried out for the two zone model. Two scenarios were created.

Scenario 1: The size of the window was increased.
Scenario 2: The heating and cooling system of the model was switched off.
For both the scenarios, simulation was done mainly for the winter and summer periods.

The technical features of the two-zone model:
Site location- 55.9^{o}N 4.1^{o}W of local meridian
Ground reflectivity: constant =0.20
The results for the scenarios are listed below:

Scenario 1: The size of the window was increased.

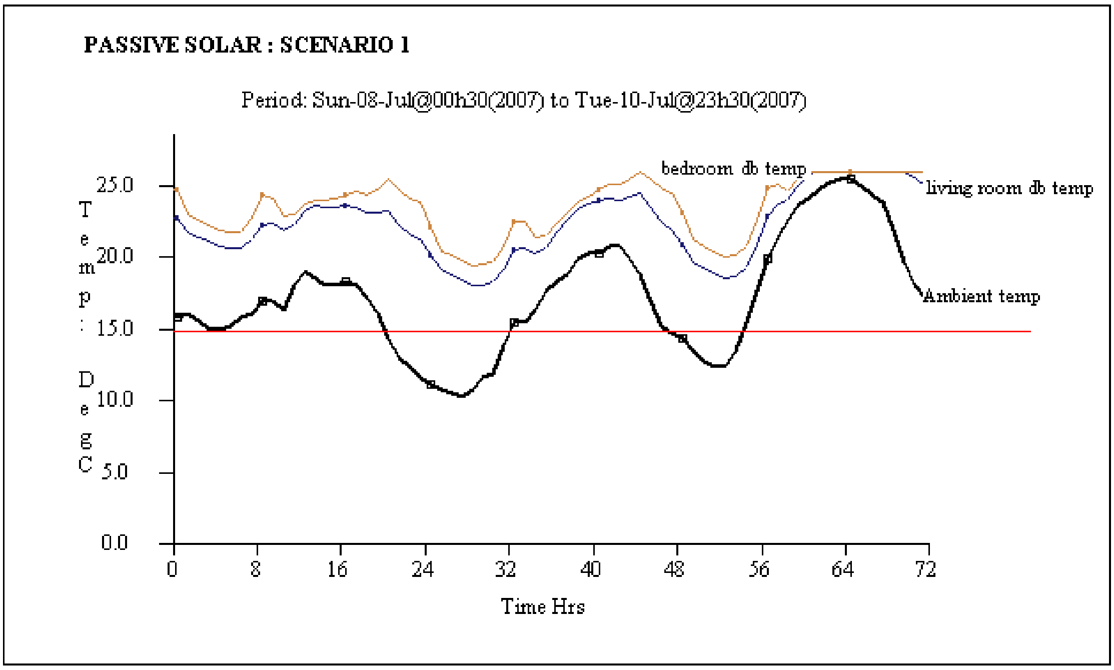

Fig.4.7: Simulation for Scenario 1 of Passive Solar

The effect of increasing the size of the windows was that it required higher heating during winters and cooling during summers. The intensity of solar radiation was very low during winter requiring additional heating.

During summer, heating load was not required. The highest ambient temperature was about 30^{o}C. It made the occupants of the room feel uncomfortable as it received maximum solar radiation. There was no cooling load. There was no heating load necessary during summer period as the room temperature was around 25^{o}C. The figure-4.7 explains the phenomenon.

Scenario 2: The heating and cooling system of the model was switched off.

During the summer period simulation was carried out without control loops and temperature of the room was around 20^{o}C as shown in figure 4.8. Bedroom and living room temperatures were almost same implying that the day time temperature of the rooms were very high & the occupants of the rooms were at discomfort.

Thus without having controls in the rooms make the residing of the occupants uncomfortable.

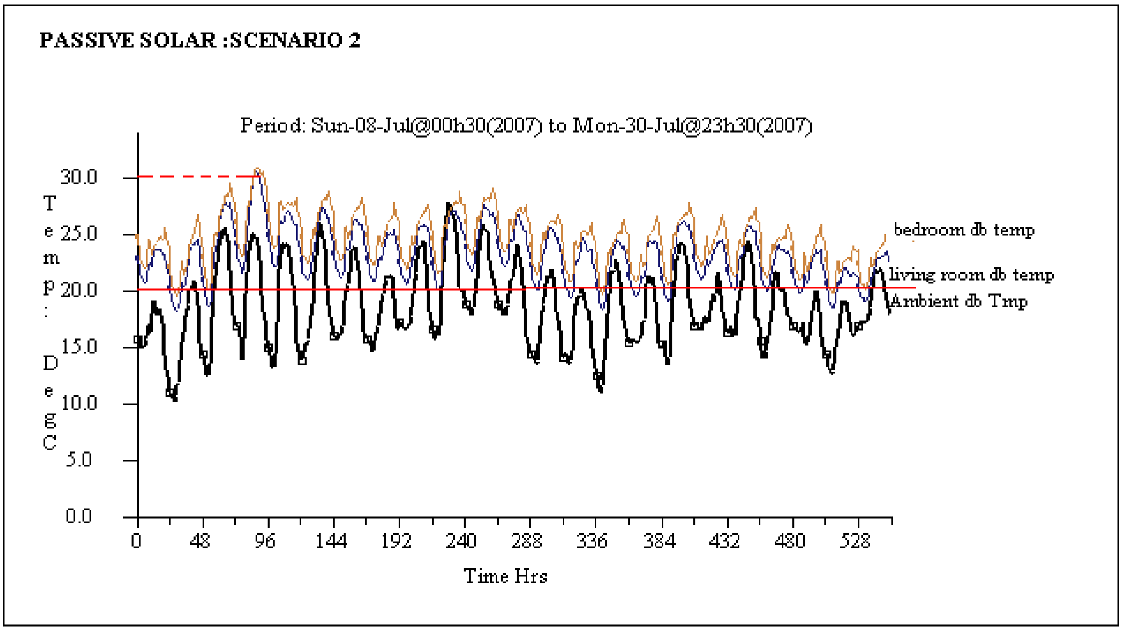

Fig.4.8: Simulation for Scenario 2 of Passive Solar.

In the next step, the model was rotated by 270 degrees anticlockwise, keeping the rooms at the same side. It was noticed that the temperature of bedroom reached more than 30^{o}C.

Hence exploring the results of the above simulation of passive solar, it shows that the solar gain depends on few factors. They are

- Dimension of the windows present in each room of the house
- Orientation of the building and also the rooms for example, rooms in the direction of south east will get the benefit of morning sun & those facing in the direction of south-west will receive the afternoon sun till the sunset. [31]
- Materials used during construction of the house and
- It will be better to install highly responsive & zoned heating systems as it will be more energy efficient than heating the room throughout the day.

Passive Solar Building Design is a technology which simply aims at interior thermal comfort during the day and also throughout the year, without using any equipment for active heating & cooling such as photovoltaic etc. It can also be referred as ‘green building design’

The Passive Solar Design does not have any moving parts since they can perform by themselves without any electrical or mechanical assistance. The main part of it is building design and constructional materials. Simple techniques can also bring a great change in our way of consuming energy and comfort level.

