CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Buildings contributes a very high energy consumption percentage compared to other economic sectors. Although these percentages vary from country to country, buildings are accounts for about 30–45% of the global energy demand. With increasing urbanization (higher in developing countries), the number and size of buildings in urban areas will increase, resulting in an increased demand for electricity and other forms of energy commonly used in buildings (Michael Laar and Friedrich Wilhelm Grimme, 2002).

In many countries, buildings consume more energy than transport and industry. The International Energy Agency (IEA) statistics estimate that globally, the building sector is responsible for more electricity consumption (42%) than any other sector. The building sector encompasses a diverse set of end use activities, which have, different energy use implications. Space heating, space cooling and lighting, which together account for a majority of building energy use in industrialized countries, depend not only on the energy efficiency of temperature control and lighting systems, but also on the efficiency of the buildings in which they operate. Other factors include; the building designs and materials, which have a significant effect on the energy consumed as well as the selection of the set of end use facilities (IEA, 2004).

Among Building services, the growth in Heating Ventilation and Air Conditioning (HVAC) system energy use is particularly significant, contributing 50% of building consumption and 20% of total consumption in the USA (Perez-lombard, Ortiz, and Pout, 2008).

In a sustainable perspective it is of great importance that the energy use stays on a low level the entire lifetime of the building and not only when it is newly built or reconstructed. In order to fulfill the requirement of low energy use over time the factors influencing the energy use need to perform well even in a long perspective (Swedish National Energy Administration, 2001).

In spite of the environmental problems connected to energy production, people's expectations of the service standards in buildings are much higher now than in the past. In other words, growth in population, enhancement of building services and comfort levels, together with the rise in time spent inside buildings, have raised building energy consumption to the levels of transport and industry (Pérez-Lombard *et al,* 2008). It has also been observed the increasing rate of installation of HVAC installations in building which have now become almost essential in parallel to the spread in the demand for thermal comfort, considered a luxury not long ago. Therefore, it is important to also focus on the usage of energy.

The growing trend in building Energy consumption will continue during the coming years due to the expansion of built area and associated energy needs, as long as resources and environmental exhaustion or economic recession allows it. Therefore, private initiative together with government intervention through the promotion of energy efficiency, new technologies for energy production, limiting energy consumption and raising social awareness on the use of energy will be essential to make possible a sustainable future (Luis *et al*, 2008)

The energy used by a building is broadly determined by the building fabric, the building services and the management of the building and the occupants' day to day activities. Moreover, with growing global concern for environmental sustainability, it is imperative to promote sustainable design, enhance building's performance and reduce environmental impact (Okafor, Hassan, and Awal, 2008).

Energy is used in buildings for various purposes: heating and cooling, ventilation, lighting and the preparation of hot sanitary water. In residences and Public buildings, installed equipment and appliances require energy, as do removable devices like mobile phone chargers and portable computers. However, identification of fixed and fluctuating demand for energy rarely appears in a building's consumption metric, as most measurement consider only the total amount consumed by the whole building (Sunikka, 2006)

In non-domestic buildings, the type of use and activities make a huge impact on the quality and quantity of energy services needed. Nonresidential building include the Public Building as well as the industrial buildings which account for a large amount of the energy consumption in the building sector (Energy Information Administration, International Energy, 2006)

According to the National building (NEC) Code (2006) Public Buildings are defined as buildings to which the public is admitted such as assembly halls and theatres, places of worship, etc. taking into consideration the required facilities for the physically challenged persons.

This is consistent with the definition given by the Guideline on the Application of Health (public building) Regulation of Australia (2002), which defined a public building as " A building or place or part of a building or place where persons may assemble for :(i) civic, theatrical, social, political or religious purposes;(ii) educational purposes;(iii) entertainment, recreational or sporting purposes; and (iv) business purposes. An Alternative Definition Stated by the same Australia Health Act, defines Public building as any building, structure, tent, gallery, enclosure, platform or other place or any part of a building, structure, tent, gallery, enclosure, platform or other place in or on which numbers of persons are usually or occasionally assembled, but does not include a hospital.

Public building services (such as: air-conditioning, lighting, fire protection, cabling and telecommunication) is an essential element of every building nowadays. In spite of the pressing need for a sustainable Energy consumption in buildings, it is necessary to accommodate these services and consider the needs of the occupants

According to Pérez-Lombard *et al* (2008), there has been the intensification of energy consumption in the HVAC systems, which has now become essentially in parallel to the spread in the demand for thermal comfort which is no longer considered a luxury as it use to be. It is the largest energy end use both in the residential and Public Buildings sectors, comprising heating, ventilation and air conditioning. Its predominance is obvious compared with other energy end uses in the building.

However, in Nigeria, most of the efforts are channeled towards developing sustainable energy generation processes with little or no attention given to the energy consumption end uses and the amount these end uses. Therefore, identifying the major end uses of the energy generated and proper management thereof, ought to be given similar attention for potential energy saving in the building sector for sustainability. Thus, this study is timely as Nigeria is currently experiencing serious energy crisis and massive energy wastage which is accompanied with the environmental depletion.

1.2 Statement of the Problem

Decreasing the energy consumption or reducing the energy wastages of Heating Ventilation and Air Conditioning (HVAC) systems is becoming increasingly important due to rising cost of fossil fuels and environmental concerns. Therefore, finding novel ways to reduce energy consumption in buildings without compromising comfort and indoor air quality is an ongoing research challenge (Vakiloroaya, 2014). The reality of the energy management of HVAC installation lies on the predictive approach adopted in order to envisage the energy consumption and consequently plan the energy consumption.

Heating and cooling of buildings is one of the biggest costs for business. The HVAC systems have business and environmental costs. HVAC system provides year-round indoor comfort in buildings regardless of the type or temperature outside. HVAC systems account for between 40-50% of the Public building energy usage and contribute 34.7 megatoonnes of carbon dioxide emissions every year (Energy Conversation Building Code (ECBC), (2007).

According to a research carried out by Lius *etal,* (2008), on the energy consumption information, it was identified that among building services, the growth in HVAC system energy consumption is particularly significant accounting for 50%of building energy consumption and 20% of total consumption in the USA). Lius *et'al,* observed that the key building services energy end uses in the building envelopes are: HVAC, lighting and appliances and it accounts for 85% of the total energy consumption. Thus, with the consolidation of the demand for thermal comfort, HVAC systems(and its associated energy consumption) alone has become an unavoidable asset, accounting for almost half the energy consumed in buildings and around 10-20% of the energy consumption in developed countries (Lius *et al,* 2008).

The growing reliance on HVAC systems in residential, Public and industrial environments has resulted in a huge increase in energy usage, particularly in the summer months. Developing energy efficient HVAC systems is essential, both to protect consumers from surging power costs and to protect the environment from the adverse impacts of greenhouse gas emissions caused by the use of energy inefficient electrical appliances.

In general, the trend of installing HVAC systems increases in public and public buildings like Hotels even in Nigeria. However, while other countries have taken the lead of sorting out their energy challenges by evaluating the energy usage and its related factors, the case in Nigeria has been focused mainly on developing sustaining energy production measures. Conversely, this study is channeled towards evaluating energy usage and waste in the study area resulting from HVAC system installation in the Hotels.

While facilities managers have saved money by upgrading their visual systems, HVAC systems are largely being neglected even though it promises a large savings because it's one of the largest energy end use contributor. Thus, if attention is directed towards management of the HVAC installations potential energy can be saved and consequently the cost implication. Unfortunately, in the research area, there is a dense population of people and proliferation of hotels in Owerri municipal. Similarly, owing to the quest for excellent comfort level in these hotels to meet client/customer demand, it has also lead to unparalleled use of HVAC systems in the Hotels irrespective of the energy demand, energy cost and the corresponding environmental impact of the energy demand.