(i) Lighting Control

The present report discusses the impact of day light use to offset the use of artificial lighting in the buildings. It also comments on the climate, control on heating and cooling requirements stating few principles of lighting and lastly discussing the results of the simulation and environmental impact of it.

A seasonal simulation was then carried out with the help of ESP-r on daylight control of light switching. This lighting control was carried out for and the two-zone model created in ESP-r, similar to the two-zone model built in ESP-r. Heating and cooling loads were taken into account. A lighting control scheme was introduced taking few assumptions as follows:

- Control period was selected for 24 hours
- User defined daylight factor [DF] was taken into consideration
- Photocell location was selected as centre of the ceiling facing down
- Day light factor was increased accordingly.

The above stated assumptions enabled to carry out the dynamic simulation and interpret on the impact of the controllers at home.

This simulation was carried out to visualize the effect of lighting in building heating and cooling loads. The first simulation was done for a lighting gain of 106W for the occupied period (in case of bedroom) for weekdays and weekends as casual gain. Winter and summer simulation was done. It was found that during winter the heating load of bedroom was lower than the living room by about 20%. This was due to the fact that the lighting gain released heat for which the heating required in bedroom is not as much as compared to living room.

Next part of this simulation was carried out by adding lighting control system. It was noted that introducing control loop system, affected the heating load in summer and cooling load during winter. The control loop system helped to save energy as maximum daylight was allowed to pass the room through the window and also by switching off the lights as required.

Thus from the above analysis, it clearly shows that diffused solar radiation, relative humidity, sensible and latent heat energy and ambient temperature influence the heating and cooling of the rooms. Along with it the external factors like climate, location of the building, amount of sunlight (passive solar) received by the building, colour are taken into account while designing a house. Thus lighting loads can be helpful in saving energy if properly designed with the control (timer).

4.3. Recommendations

The set of preliminary guidelines for the above project is split into two sub sections due to its different aspects of Intelligent Controls. Thus the recommendations present a supplementary information on the technology should have the vision to approach the problem in wide perspective in order to achieve balance between technical solutions and sustainability. The key elements required for this feasibility study are:

- Project Checklist
- Modeling and Technical assistance

4.3.1. Project Checklist

The project checklist provides a detailed list of the key elements that should be considered before venturing into the project. The following checklist will assist in carrying out project.

Simulated-Assisted Control is the main theme of the project therefore proper literature review is recommended to understand it requirement which will assist in developing new ideas chipping in with the concept.

Need to create a *daily electrical consumption* profile for a house considering all the electrical appliances available in a house.

If any doubt arises, go small, like taking into consideration two bedrooms flat, which will help in listing all the appliances found in each room and thus will help in creating the profile. To begin with, assume winter period.

Note the current expenditure for the house.

Carry out a field study which will facilitate the process of building up the profile.

Next carry out simulation with a building simulation tool. If ESP-r is being used, it is recommended to use in LINUX platform.

4.3.2. Modeling and Technical Assistance

Designing, modeling and carrying out simulation, is critical as it involves minute details to be noted down. It requires good technical background to understand the parameters required for the investigation. It also requires preliminary investigation of electrical energy distribution (cooling, lighting equipment process etc) in the house. It is recommended that listing all the items that uses electrical energy enables to evaluate the consumption of electricity for each entity available in the house.

Next making a list of remarks as which of the entities can be controlled with such a system will facilitate the process of modeling and eventually the simulation.
Small operating station can monitor such process for the entire building. It is to be noted that, not only house, these controls can be a part of community buildings and campuses forming the base of such schemes. This concept will then develop over time.

In order to carry with the further research, it is recommended to carry out a field study which enables to build a concept on the user behaviour and also to assist in making sensible assumptions. Electrical consumption profile is the vital section of the research. Therefore to create the profile, it is suggested to note the details for every two minutes as that minimizes the error to a great extent. Calculations should be done minutely as little mistake in formulae's changes the interpretation of results. There are many fields which could be modified and be a part of this feasibility study further as discussed later in the section future work.

Next for the simulation, software should be chosen according to the comfort level. This increases the degrees of freedom and helps to explore the different options of the software enabling to interpret the results with more technical details.

Therefore the above set of guidelines will make it smoother to carry out this study for future research.

CHAPTER-5

DESIGNING OF SMART CONTROLS

This chapter adds finesse to the overall report. It introduces the control logic behind the complete smart control system and the hardware components required to build a controller.

The discussion is initiated by introducing controller, its control logic and then with the help of a conceptual diagram lists the hardware components for smart control. This section also states the differences between the pneumatic and the direct digital control along with its advantages. The control mode is also defined. This builds a foundation to explore further about the essential hardware components required to design the controller.

5.1. Controller

Controllers are a part of an interdisciplinary branch of engineering, dealing with the behaviour of the dynamic system. It generally works on the flat-form of control theory and monitors and affects the operational conditions of a dynamical system. A controller generally manipulates the input and tries to obtain the desired effect on the system. There are various kinds of controllers available like supervisory control, pneumatic control etc. but in this report we will discuss about computer-based controller [direct digital control, DDC]. The only difference in computer based control with supervisory control is that it does not have analog controller and the computer works as a fundamental part of the feedback system. [6]

5.1.1. Direct Digital Control [DDC]

The computer industry gave an initial momentum to the digital electronics to produce smaller, cheaper, faster integrated circuits[IC] s. The evolution of digital computers having speed, reliability, smaller size and reduced cost increased its use in process control. The ultimate result of computer applications in process control has been to use the computer to perform continuous controller functions (Appendix-3). [1, 6]

An energy management system (EMS) is defined as a fully functional control system including controllers, various communications devices and the full complement of operational software necessary to have a fully functioning control system. [32]

Thus elaborating it, the use of DDC started from the use of main frame computers handling many control loops, to mini and microprocessor based computers controlling fewer control loops to microprocessor based computer embedded in the sensor controlling only one loop. These are often regarded as 'smart sensors', interfaced with supervisory computers and final control elements using serial buses or local area networks [LAN]. [6]

The basic DDC loop is shown below (figure 5.1):

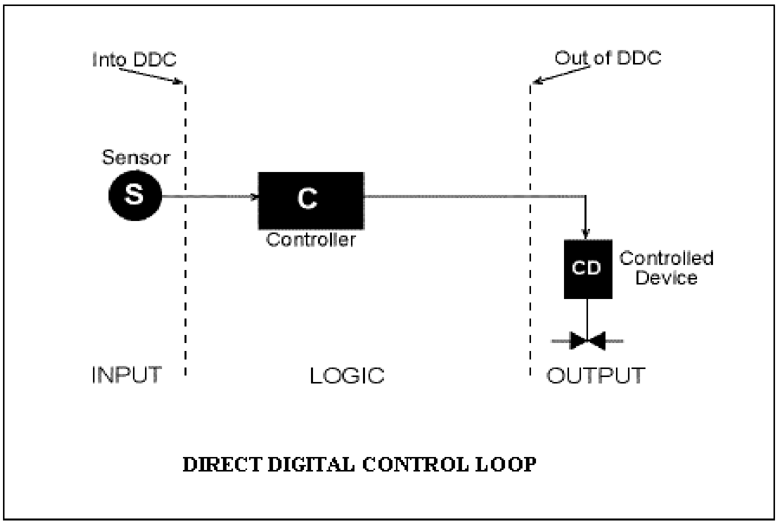

Fig. 5.1: Diagram showing basic DDC loop [32]

DDC is a *closed control loop*. In a closed-loop control system, a sensor observes the output and supplies that data to the computer which continuously regulates the control input as it is necessary to keep the error minimum. For example, in a closed loop system, if a home thermostat were installed outside the house, the output (furnace heat) would have no effect on the input to the thermostat, in case of outdoor temperature. Now by closing the loop i.e. bringing the thermostat indoors, the output (furnace heat) would now affect the input (indoor temperature). In this closed loop control system, the output is fed back and is 'compared with the desired value and the difference between the two is used as an actuating signal to actuate the control device (gas valve) for a gas furnace'. [1, 7]

DDC can be explained by breaking down the terms into '*direct*' and *'digital'*. "The term 'Direct' means that the microprocessor in the control loop and the term 'Digital' means, control is accomplished by the digital electronics of the microprocessor." [1] The control of valves and dampers is very accurate because of the use of proportional-integral-derivative [PID] control as shown in figure 5.2.

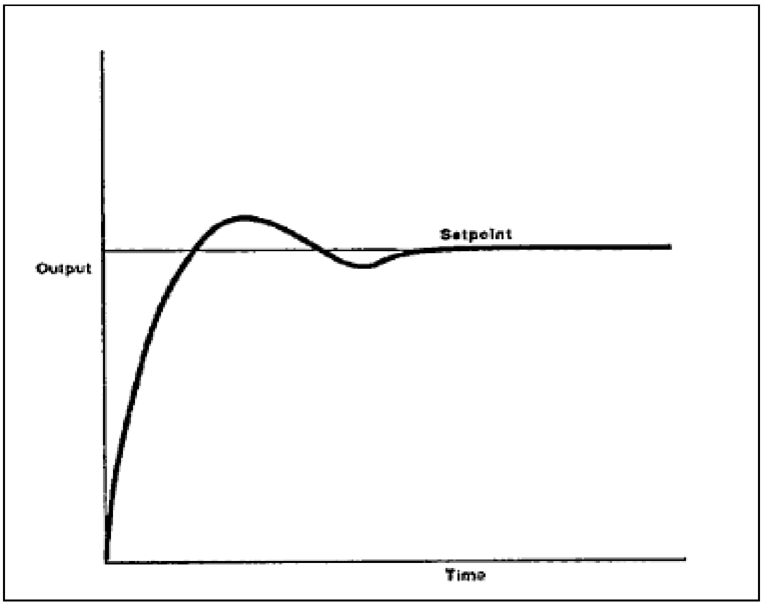

Fig.5.2: Proportional-Integral-Derivative Control [1]

"It provides fast, responsive, operation of a heating valve by reacting to the temperature changes in three ways: the difference between the set-point and actual temperature (proportional), the length of time the difference has existed (integral) and the rate of temperature change (derivative)." [1]

This type of control logic not only saves energy but also increases accuracy simultaneously getting rid of hunting and offset by decreasing over-shooting of the temperature and minimizing the amount of time required to settle the desired temperature. Pneumatic control deficiency was that, it could handle only one loop in a fixed manner where as the DDC can handle numerous control loops and can be programmed for different control functions without hardware changes. A comparison chart is attached in appendix 4 which will illustrate the effectiveness of DDC over conventional pneumatic controls. [1, 6, 7]

Utilizing DDC in building automation has few advantages like:

- It reduces energy consumption
- It reduces HVAC labour
- Improves and assures occupant comfort and
- Provides greater operating convenience.[1]

The brief discussion about DDC will guide the way to the components required for designing a controller.

5.2. Hardware Components of Smart Control

Hardware as well as software is required to build a DDC. Hardware must be reliable, industrial grade and engineered to interface with equipment. There are five basic components necessary in BEMS. They are as follows:

- *Sensors*
- *Actuators*
- *Microprocessor based field panels (controllers)*: they are mainly an interface between the remote sensors and actuators. It is the DDC.
- *Communication links*
- *Central Operating System* [1, 7, 10]

The working of these components is described briefly. The location of the *sensors* and/ or actuators is at the equipment which is being controlled. The information that is passed on (is identified as single operating condition like temperature or pressure) is conveyed to the field panels (controllers) for monitoring or decision making purposes. The actions initiated by the controllers put into action the *actuators* defined as the mechanical interfaces. These actions can be self-initiated or initiated by the controllers as outcome of information received from sensors. *Field panels* merge the input from the sensors and distribute the output to the actuators as received from the controllers. *Communication links* enables to transmit the information to the *central operating station* and these links carry information throughout the entire system. [1]

A conceptual diagram as in figure 5.3 will help to list the hardware components required to build the smart control.

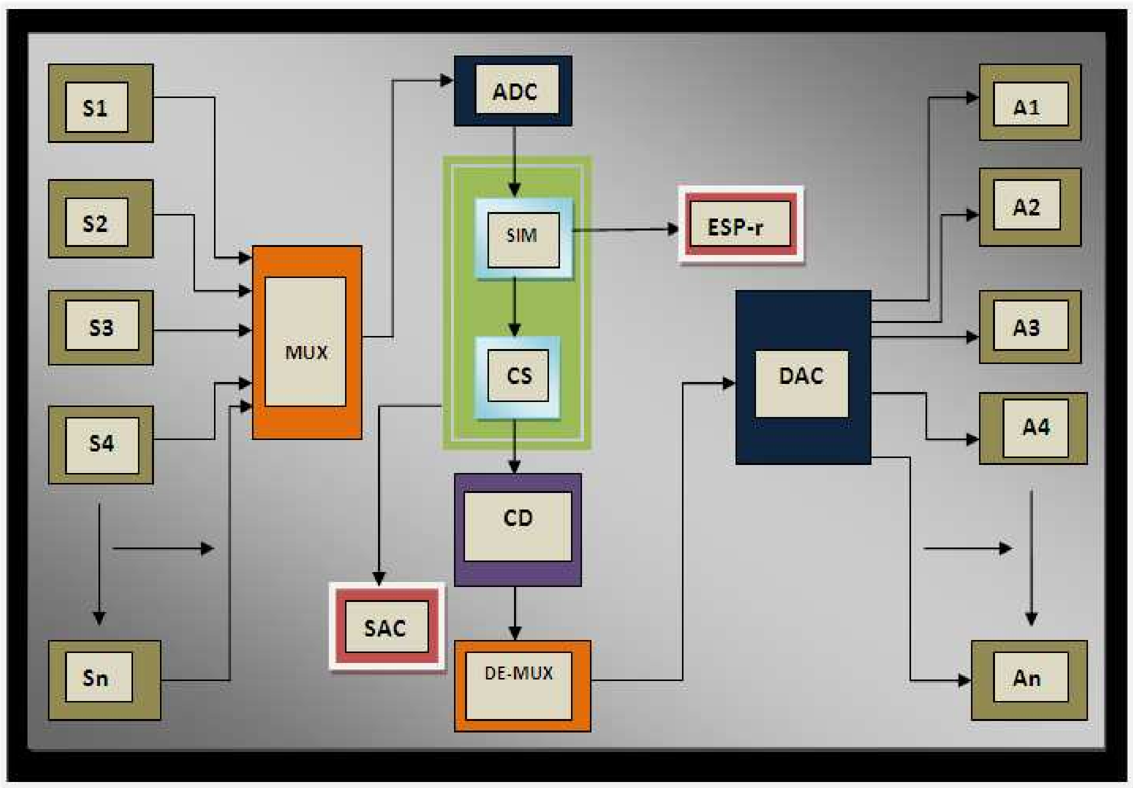

Fig.5.3: Conceptual diagram of Smart Control

Legends of the Fig. 5.3:

S1, S2, S3, S4…., Sn are ‘n’ number of Sensors

A1, A2, A3, A4…., An are ‘n’ number of Actuators

MUX-Multiplexer

ADC-Analog to Digital Convertor

SIM-Simulator

CS-Control Strategy

CD-Control Decision

DE-MUX- De-Multiplexer

DAC-Digital to Analog Convertor

SAC-Simulated-Assisted Control

ESP-r is the software for simulation

Now the main electronic components necessary to design a smart control are:

- *Sensors*
- *Actuators*
- *Multiplexer*
- *De-multiplexer*
- *Analog to Digital Convertor [ADC]*
- *Digital to Analog Convertor [DAC]*
- *Computer for programming*
- *Building Simulation Software*

Each of the components is described below:

- **Sensors** these are electronic devices. It has contact with the ambient conditions and responds by varying voltage or current. Sensors like movement control sensors, temperature sensors detects the movement and the ambient as well as the dry bulb temperatures which enables to transmit this signal, to ADC to convert the data into digital form for further evaluation.

- **Actuators** these devices transforms electric or pneumatic coded instructions into mechanical response. Signals through DAC are transmitted to it.

- **Multiplexer or MUX**

It is also known as mux and is called *data-selector*. It is a device that multiplexes or multiplies. “A MUX has 2^n data inputs, n control or select inputs and an output terminal where n =1, 2, 3 or 4. The selection of one of the 2^n data inputs is made by the signals applied to the select lines.”[11]

A diagrammatic representation of mux is shown below:

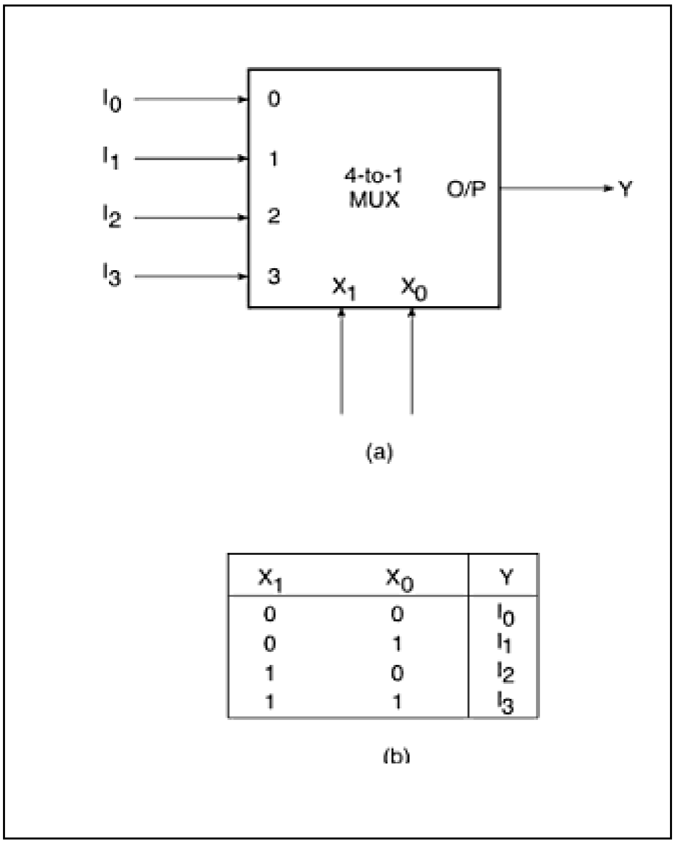

Fig.5.4: (a) 4 to 1 multiplexer circuit representation, (b) 4 to 1 multiplexer Truth-Table [1]

Therefore from the diagram above, it notice that a multiplexer takes as many input signal, and generates only one output.

Multiplexer selects binary information present in any one of the input lines depending upon the logic status of the selection inputs and routes it to the output line. Thus if a multiplexer has ‘n’ number of input lines, the maximum possible input lines will be 2^n and the multiplexer will be referred as 2^n to one multiplexer. In this case several input information is signaled into one output signal carrying many communications channel by means of some multiplex technique. [7]

- **De-Multiplexer**

It is also known as de-mux and is called *data-distributor*. It is just reverse of multiplexer. A diagrammatic representation of a de-mux is shown below:

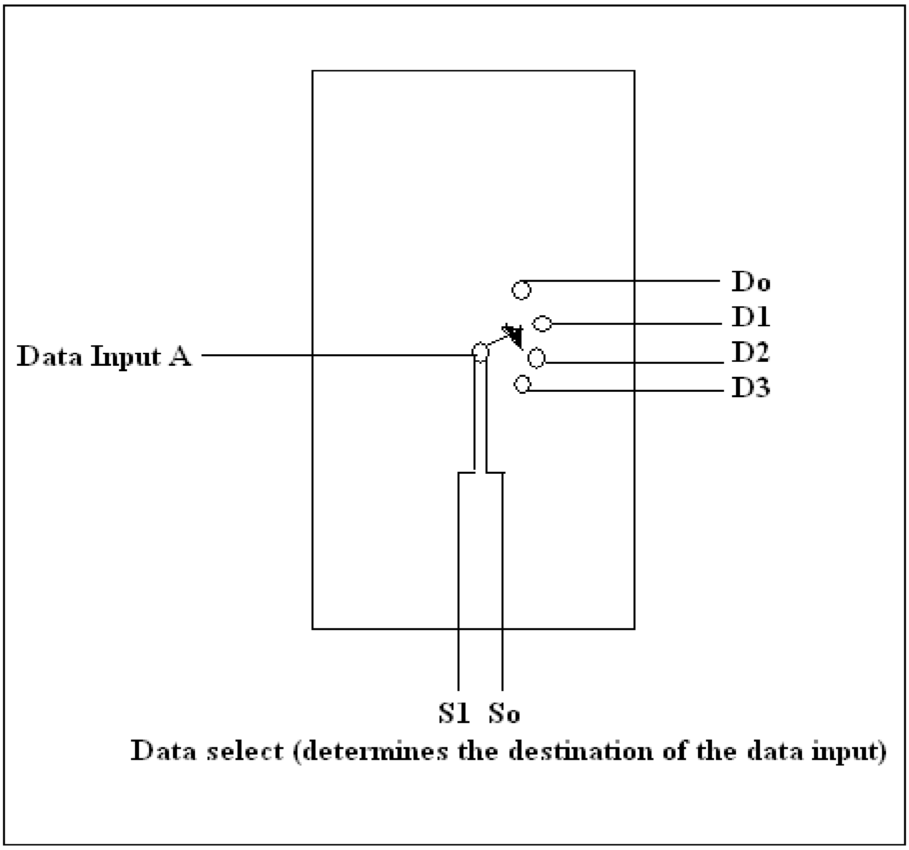

Fig.5.5: Functional Diagram of 4 line De-Multiplexer [9]

It is basically single input multiple output switch. It takes a single input data value and routes it into one of several outputs as shown in the above figure 5.4.