Often times the HVAC installations in this hotels are rarely given maintenance attention as much as it is given to the aesthetics even though the HVAC has both energy and cost implication. Thus, this study seeks to evaluate extent of maintenance of the HVAC systems and its energy implications. The conformation of the HVAC installation to the standards and the possibility of adopting a predictive model that will both predict and optimize the energy consumption. Upon these premises, the study seeks to develop a model that can lead to sustainable/optimized energy consumption in hotel buildings in Owerri municipal.

1.3 Aim and Objectives

The aim of this research is to develop a Model for Sustainable Energy Consumption of HVAC Installations of Hotels in Owerri, Imo state Nigeria with a view of optimizing energy consumption while predicting the consumption.

In view of this, the following are the objectives of the work

i. To determine the type and characteristics of HVAC Building service installations used in Hotels in Owerri, Imo State Nigeria.

ii. Ascertain the level of maintenance of HVAC system components installations and its energy consumption implications

iii. Determine the key strategies for saving or reducing energy wastage using the HVAC installation system in Owerri, Imo State Nigeria.

iv. To ascertain the variations between HVAC installations in the study area and the standard requirement as stipulated by ASHRAE Standard 62.1 and 62.2.

v. To develop a Model using the Model Predictive Control theory cable of predicting the energy consumption of the HVAC installation while reducing the energy consumption as well.

1.4 Research Questions

i. What are the types and characteristics of HVAC Building Service installations used in Hotels in Owerri Imo State Nigeria?

ii. To what extent does HVAC installation maintenance affect energy consumption of the system in the Hotels in Owerri, Imo State Nigeria?

iii. What are the key strategies for saving or reducing energy wastage using the HVAC installation system in Owerri Nigeria?

iv. What are the variations between HVAC installations in the study area and the standard requirement as stipulated by ASHRAE Standard 62.1 and 62.2?

v. How does the Model Predictive Control (MPC) theory cable to predict the energy consumption of the HVAC installation while reducing the energy consumption as well?

1.5 Research Hypotheses

H_{01} HVAC components system has not been of adequate maintenance in Hotels in Owerri Nigeria.

H_{02} There is no HVAC installation components that are better maintained in the Hotels

H_{03} Maintenance of HVAC installations do not significantly affect Energy Consumptions of the systems in the area

H_{04} There is no key strategy for saving energy using HVAC system.

1.6 Significance of Study

This research on conclusion is of great importance to managers (facilities manager) and the public building users. It enlightens the management on measure to adopt in rationing energy within the Public building without jeopardizing the functionalities of the building in providing the necessary services to meet users' requirement.

The research enlightens clients and facilities manager on the possible savings that can be made from adequate selection of HVAC installation in Hotels during the construction of new buildings or the retrofitting of existing building considering the fact that the efficiency of new buildings determine the efficiency of existing buildings over time. Consequently, the energy efficiency of new buildings determines the building sector's energy consumption for far longer than other end-use sectors components determine their sector's efficiency (Boardman *et al*., 2005; Sunikka, 2006). Hence, by improving the efficiency of HVAC systems in the study area, decrease in energy consumption can be actualized. Lowering of operation cost for businesses as well as reducing greenhouse gas emission can be realized.

The research identified the contribution/impact of the poor maintenance of HVAC system installation to the building energy consumption. It also exposes the need to ensure that HVAC installation in new buildings or the improvement of existing building are done in compliance with standards (ASHRAE Standard 62.1 and 62.2)

It also guides organizations on measures to adopt to achieve optimum utilization of energy within the interior without compromising customer satisfaction while reducing the general cost and energy wastage.

It also enlightens the public building user on the attitudes they need to cultivate to avoid misuse of energy resulting from the use of HVAC installations and the consequently environmental implication. The research also provides a qualitative and qualitative data for students who intends to carryout research on similar area of study.

1.7 Scope and Delimitation of the Study

The research focuses on the implication of HVAC building services Installations on the energy consumption of hotels within Owerri Municipal as well as the influence of poor maintenance culture and faulty installation of the HVAC installation as an energy end use in Owerri Municipal only. The study covers the Hotels within the Owerri municipal only, residential buildings was not considered. The research also focuses on the development of a Model Predictive Control for simulation using only metrological (Dry bulb temperature, relative humidity) data peculiar to owerri municipal only. The Model Predictive Control was also developed with the peculiarities of Hotel buildings within the study area only.

1.8 The Study Area

Owerri municipal council is one of the 27 local government areas of Imo State and it is the proposed study area. It is located on the South Eastern part of Nigeria. Owerri Municipal council is located on latitudes: 5°25''50.23'N and longitude 7°2''149°.33'E. Owerri municipal has a population of 127,213 inhabitants, 62,990 males, and 64,223 females with about 17,000 households, including shops and offices (NPC, 2006). It is bounded on the North by Amakohia on the North East by Uratta, on the East by Egbu, on the South East by Naze, on the South by Nekede and on the North West by Irete. Owerri Municipal, which is an urbancenter is known for its Public activities. Most of the buildings in these densely populated regions are public buildings like: schools, restaurants, shopping centres, banks, hostels and hotels to accommodate the influx of people for Public, academic and social activities (Adeyemi and Ibe, 2014). Obviously, the services to meet the need and purpose of the public building places a high demand on the requirement for energy and its consequent implication on the environment. This therefore means using Owerri municipal as case study is a tremendous success to the research work.