At the receiving end of the data link a complementary *de-multiplexer* is normally required to break single data stream back down into the original streams.

Multiplexer and de-multiplexer are the types of combinational circuits available in Electronics. [9]

➢ **Analog to Digital Convertor and Digital to Analog Convertor**

In this world, most of the physical quantities are analog in nature, like temperature, heat, light, pressure, speed. Therefore it is required that these quantities are understood by the digital system. This conversion takes place with the help of *analog to digital convertor* commonly known as ADC. It is an electronic device that converts continuous signals to discrete digital numbers. Now it is to be noted that when a computer is used for control the analog devices, these quantities should be converted with the help of *digital to analog convertor* commonly known as DAC. It performs in the reverse manner to ADC. The ADC and DAC are shown in figure 5.6.

There are devices that convert these quantities into electrical quantities, known as transducers. A commonly used transducer is a thermistor. It is device which is sensitive to temperature. The resistance increases if there is an increase in temperature or if the temperature remains constant, voltage is measured across it. [9, 11]

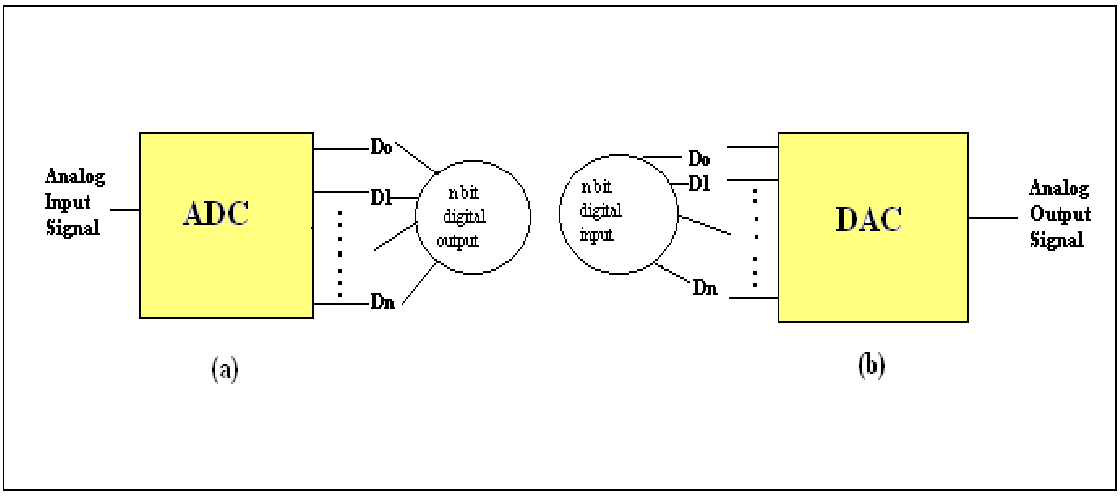

Fig.5.6: Block Diagram of (a) ADC convertor (b) DAC convertor [11]

Computerized acquisition of analog quantities is becoming more important than ever in today's automated world. Therefore it is now common to employ a complete *data acquisition system* [DAS] on a printed circuit board that interfaces easily with popular computer systems such as PCs or Macintosh computers.

These boards typically provide analog to digital conversion of input signals, digital to analog conversion of computer outputs and a number of digital input and output lines.

A particular significant feature of such systems is that they come with software routines performing input output using the onboard data input and output devices simplifying the task of the software design since data input and output are facilitated by calls to one of these routines. The entire system communicates with the help of data bus and control bus. Data bus may comprise of ADC, microprocessor, memory etc sending control signals to and from various devices for such things as chipset, system clock, triggers etc. [6, 7, and 9]

Computer and its **software** play an important role in process control. When the controller function is taken over by a computer error determination and controller mode equation evaluation is done with the help of software. Software must be of a design proven to be comprehensive, flexible and easy to use. It is the software which determines the ultimate capability of DDC. The input data operations for the computer based controller starts from putting the data in to suitable form for a controller-mode operation.

Thus the entire operation of the smart control is discussed required for efficient building energy management systems. This chapter briefly outlines the functions of the components required for the system discussing the sensing mechanism of it.

CHAPTER-6

CONCLUSIONS AND FUTURE WORK

6.1. Conclusions

The aim of this project was to do a feasibility study, providing Glasgow City Council with a preliminary investigation report on the impact of intelligent controls in residential buildings in Glasgow. This project was carried out successfully by breaking it down into various objectives and field study, comparative analysis and energy modeling and monitoring became a part of the project.

The main objective of the project as stated was to look into the different options of deploying these controls at homes. To report on the impact of smart controls, different methods were adapted like preparing a questionnaire, comparative study and then finally carrying out simulation with the university software. Many people in UK or rather in Glasgow are unaware of the technology and when talked about, they comment it as 'costly'. These feedbacks are useful as it will be a mode of learning as it will have certain weight age on the decisions made in future.

The impact of the smart controls was carried out by developing a case study for a two bedrooms flat in Glasgow. Profile was then created which enabled further simulation with the building simulation tool ESP-r.

Based on those results, a set of recommendations are prepared. This will throw some light for the future research in this field. This part of the report is considered as the vital portion of recommendations as it gives a scope to carry out this work in much more modified technical manner. An environmental implication of smart homes, with smart controls, is briefly discussed in this report, giving an impression that it can be an active member in the field of green technology.

A control logic diagram is build to build a path to new software that would help to monitor the electrical energy consumption at homes. This is similar to the flow diagrams used by the programmers and in effect some required programs can often be 'written (coded) directly from such a process-operation diagram.'[3]

Though the concept simulated-assisted control is new, but will definitely be part of future technology enabling the user to use electrical energy more efficiently and save money. As shown in the report the amount of carbon reductions implies that it itself substantiate in being a part of the green technology in future in Glasgow as well as in UK.

Thus it can be concluded that, deploying intelligent controls at homes will entirely influence the way of living of people in Glasgow. This change will not take place immediately but gradually over time, it will start showing its effect and enable us to guide our way to a better sustainable living.

6.2. Future Work

Many developments can be made further, in this study in future by breaking down the topic into the sections as shown below:

- Looking into the environmental perspective of the study.
- Looking into the financial perspective of the study.
- Carry out the simulation considering the different types of houses and also for the different commercial buildings available in UK.
- Creating a logic diagram along with a software code for the smart control.
- Looking into the designing of the smart control in more details.

Environmental study will look into the matters related to sustainability of the control system being installed and also the keeping an eye to its carbon emission each year. A similar project is being carried out on 4M [modeling, monitoring, mapping and management] is being carried out by the University of Lou borough, trying to regulate the carbon emissions in UK cities and also deploying energy efficient measures for this carbon management. Integrating renewables in smart control could also be discussed as a part of the environmental study helping it to become a member of the ‘green technology’.

Financial perspective will look into the payback period and NPV [Net Present Value] analysis will give an entire idea of the amount required for the project focusing in the cost benefit that would be acquired from it.

Considering the different types of houses and the commercial buildings available in UK will offer a variety to the project. It will not only look into the flats but also look into the houses and the other buildings enabling to infer broadly on saving of electricity and bringing sustainability.

The logic diagram together with the software code will demonstrate on the working of the smart control. Designing the smart control could be discussed in more details evaluation it for error calculation, signal processing, sampling the data, data acquisition etc could be explained thus bringing the details of the ‘control theory’ required for to build the smart control.

Thus the above sections discussed above are the recommended areas which could be carried out for future research area in wider aspect.

REFERENCES

7.1. Books

1. Richard A. Panke, C.E.M, (2002), *Energy Management Systems & Direct* Digital Control, Francis

2. Levermore G.J, (1992), *Building Energy Management Systems*, E&FN Spon

3. G.J.Levermore, (2nd Edition), *Building Energy Management Systems, Application to Low Energy HVAC and Natural Ventilation Control*, E&FN Spon

4. Anibal T De Almeida and Arthur H Rosenfeld,(Vol 149), *Demand Side Management and Electricity End Use Efficiency*, Kluwer Academic Publishers

5. R D Evans and H P J Herring (1990), *Energy Use and Energy Efficiency in the UK Domestic Sector up to the year 2010*, Energy Efficiency Office.

6. Curtis D Jhonson, (Seventh Edition), *Process Control Instrumentation Technology*, Pearson Education

7. Albert Thumann, P.E.,C.E.M., D.Paul Mehta, (Sixth Edition), *Handbook of Energy Engineering*, Fairmont Press and CRC Press-Taylor and Francis Group

8. Scott. H. Clearwater, (1996), *Market-Based Control: A Paradigm for Distributed Resource Allocation,* World Scientific Publishing Company
9. William Kleitz, (Fifth Edition), *Digital Electronics-A Practical Approach*, Prentice Hall

10. Anil Kumar Maini (2007), *Digital Electronics: Principles, Devices and Applications*, Wiley Blackwell

11. D. C. Green (5th Edition), *Digital Electronics*, Longman Publishers

7.2. Journals and Papers

12. J.A. Clarke, J. Cockroft, S. Conner J.W. Hand, N.J. Kelly, R. Moore, T. O'Brien, P. Strachan, (2002), *Simulation-assisted control in building energy management systems.*

13. John Macqueen, (1997), *The Modeling and Simulation of Energy Management Control Systems.*

14. Clarke J A, Cockroft J, Conner S, Hand J W, Kelly N J, Moore R, O'Brien T and Strachan P, (2001), *Control in Building Energy Management Systems: The Role of Simulation.*

15. Sally Caird & Robin Roy & Horace Herring, (2007), *Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low- and zero-carbon technologies.*

16. Ardeshir Mahdavi, Bojana Spasojević, and Klaus A. Brunner, (2005), *Elements of Simulated-Assisted Daylight Control Responsive Illumination Systems Control in Buildings.*

17. Yigzaw G. Yohanis , Jayanta D. Mondol, Alan Wright, Brian Norton, (2008), *Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use*.

18. Jayanth Krishnappa, (2008), *Active Networks: Demand Side Management & Voltage Control*

19. William E. Rees, (1999), *The Built Environment and the Ecosphere: A Global Perspective*

20. Jon William Hand, (2008), *The ESP-r Cook Book*

21. E. Sierra, A. Hossian, D. Rodríguez, M. García-Martínez, P. Britos, and R. García-Martínez, (2007), *Optimizing Building's Environments Performance Using Intelligent Systems*

22. Alfio Galatà, (1998), *Fuzzy Controller for Artificial Lighting System*

23. Jeremy Cockroft, Aizaz Samuel, Paul Tuohy, (2007), *ESRU report on Development of Methodology for evaluation of Domestic Heating Controls.*

7.3. Websites

24. Rob Edwards, Environmental News and Comments, cited May 2009, Available at: http://www.robedwards.com/2008/06/glasgow-bids-to-go-greener.html

25. Good Practice Study 2, Building Energy Management Systems at UCD Belfield, cited June 2009, Available at: http://www.sei.ie/uploadedfiles/FundedProgrammes/cs2bemsatucd.pdf

26. Energy Consumption in UK, cited June 2009, Available at: http://www.berr.gov.uk/files/file11250.pdf

27. Smart Home Controls, cited June 2009 Available at: www.smartkontrols.co.uk

28. Smarter Homes, cited June 2009, Available at: http://www.smarterhomes.org.nz/

29. Home of Carbon Management, carbon foot-print, cited August 2008,
Available at: http://www.carbonfootprint.com/carbonfootprint.html

30. Electrical Consumption and Carbon-di-oxide, ESRU report, cited July 2009,Available:
http://www.esru.strath.ac.uk/EandE/Web_sites/0102/RE_info/C02.htm#Scottish%20Household%20Carbon%20Dioxide%20Emissions

31. Passive Solar Design, ESRU report, cited July 2009, Available at: http://www.esru.strath.ac.uk/EandE/Web_sites/002/RE_info/passive_solar.htm

32. Introduction to DDC systems online, cited August 2009,
Available at: http://www.ddc-online.org/intro/intro_chapt01.aspx

33. Commercial Building Real Estate, The magazine of the CCIM Institute, cited August 2009,
Available at: http://www.ciremagazine.com/article.php?article_id=433

APPENDICES

8.6. APPENDIX 1- THE QUESTIONNAIRE

1. Where do you stay?
   ANS:

2. What type of house do you stay? (2 Bedroom or 3 Bedroom or 4 Bedroom Flat)
   ANS:

3. What is your electricity bill:
   (i) During winter- **£**
   (ii) During summer- **£**
   (iii) During transition-**£**

4. How long do you switch on the room heaters (in Hours):
   (i) During winter-
   (ii) During summer-
   (iii) During transition-

5. What is the rating of the lights (in Watts)? Do they have same rating?
   ANS:
   How many lights do you have:
   (i) In kitchen-
   (ii) Bedroom-
   (iii) Bathroom-
   (iv) Corridor-
   (v) Living room-

6. What are the other utilities do you have in your home?
   ANS:

7. Do you have smart control (Y/N)?
   If yes, what type of control?
   ANS:

8.2. APPENDIX 2

- **ESP-r Programming**

ESP-r namely stands for *Environmental Systems Performance research* version. It is a 'state-of-art simulation program' which is entirely based on integrated approach. It is an energy simulation program which permits an assessment of the performance of existing or proposed building designs, incorporating traditional and/ or advanced energy features. Building and plant modeling approaches are theoretically compatible.