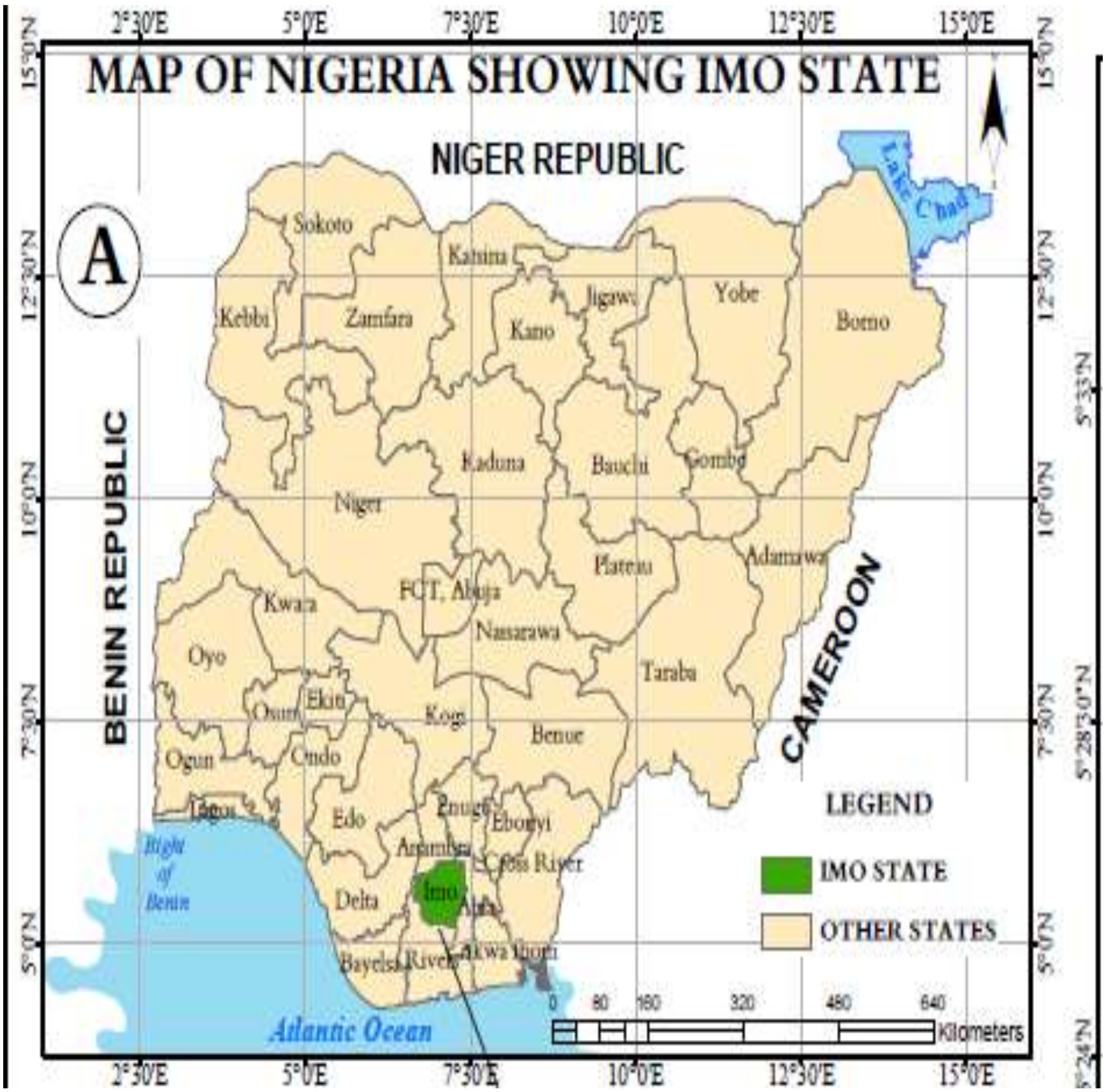


Fig 1.1 Map of |Nigeria Showing Imo State
Source: GIS LAB EVM NAU 2018

Source:

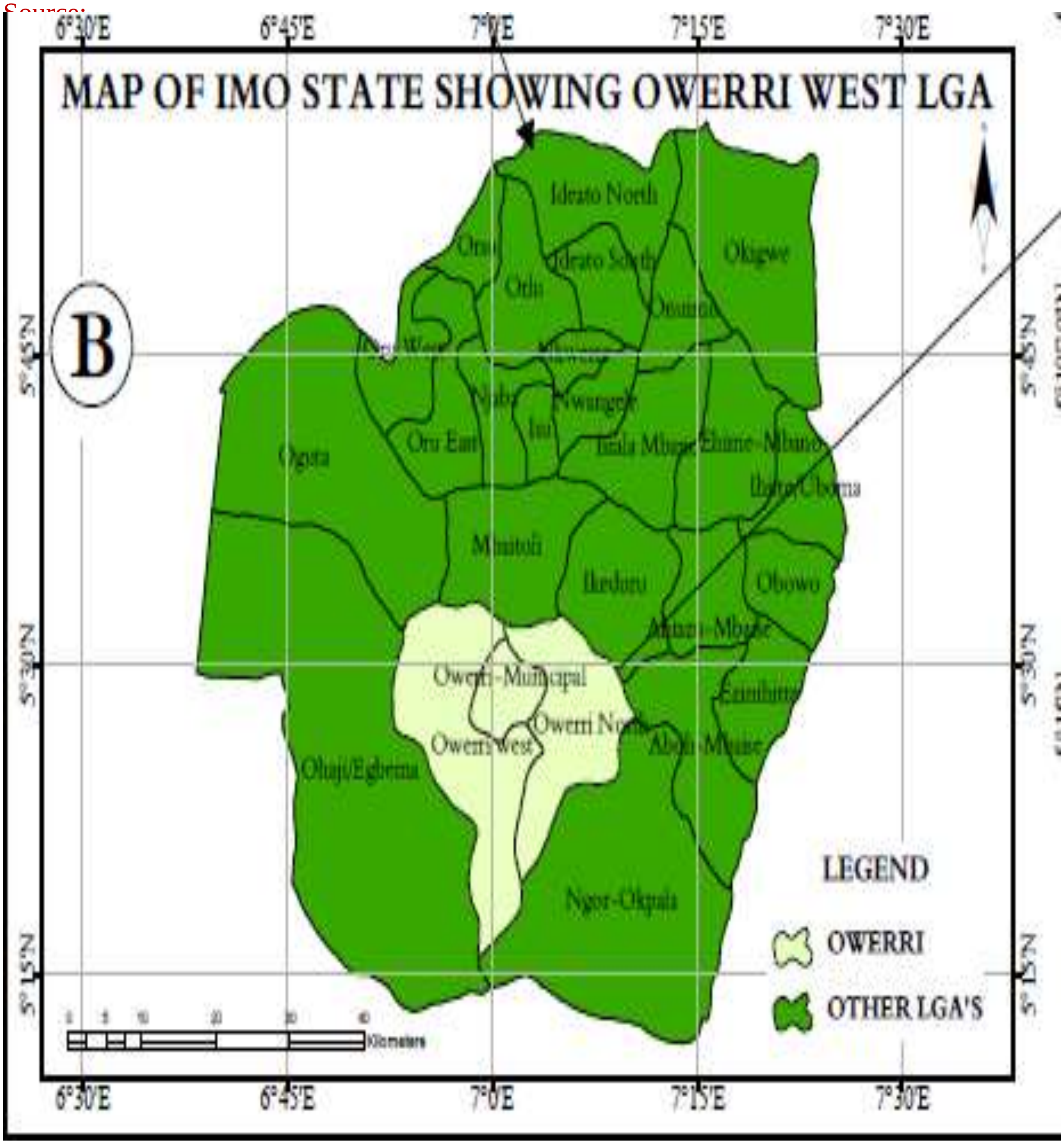


Fig 1.2 Map of Imo State Showing Owerri West
Source: GIS LAB EVM NAU 2018

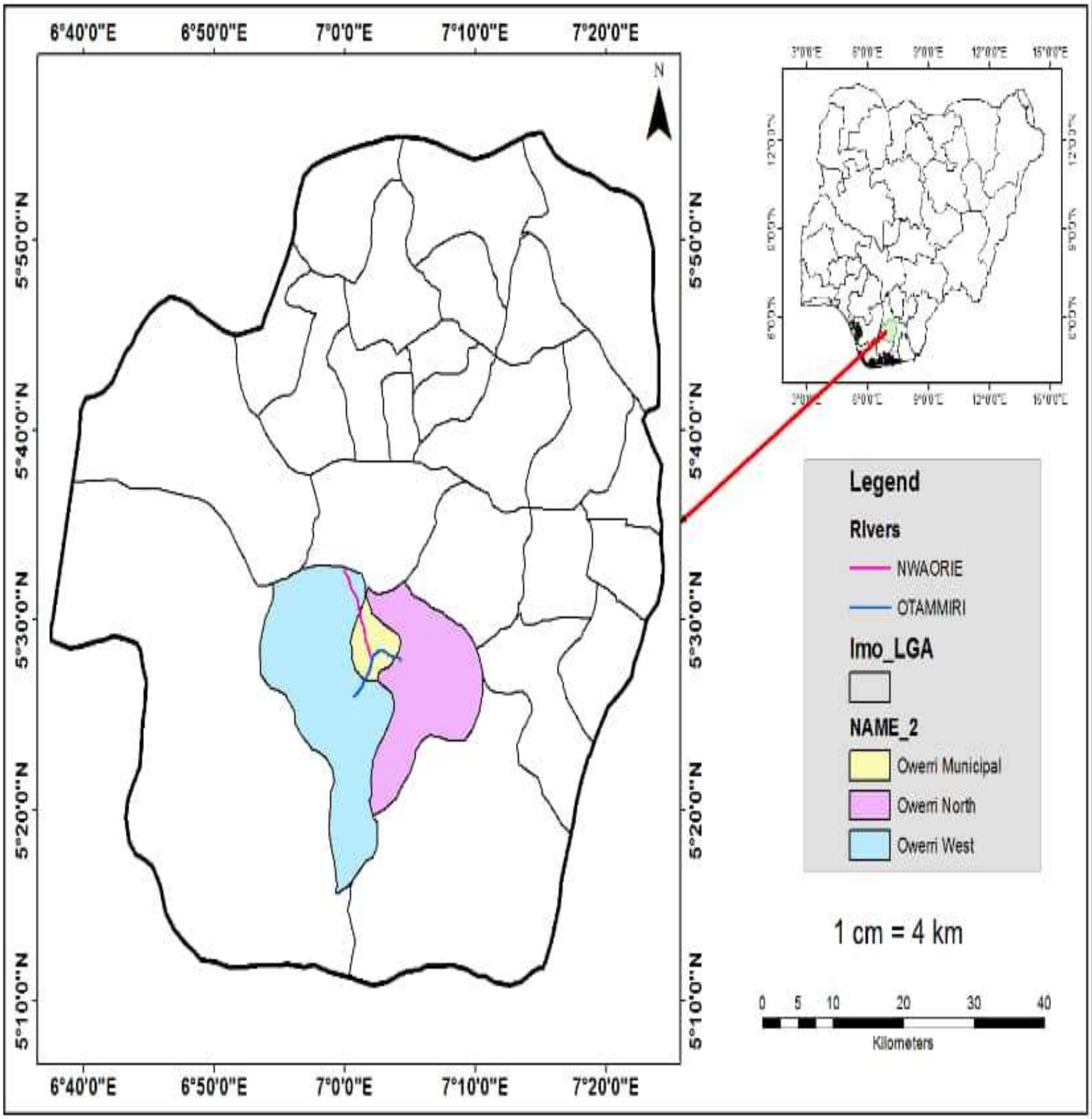


Fig 1.3:Map of Owerri West showing Owerri municipal

Source: GIS LAB EVM NAU 2018

Fig 1.4: Hotels within Owerri Municipal

Source: Google Map, 2018

1.9 Structure of Dissertation (Outline)

Contents of the Dissertation:

Preliminaries Pages

Body of Dissertation

Chapter One: Introduction

Chapter Two: Theoretical/Conceptual Framework and Review of Related Literature

Chapter Three: Research Methodology

Chapter Four: Data Presentation, and Analysis, Interpretations, summary of findings and discussions

Chapter Five: Contribution to Knowledge, Conclusion and Recommendations

References

Appendices

Description of Contents:

This dissertation is structured into 5 chapters. The contents of each chapter are briefly explained as follows:

Chapter 1 begins with a section introducing the research setting and problems. Global need for sustainable energy consumption; the challenges associate with the use of energy; and energy and inefficient energy use. The chapter also gave a brief background on the energy demand stemming from the building facilities installations as well as the role the occupant behavior play in energy consumption pattern of a building. The chapter then introduces the statement of the problem. This is followed by a presentation of the research aim, objectives with the accompanying research questions, hypotheses and significance. The chapter concludes with a delimitation of the scope of study and description of the study area.

Chapter 2 This comprises of two sections. First sections, is the theoretical/conceptual framework, which enabled the researcher to explore available perspectives of the works of others on the problem. The theoretical framework was used to develop a conceptual framework. At this point, the key variables that constitute the problem must have been extracted from the body of available literature.

The second section comprises a review of literature on HVAC services installation, influence of user attitude on energy and sustainable energy concepts.

Chapter 3 generally describe the methodology adopted for the conduct of the research. Armed with the context and the variables from the literature review, the researcher designed appropriate research instruments that would enable the researcher collect relevant data and answer the research questions in chapter 1. Specifically, the chapter concluded by describing the research design/strategy, data collection instruments, population and sample size and consequent validity and reliability of the adopted research instruments.

Chapter 4 presented the data collected from the field work and the statistical analysis employed in addressing the research objectives. Interpretations and discussion. It also presents the summary of key findings, Interpretations, summary of findings and discussions of salient results were made, to ensure clearer understanding.

Chapter 5 presents the conclusions and recommendations. Consideration would also be given to the contribution to knowledge and areas for further research on this topic

CHAPTER TWO

2.0 THEORETICAL, CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 THEORETICAL FRAMEWORK

Energy consumption in Public buildings has been increasing rapidly in the past decade. The knowledge of future energy consumption can bring significant value to public building energy management. For example, prediction of energy consumption decomposition helps analyze the energy consumption patterns and efficiencies as well as waste, and identify the prime targets for energy conservation. Moreover, prediction of temporal energy consumption enables building managers to plan out the energy usage over time, shift energy usage to off-peak periods, and make more effective energy purchase plans.

The major method of HVAC energy consumption prediction is via simulations which are based on various models with each having it advantages and disadvantages. The modeling of the Heating, Ventilation, and Air Conditioning (HVAC) system has become a prominent topic because of its relationship with energy savings and environmental, economical, and technological issues. The modeling of the HVAC system is concerned with the indoor thermal sensation, which is related to the modeling of building, Air Handling Unit (AHU) equipment's, and indoor thermal processes. Some of such simulation are based on Models such as is that simulates energy behaviors of HVAC systems in buildings, with a Multiagent Systems (MAS) based framework for energy consumption prediction.

Until now, many HVAC system modeling approaches are made available, and the techniques have become quite mature. But there are some shortcomings in application and integration methods for the different types of the HVAC model. The application and integration processes acts to accumulate the defective characteristics for both AHU equipment and building models such as nonlinear, pure lag time, high thermal inertia, uncertain disturbance factors, large-scale systems, and constraints.

A. Overview on Building and HVAC System Control Methods

The implementation of wired and wireless sensors and embedded controllers in building systems has increased rapidly over the past decades. The availability of low-cost sensors, the increase in computational power and the availability of accurate weather predictions enables the control designers to explore some possible advanced control strategies for optimizing an efficient building climate control.

The there is no unique solution to the problem of the optimization of the living space climate regulation since many variables can be included in the optimization process, in particular when on-site generation and energy storage are implemented in the building. In general, the goals of an intelligent management system for energy and comfort include the following:

i. Achieving a high comfort level, concerning thermal, air quality and visual comfort.

ii. Achieving high energy efficiency and minimizing the running cost of the building.

A variety of control logic approaches for building cooling, and heating systems have been proposed and reported in the literature.

In the 1990s research started to focus on the development and application of intelligent methods to building control systems. Smart controllers could be optimally tuned for the control of different subsystems of an intelligent building using evolutionary algorithms (López, Sánchez, Doctor, Hagras, & Callaghan, 2004). For this purpose, the learning-based approaches from Artificial Intelligence (AI) techniques offer a different approach to the energy management problem compared to conventional methods. AI based control can deal with noisy or incomplete data, and with nonlinearities in the system. After being trained, it can perform predictions at relatively high speed (Hagras, Packharn, Vanderstockt, McNulty, & Vadher, 2008). The most common AI approach are the Artificial Neural Networks (ANNs) that have been used extensively for the building predictions and HVAC control strategies. Fuzzy Logic Controllers (FLCs) also offer a potential solution, coupling and integrating the management of all the different criteria and components of an HVAC system.