The program methodology of ESP-r mainly comprises of Project Manager, Simulator and Results Analyzer. It operates in 'graphical interactive modes by menu driven command selection.' All input data is managed by the project manager. It also helps the user by managing the descriptive files making the model creation process very productive. The Simulator with the help of the input data predicts the performance of the building or plant, in accordance with the defined problem. The Results Analyzer, analysis the results stored in the Simulator. Different forms (like statistical, interrogative,) of results are available in this module. The intermingling of the three modules assists the designer in the process of decision making. [13]

- **Steps to create a model in ESP-r**

This is basic guide for new users in ESP-r. It will help them to create a model and get to know the different options available in ESP-r (in Windows platform)
ESP-r software can be downloaded from the following link below:
http://www.esru.strath.ac.uk/

After installing the software, user can go through the various exemplar models in the software or else can get started building its own two zone model by following the steps below:

1. Select create new-give a root name for your model-model description-selecting standard set of folders.

2. Year and site latitude and longitude, does not matter. It does not have a global map inside so changing latitude and longitude will not change where you are.
3. Select the climate data. It depends on the user, which place analysis is being carried out. If the desired climate data is not found, then climate data in the form of ASCII code can be fed in and then can be browsed.
4. Select Database Maintenance, and view the synoptic and graphical analysis of the climate data.

The following steps below now will help to build the model with the geometry:

5. Select browse-edit-simulate, Zone Composition-geometry and attribution-input dimensions. Now for dimensions refer ESP-r cookbook as mentioned in the reference 20.

   Note: Windows do not support bitmap.
6. Give a name to the new zone, select surface list and edges, selecting within surface creates window and at base creates a door.

   Note: In ESP-r doors and windows are surfaces.
7. Selecting surface attributes-'attribute many' enables to name the surfaces and also select appropriate construction material suitable for the surfaces. These should be linked with all the zones created.
8. Topology-surface connections and boundary-check via vertex contiguity examines the zones created and its surface connections and boundary.
9. Now selecting operational details helps to input the casual gains for occupants, lights and small power. For a house the ESRU report on Development of a Methodology for the Evaluation of Domestic Heating Controls will give an idea of the casual gain for bedroom and living room.
10. Control loop can be selected as desired by selecting the control period for weekdays and weekends.

    Similarly the operational details and the control loop details should be linked with the zones created.
11. Run simulation. Selecting simulation preset assist in changing the period of simulation and thus it can be carried out for any desired month of the year.

    To change the period of simulation, the user needs to go to the 'simulation presets' and change the period for simulation.

12. Result analysis, gives the entire result as per the input given. Graphs for ambient temperature, dry bulb temperature can be noted along with sensible and latent heat loads. Enquire about option helps to note the energy delivered for the required number of hours.

These are the basic steps which will enable to build a model in ESP-r and will be a guide for new user in this software. There are other options which can be explored once the user gets proficient with the tool. It can integrate renewable energy into the model and run simulation for the desired period.

Note: Linux is a good plat form to start with ESP-r. As in the windows plat form it gets hanged and many times the data fed in gets lost since the files in it gets corrupted.

8.3. APPENDIX 3

This table below answers the question the when did *central management system* began [1]

1st Generation (1950's)

Remote monitoring panel using temperature sensors and switches to manually read conditions and start or stop motors.

2nd Generation (1960's)

Use of electronics, introduced low voltage circuits to automate or speed up monitoring of panel functions.

3rd Generation (1960's-1973)

Multiplexed systems consisted of groups of sensing and control points tied into a local system panel and a pair of wires that run back to a central console from multiple panels. Scanning the points in a system was accomplished electronically (response time was slow and failure of the Central Processor meant total system down).

4th Generation (1983)

Individual building panels become electronically smarter with their own stand-alone minicomputer. They can carry out most functions that the central computer used to do, and also relay information back to a central console. The processing of system functions is throughout the system.

The speed of the electronics, as well as software, and hardware reliability soon "over powered" conventional pneumatic control systems with simple proportional control and offset. EMS sensor locations were duplicated with pneumatic and electronic sensors.

5th Generation (1987)

Direct Digital Control (DDC) uses a small microprocessor and software for system sensing and control. DDC units can stand alone to provide various digital control sequences, or several DDC units can be tied to a central operator station. On any size system, this could be an IBM-PC or compatible. Most EMS manufacturers have their own software packages which results in the EMS becoming proprietary, as does the DDC system.

8.4. APPENDIX 4

COMPARISON OF PNEUMATIC AND DIRECT DIGITAL CONTROL **[Part 1]**

COMPARISON CATEGORY	CONVENTIONAL PNEUMATIC CONTROLS	DIRECT DIGITAL CONTROL	BEST CONTROL SYSTEM
Performance	• Proportional control only. • Single loop controllers. • Complex control is difficult or costly. • Adequate control.	Full PID control and more. Multi-loop controller. Easy to define complex sequences. Closer control.	DDC
Initial Cost	• Cost rises with number of control loops. • Complex control is very expensive.	Once cost of DDC controller is absorbed, cost rises with number of sensors and actuators. Capable of most complex control.	Comparable
Reliability	• Proven reliability over many years, however, control system must be well maintained and recalibrated regularly. • Relies on air supply.	Proven reliability in process industry and many commercial HVAC applications. Each DDC controller can stand alone.	DDC
Maintainability	• Relatively easy to maintain. • Require regular recalibration due to drift.	Automatic as-builts. Built-in diagnostics. Fewer components. No drift. Service by board replacement.	DDC

COMPARISON OF PNEUMATIC AND DIRECT DIGITAL CONTROL **[Part 2]**

COMPARISON CATEGORY	CONVENTIONAL PNEUMATIC CONTROLS	DIRECT DIGITAL CONTROL	BEST CONTROL SYSTEM
Flexibility	• Changes or additions require new or different controllers re-piping and often wiring, and then recalibration.	Programmable controller. New control strategies defined at central. New control easily added.	DDC
Ease of Use	• All operator interaction at local control panels. • Can read temperatures and change set-point.	Full English language reports. Color Graphic Displays Automatic Records of all control strategies.	DDC
Life Cycle Cost	• Requires regular recalibration. • Modification and expansion require additional controllers.	Easy to maintain. Easy to modify. Easy to expand.	DDC
Cost to Add Energy Management	• Each new function usually requires additional equipment and labor.	New functions are easily defined by operator.	DDC

[1]