In recent years, there is an increasing number of surveys aimed at analyzing the opportunity offered by the implementation of techniques based on classical control principles were published. From the work done by these works it has emerged and indicates that Model Predictive Control (MPC) algorithms are an effective method to improve building energy efficiency.

In particular, the reviews on MPC can be grouped into:

a) The categories that focused on optimal-intelligent control methods adopted for a single HVAC component (e.g., ventilation systems (Chenari, Dias Carrilho, Gameiro Da Silva, 2016), ground-coupled heat pumps (Atam, & Helsen, 2016), thermal storages (Yu, Huang, Haghighat, Li, & Zhang, 2015), window control (Firląg, Yazdanian, Curcija, Kohler, Vidanovic, Hart, & Czarnecki, 2015).

b) Those that are channeled to the control strategies for the energy management of the entire building. Surveys can be further classified into two main groups: those that consider MPC just as one among many possible control methods, and those that are entirely focused on MPC.

B. Model predictive control (MPC)

Model predictive control (MPC) has had an enormous impact in the process industry over the last 15 years. It is an effective means of dealing with multivariable constrained control problems and the many reports of industrial applications confirm its popularity.

Many control methods have been developed or proposed for HVAC systems. However, because of their simplicity, on/off and PID control are still used in many HVAC systems, resulting in inconsistent performance among such systems. With advances in data storage, computing, and communication devices, it is now feasible to adopt and implement a proper control approach to overcome the inherent issues in HVAC control. Consequently, this research work is centered on the adoption of the Model Predictive Control (MPC) approach because research on MPC development for HVAC systems has intensified over the last years due to the following inherent advantages it promises, which include

i. Use of a system model for anticipatory control actions rather than corrective control;

ii. Integration of a disturbance model for disturbance rejection;

iii. Ability to handle constraints and uncertainties;

iv. Ability to handle time-varying system dynamics and a wide range of operating conditions;

v. Ability to cope with slow-moving processes with time delays;

vi. Integration of energy conservation strategies in the controller formulation;

vii. Use of a cost function for achievement of multiple objectives;

viii. Use of advanced optimization algorithms for computation of control vectors;

ix. Ability to control the system at both the supervisory and local loop levels.

C. History of Model Predictive Control

The development of modern control concepts can be traced back to the work of Kalman in the early 1960s with the linear quadratic regulator (LQR) designed to minimize an unconstrained quadratic objective function of states and inputs. The infinite horizon endowed the LQR algorithm 8 common theme of these strategies was the idea of using a dynamic model of the process (impulse response in the former and step response in the later) to predict the effect of the future control actions, which were determined by minimizing the predicted error subject to operational restrictions. The optimization is repeated at each sampling period with updated information from the process. These formulations were algorithmic and also heuristic and took advantage of the increasing potential of digital computers at the time. Stability was not addressed theoretically and the initial versions of MPC were not automatically stabilizing. However, by focusing on stable plants and choosing a horizon large enough compared to the settling time of the plant, stability is achieved after playing with the weights of the cost function. Later on a second generation of MPC such as quadratic dynamic matrix control (QDMC; Garcia, & Morshedi, 1986) used quadratic programming to solve the constrained open-loop optimal control problem where the system is linear, the cost quadratic, the control and state constraints are defined by linear inequalities.

Another line of work arose independently around adaptive control ideas developing strategies essentially for mono-variable processes formulated with transfer function models (for which less parameters are required in the identification of the model) and Diophantine equation was used to calculate future input. The first initiative came from Astron et al. (1970) with the Minimum Variance Control where the performance index to be minimized is a quadratic function of the error between the most recent output and the reference (i.e. the prediction horizon Ny=1). In order to deal with non-minimum phase plants a penalized input was placed in the objective function and this became the Generalized Minimum Variance (GVM) control. To overcome the 9 limitation on the horizon, Peterka (1984) developed the Predictor-Based Self-Tuning Control. Extended Prediction Self Adaptive Control (EPSAC) by De Keyser et al. (1985) proposes a constant control signal starting from the present moment while using a sub-optimal predictor instead of solving a Diophantine equation. Later on the input was replaced by the increment in the control signal to guarantee a zero steady-state error. Based on the ideas of GVM, Clarke et al. (1987) developed the Generalized Predictive Control (GPC) and is today one of the most popular methods. A closed form for the GPC is given by Soeterboek. State-space versions of unconstrained GPC were also developed.

D. Stability of the Model Predictive Control

Stability has always been an important issue for those working with predictive control. Due to the finite horizon stability is not guaranteed and is achieved by tuning the weights and horizons. Mohtadi proved specific stability theorems of GPC using state space relationships and studied the influence of filter polynomials on robustness improvement. However a general stability property for predictive controllers, in general, with finite horizons was still lacking. This lead researchers to pursue new predictive control methods with guaranteed stability in the 1990s. With that purpose a number of design modifications have been proposed since then including the use of terminal constraints (Kwon et al., 1983; Meadows et al. 1995), the introduction of dual-mode designs (Mayne & Michalska, 1993) and the use of infinite prediction horizons (Rawlings and Muske, 1993), among others. Clarke and Scattolini (1991) and Mosca et al. (1990) independently developed stable predictive controllers by imposing end-point equality constraints on the output after a finite horizon. Kouvaritakis et al. (1992) presented a stable formulation for GPC by stabilizing the process prior to the 10 minimization of the objective function. Many of these techniques are specialized for state-space representations of the controlled plant, and achieve stability at the expense of introducing additional constraints and modifying the structure of the design. Practitioners, however, avoid changing the structure of the problem and prefer to achieve stability by tuning the controller. For that a good doses of heuristics is used.

E. Previous Reviews That Consider MPC Only as One among Many Possible Control Methods

Wang, 2007 and Dounis, 2009 conducted two preliminary surveys dealing with advanced control systems for energy and comfort management in buildings. The details in (Wang, 2007) provides a useful framework of the early studies about the model-based supervisory control methods up to 2006 is provided. In view of this (Esther, 2016; Lazos, 2014) Demand Side Management (DSM) procedures are reviewed with the aim to clarify the possible energy management strategies based on load forecasts and predictions. Consequently, in (Lazos, 2014) MPC is considered as the most diffused and effective instrument in an energy management optimization framework, which represents the higher level of intelligent control of a building for the authors. Moving with the research trend, in (Shaikh *et al*, 2014; Naidu, 2011) an entire section is focused on MPC, and a summary of its main features and advantages for energy management was provided.

With the recent study (Aste, Manfren, Marenzi, 2017), provides a detailed overview of the various control strategies that can be applied to a building, focusing in particular on model-based controllers, such as MPC. This remarkable paper provides a framework that highlights strengths and weakness of those strategies.

F. Previous Reviews That Are Entirely Focused on MPC

To the best of authors' knowledge, the work of Afram and Janabi-Sharifi (2014) can be considered the most remarkable review on MPC due to the worthy scheme of MPC implementation that it offers, combined with clear classifications criteria. This review highlights all the steps necessary to correctly implement the MPC problem and to formulate the optimization problem for building energy management. This review dates back to 2013. From that time, as far as authors know, more than 100 new articles have been published about MPC algorithm for building thermal management, reflecting the increasing magnitude that this topic is getting. Hilliard et al. (2016) published in 2014 an excellent review of trend and opportunities for MPC implementation in public buildings. After an introductory description of MPC main features, the article summarizes details of 19 scientific works using a series of tables that capture the salient points and allow for comparison. Results of this work were used by the same authors also in (Kavgic, M.; Hilliard, T.; Swan, L, 2015) to define the primary requirements of a Public buildings to be controlled appropriately by MPC.

Recently, (Mirakhori, 2016; Afram, 2017) produced a paper that is one of the most recent reviews on MPC applied to building and HVAC system control. They are both not general surveys, but works focused on particular aspects of building-related MPC problems. The first one (Afram, 2017) is focused on ANN based MPC. The second one (Mirakhori, 2016) is focused on occupant behavior based MPC problems for internal temperature regulation. Eventually, (Killian & Kozek, 2016) provided a good overview and vision of the current and future potential applications for MPC building thermal regulation.

2.1.2 Framework and Structure of the Model Predictive Control

The dynamic response of the outputs of a system is affected by controlled inputs (or manipulated variables) and uncontrolled inputs (or disturbances) (Rawlings & Mayne, 2012). A dynamical model of the system can capture such dynamics. Afterward, the controller can exploit them to make predictions of the possible future response of the system as a function of future controlled and uncontrolled inputs. MPC uses these predictions to select the best sequence of future manipulated variables, according to a specific performance index.

The latter is defined over a time window that starts from the current time and spans a given prediction horizon in the future. The best sequence is obtained by solving a numerical optimization problem, that also takes into account the constraints on input and output variables one must satisfy during the operation of the building. The difference between MPC and open-loop optimal control is that the former only applies the first optimal move of the sequence at the current time instant, optimizing a new sequence at the following time-step again. This way of acting and re-planning continuously over time is denoted as the “receding horizon” concept and is sketched in Figure 2.1

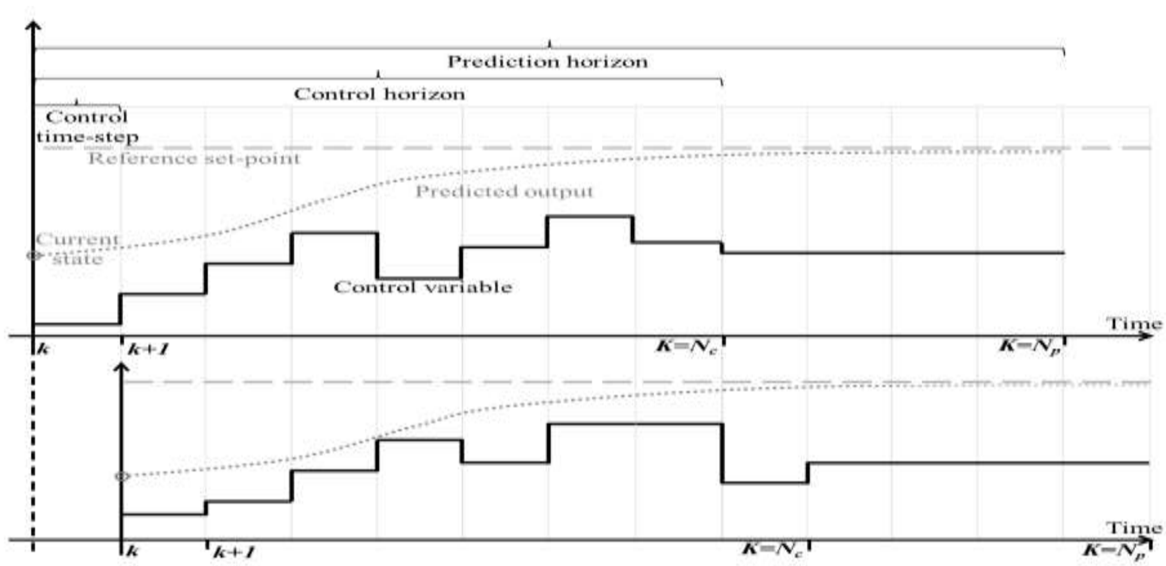


Fig 2.1 Schematic of the principle of receding horizon. The difference between the top and the bottom figure is one time-step
Source: (Gianluca *etal,* 2018)

The following notation is introduces to describe the receding horizon problem:

i. Current instant (*k*): the current sampling step the controller is applied.

ii. Control time-step (T_s): it is the time between control updates and iterative receding horizon optimizations. The discrete variable k is generally used to refer to a specific control time-step.

iii. Prediction horizon (N_p) (also referred to as planning horizon): the number of control time-steps the controller looks ahead in the future to optimize the cost function under constraints.

iv. Control horizon (N_c) (also referred to as execution horizon or manipulated input horizon): the number of possible different values the manipulated variables can take in the future, that relates to the dimension of the optimization vector.

A general framework of the MPC formulation is presented in figure 2.2. All the aspects of the MPC framework shown in this figure are discussed further below.

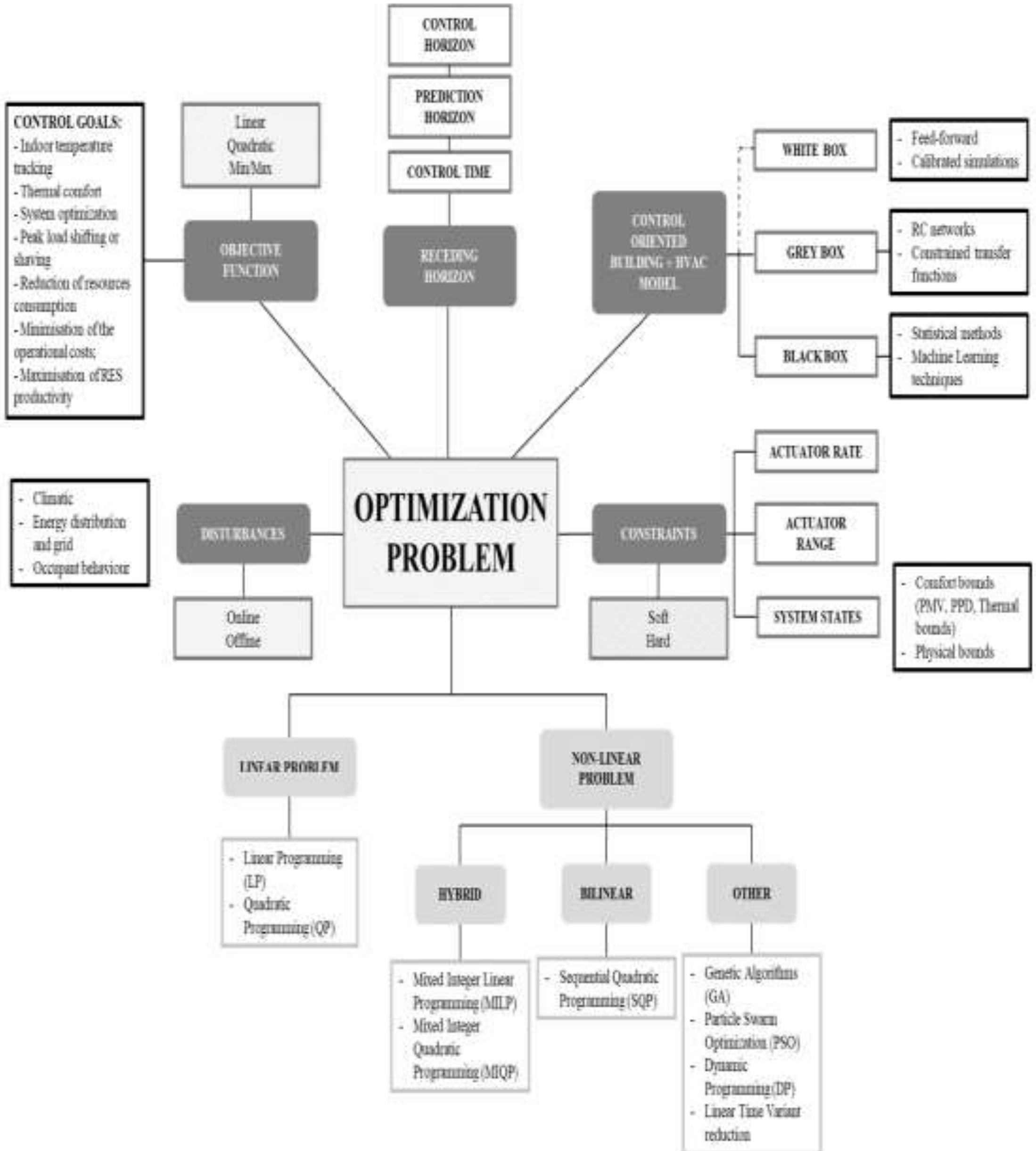


Fig 2.2. Framework and critical elements of the MPC optimization problem applied to building and HVAC system.
Source: (Gianluca *et al*, 2018).