8.5. APPENDIX 5 (A)

All gains in Watts
Wkd = Weekday

Living Zone

Day type	Gain no/ Description	Period Hours	Sensible Gain	Latent Gain	Radiant Fraction	Convective Fraction
Wkd	1 Occupt	0 - 7	0.0	0.0	0.30	0.70
Wkd	2 Occupt	7 - 9	130.0	56.0	0.30	0.70
Wkd	3 Occupt	9 - 16	0.0	0.0	0.30	0.70
Wkd	4 Occupt	16 - 19	60.0	0.0	0.30	0.70
Wkd	5 Occupt	19 - 24	186.0	89.0	0.30	0.70
Wkd	6 Lights	0 - 7	10.0	0.0	0.50	0.50
Wkd	7 Lights	7 - 9	65.0	0.0	0.50	0.50
Wkd	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Wkd	9 Lights	16 - 19	24.0	0.0	0.50	0.50
Wkd	10 Lights	19 - 24	84.0	0.0	0.50	0.50
Wkd	11 Equipt	0 - 7	50.0	0.0	0.00	1.00
Wkd	12 Equipt	7 - 9	200.0	0.0	0.00	1.00
Wkd	13 Equipt	9 - 16	50.0	0.0	0.00	1.00
Wkd	14 Equipt	16 - 19	70.0	0.0	0.00	1.00
Wkd	15 Equipt	19 - 24	250.0	0.0	0.00	1.00
Sat	1 Occupt	0 - 7	0.0	0.0	0.30	0.70
Sat	2 Occupt	7 - 9	130.0	56.0	0.30	0.70
Sat	3 Occupt	9 - 16	0.0	0.0	0.30	0.70
Sat	4 Occupt	16 - 19	60.0	0.0	0.30	0.70
Sat	5 Occupt	19 - 24	186.0	89.0	0.30	0.70
Sat	6 Lights	0 - 7	10.0	0.0	0.50	0.50
Sat	7 Lights	7 - 9	65.0	0.0	0.50	0.50
Sat	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Sat	9 Lights	16 - 19	24.0	0.0	0.50	0.50
Sat	10 Lights	19 - 24	84.0	0.0	0.50	0.50
Sat	11 Equipt	0 - 7	50.0	0.0	0.00	1.00
Sat	12 Equipt	7 - 9	200.0	0.0	0.00	1.00
Sat	13 Equipt	9 - 16	50.0	0.0	0.00	1.00
Sat	14 Equipt	16 - 19	70.0	0.0	0.00	1.00
Sat	15 Equipt	19 - 24	250.0	0.0	0.00	1.00
Sun	1 Occupt	0 - 7	0.0	0.0	0.30	0.70
Sun	2 Occupt	7 - 9	130.0	56.0	0.30	0.70
Sun	3 Occupt	9 - 16	0.0	0.0	0.30	0.70
Sun	4 Occupt	16 - 19	60.0	0.0	0.30	0.70
Sun	5 Occupt	19 - 24	186.0	89.0	0.30	0.70
Sun	6 Lights	0 - 7	10.0	0.0	0.50	0.50
Sun	7 Lights	7 - 9	65.0	0.0	0.50	0.50
Sun	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Sun	9 Lights	16 - 19	24.0	0.0	0.50	0.50
Sun	10 Lights	19 - 24	84.0	0.0	0.50	0.50
Sun	11 Equipt	0 - 7	50.0	0.0	0.00	1.00
Sun	12 Equipt	7 - 9	200.0	0.0	0.00	1.00
Sun	13 Equipt	9 - 16	50.0	0.0	0.00	1.00
Sun	14 Equipt	16 - 19	70.0	0.0	0.00	1.00
Sun	15 Equipt	19 - 24	250.0	0.0	0.00	1.00

[22]

APPENDIX 5(B)

All gains in Watts
Wkd = Weekday
Non-living Zone

Day type	Gain no/ Description	Period Hours	Sensible Gain	Latent Gain	Radiant Fraction	Convective Fraction
Wkd	1 Occupt	0 - 7	185.0	74.0	0.50	0.50
Wkd	2 Occupt	7 - 9	139.0	56.0	0.50	0.50
Wkd	3 Occupt	9 - 16	0.0	0.0	0.50	0.50
Wkd	4 Occupt	16 - 19	120.0	0.0	0.50	0.50
Wkd	5 Occupt	19 - 24	150.0	22.0	0.50	0.50
Wkd	6 Lights	0 - 7	12.0	0.0	0.50	0.50
Wkd	7 Lights	7 - 9	64.0	0.0	0.20	0.80
Wkd	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Wkd	9 Lights	16 - 19	34.0	0.0	0.50	0.50
Wkd	10 Lights	19 - 24	75.0	0.0	0.20	0.80
Wkd	11 Equipt	0 - 7	100.0	0.0	0.00	1.00
Wkd	12 Equipt	7 - 9	300.0	0.0	0.00	1.00
Wkd	13 Equipt	9 - 16	100.0	0.0	0.00	1.00
Wkd	14 Equipt	16 - 19	300.0	0.0	0.00	1.00
Wkd	15 Equipt	19 - 24	300.0	0.0	0.00	1.00
Sat	1 Occupt	0 - 7	185.0	74.0	0.50	0.50
Sat	2 Occupt	7 - 9	139.0	56.0	0.50	0.50
Sat	3 Occupt	9 - 16	0.0	0.0	0.50	0.50
Sat	4 Occupt	16 - 19	120.0	0.0	0.50	0.50
Sat	5 Occupt	19 - 24	150.0	22.0	0.50	0.50
Sat	6 Lights	0 - 7	12.0	0.0	0.50	0.50
Sat	7 Lights	7 - 9	64.0	0.0	0.20	0.80
Sat	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Sat	9 Lights	16 - 19	34.0	0.0	0.50	0.50
Sat	10 Lights	19 - 24	75.0	0.0	0.20	0.80
Sat	11 Equipt	0 - 7	100.0	0.0	0.00	1.00
Sat	12 Equipt	7 - 9	300.0	0.0	0.00	1.00
Sat	13 Equipt	9 - 16	100.0	0.0	0.00	1.00
Sat	14 Equipt	16 - 19	300.0	0.0	0.00	1.00
Sat	15 Equipt	19 - 24	300.0	0.0	0.00	1.00
Sun	1 Occupt	0 - 7	185.0	74.0	0.50	0.50
Sun	2 Occupt	7 - 9	139.0	56.0	0.50	0.50
Sun	3 Occupt	9 - 16	0.0	0.0	0.50	0.50
Sun	4 Occupt	16 - 19	120.0	0.0	0.50	0.50
Sun	5 Occupt	19 - 24	150.0	22.0	0.50	0.50
Sun	6 Lights	0 - 7	12.0	0.0	0.50	0.50
Sun	7 Lights	7 - 9	64.0	0.0	0.20	0.80
Sun	8 Lights	9 - 16	0.0	0.0	0.50	0.50
Sun	9 Lights	16 - 19	34.0	0.0	0.50	0.50
Sun	10 Lights	19 - 24	75.0	0.0	0.20	0.80
Sun	11 Equipt	0 - 7	100.0	0.0	0.00	1.00
Sun	12 Equipt	7 - 9	300.0	0.0	0.00	1.00
Sun	13 Equipt	9 - 16	100.0	0.0	0.00	1.00
Sun	14 Equipt	16 - 19	300.0	0.0	0.00	1.00
Sun	15 Equipt	19 - 24	300.0	0.0	0.00	1.00

[22]