The filled in dark grey indicate factors that directly influence the optimization problem; the light grey boxes denotes types of resulting optimization problems; all the boxes list the possible forms that the MPC formulation for building and HVAC system can take

A. MPC Typologies

Multiple MPC typologies can be adopted, when solving a building control problem and they have to be selected according to the nature of the controlled process, in particular to the type of prediction model one has developed to describe it. Also the optimization algorithms used vary depending on the nature and type of the optimization problem.

Depending on the nature of the controlled system dynamics, the MPC problem can be either linear or nonlinear. The extension of MPC from linear to nonlinear problems is not a trivial matter due to additional computational complexity, the reliability of nonlinear programming solvers, and lack of general purpose nonlinear systems identification techniques (Camacho & Bordons, 2007).

When the effect of unmeasured disturbances or model mismatch is a concern, sometimes is useful to embed a model of the possible mismatch between the nominal and real system within the MPC problem formulation. Generally, with expert knowledge of the controlled process or during the model validation phase from data, it is possible to define the magnitude of the uncertainties affecting the system and their effect on the model response.

An MPC is called robust MPC when the stability and the performance specifications are maintained for all possible model variations and a class of noise signals (uncertainty magnitude) within a specified range (Bemporad, & Morari, 2007). In this case, the uncertainties are bounded, and the resulting control strategy always satisfies the defined constraints within the uncertainty range. An alternative solution is offered by the stochastic MPC, where a stochastic dynamical model of the process is used to predict its possible future evolution. Disturbances and constraints are included as random variables with a given probability distribution (e.g., Markov Chains). In case of continuous distributions, one allows for unbounded uncertainties and enforces constraints within a finite probability.

Contrariwise, in case of discrete distributions, that is if the uncertainty can only take value from a limited set with a given probability, one can optimize stochastic measures (such as a trade-off of expectation and variance, or conditional value at risk) and enforce constraints either for all disturbances (worst-case) or in probability, depending on how critical are the constraints (Bernardini, & Bemporad, 2012).

In numerous energy management applications, the system is of a hybrid nature, in the sense that it includes both continuous dynamics (affecting real-values inputs and states) and discrete dynamics (involving finite-state machines and Boolean input and states), leading to a nonlinear model with discontinuities. In this case, the optimization most commonly can be cast as a Mixed Integer Programming (MIP) problem, and the MPC formulation is commonly referred as hybrid MPC (Bemporad, 2015). This MPC approach is frequently used when the operation of the system involves discrete states, functioning modes, open or closed, On or Off, or scheduling requirements.

The MPC problem can be formulated in an implicit or explicit formulation. While in implicit MPC the control law is defined by solving the optimization problem in real-time, in explicit MPC multi-parametric programming algorithms are run offline to recast the control law as a lookup table of linear gains (Bemporad, 2015). Explicit MPC is used in those applications of small size where the computing power is limited or a very short computational time is needed (e.g., in embedded controllers that are required to perform the online optimization).

Indeed, models are the cornerstone of MPC and, following the Camacho and Bordons, (2007) indications, two different essential models can be discerned within the implementation of an MPC controller for buildings and their HVAC systems:

i. The control-oriented building and its HVAC system model, which represents the thermodynamical behavior of the building, used by the MPC for the on-line optimization.
ii. The disturbance models that allow the forecast of the behavior of the uncontrolled variables affecting the dynamic response of the system.

While the two aforementioned models are always required for the MPC controller implementation, a further model is necessary at the design and prototype phase:

iii. The surrogate simulated building model that is a virtual, possibly high-accuracy representation of the controlled system needed to close the control loop in simulation.

A scheme of the different models entering in MPC problems for building and HVAC systems is shown in figure 2.3

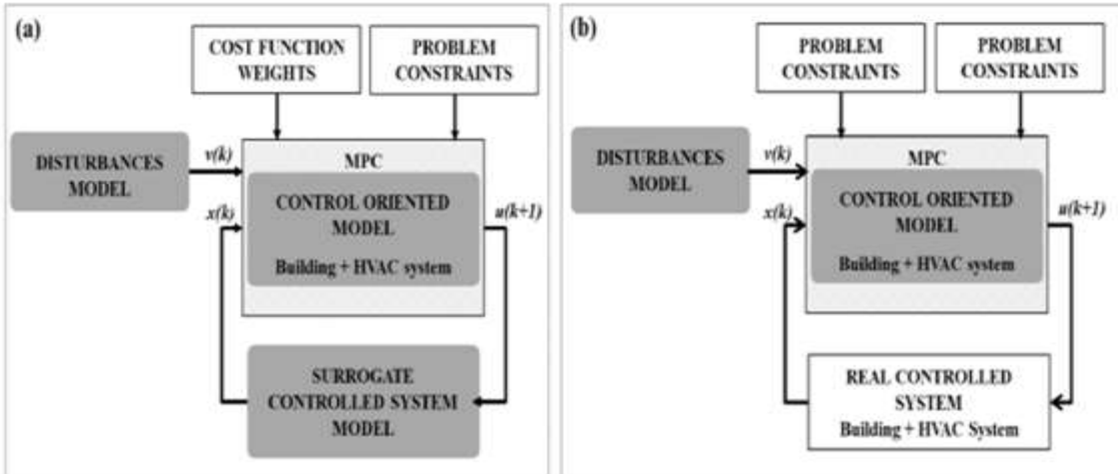


Fig 2.3 Model involved in MPC problems are highlighted with grey boxes (a) MPC formulation in absence of a real controlled system; (b) MPC formulation for real controlled system implementation
Source: (Bemporad, 2015)

B. ASHRAE Classification of Modeling of Building and the HVAC System

ASHRAE (2013) categorizes modeling methods into two different categories: the forward (classical) approach and the data-driven (inverse) approach. On the one side, the forward approach (also known as white box models or engineering methods) presumes detailed knowledge of the various system processes and interactions. The main advantage of this approach is that the system does not require to be physically built to evaluate its performance. Thus, in modeling the energy behavior of a building, the forward approach is usually suitable for preliminary predictions of energy needs and design of system loads.

On the other hand the data-driven models were further classified by ASHRAE, (2013) in three broad groups, highlighted in Fig 2.4, that have also been adopted in the following classifications (Capozzoli, Cerquitelli & Piscitelli, 2016):

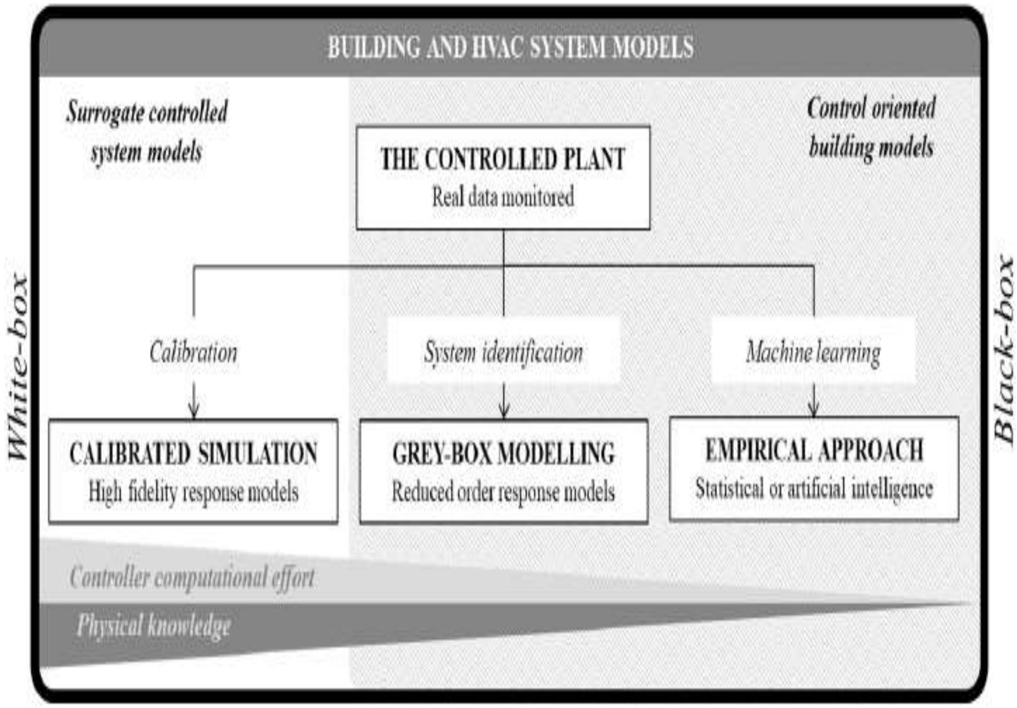


Fig 2.4: Classification of the data-driven models according to ASHRAE
Source: ASHRAE, (2013)

i. Calibrated simulation models: these are high fidelity response models based on physical principle to calculate thermal dynamics and energy behavior of whole building level or for sublevel components (Magoulès, 2016). The approach is the same as the one mentioned in the forward approach, but in this case the models are calibrated using real data gathered on field.

ii. Black-box models (also known as empirical approach): that are developed by fitting parameters of a model to historical behavior of the system and do not require full knowledge of the system or the process. Black-box models become particularly suitable for predicting the behavior of processes where a priori deterministic knowledge of the physical relationship between input and output is not univocally defined (e.g., evolution of climatic disturbances and occupant behavior related disturbances).

iii. Grey-box models: that retain the physical description of the system they represent and their parameters can be estimated using system identification methods. Grey-box models have fitting parameters that include the dynamics of the physical system described. Semi-Deterministic Physical Modelling (DSPM) uses a Resistance-Capacitance (R-C) electrical network analogue to explain the thermodynamics of a system. Figure 2.5 represents an example of R-C modeling of a building. Usually, the model parameters are estimated by tuning to historical measurements, and this approach has been presented in a wide variety of papers (Gyalistras & Gwerder, 2009).

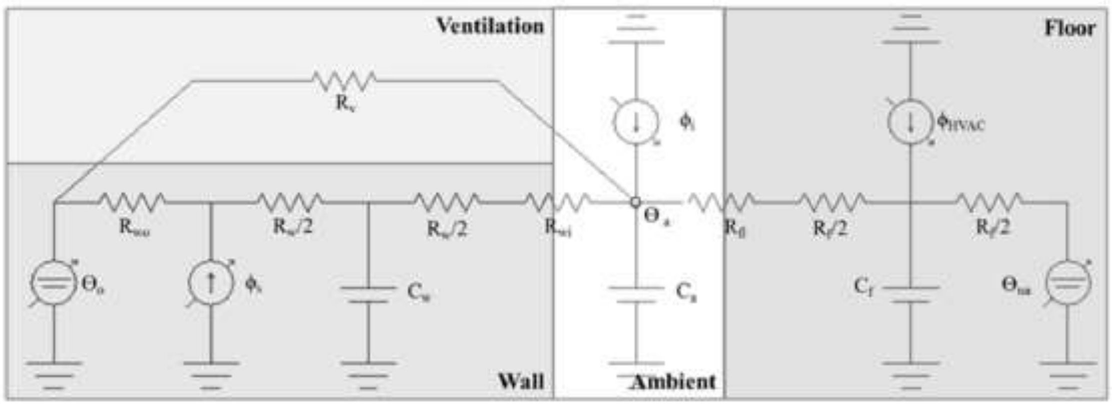


Fig 2.5 A typical example of an R-C network for MPC applications
Source: (Magoulès, 2016)

2.1.3 Modelling HVAC System in the Building

To correctly apply an MPC strategy it is necessary to generate a virtual image of the controlled system, called Control-Oriented Building Model, capable of describing the physics of such controlled process accurately (Wallace *et al*, 2012). This control-oriented building model must be accurate enough to ensure satisfactory prediction capabilities and capture the fundamental engineering processes that influence the dynamics of the controlled building, but at the same time has to be simple to ensure a reasonable computational time of the optimization process (Nassif, 2013). Since these system models, even if they are a simplification of the real physical system, are required to represent its response accurately enough for the optimization to be effective, thus in most cases they are supported by a data-driven approach. In experimental case studies, historical data of states and disturbances, measured by sensors, can be utilized for this purpose.

Inputs to the models for prediction and calibration include:

i. The most significant climatic disturbances and

ii. occupancy related disturbances,

iii. As well as controllable inputs such as the thermal energy delivered by the HVAC.

Common inputs to the thermal model include outdoor temperature, solar radiation, internal gains (solar or occupancy related) and heating or cooling energy delivered by the HVAC.

The measured response is generally the indoor air temperature; in some cases, mainly simulated, the measured response can also include the average walls or other building components temperature (Privara *et al*, 2012). While the measured indoor air temperatures typically are monitored using sensors integrated into the BAS, the temperature of the walls, floors, ceilings, and other building components generally are estimated, with no feedback from sensors. In some cases, the HVAC system states can also be considered in the model (e.g., in Fiorentini (2017), the TES operation was optimized, by considering it as a lumped temperature node). Similarly, to the applications where the control-oriented model states relate to temperature nodes, some other authors include in this model also other variables that affect the occupants' comfort. For example (Parisio, 2014) posits that the internal carbon dioxide concentration level is also considered as controlled variable together with the internal temperature. In (Lehmann, *et al*, 2013) also, the light level was taken into account. The light level can be controlled using the blinds position, while the carbon dioxide concentration level was controlled by managing the air change rate.

From a thermodynamic perspective, a building can be treated as a single-zone or as a multi-zone. The number of zones coincides with the number of internal nodes that are used to model the building dynamics. From the MPC prospective and its use in the thermal regulation of indoor spaces, a multi-zone building can be modeled in its entirety in the control-oriented building model, in the attempt to find an optimal solution for the operation of the entire building. In other cases, a distributed approach is taken, where various controllers manage a separate zone. A model with reasonable prediction properties is an ultimate condition for excellent performance of the predictive controller, and extensive research has been undertaken to aid the selection of the most appropriate model for the task (Privara, 2012).

It is unlikely that white-box or calibrated simulation models can be utilized as a control-oriented building model, as in general they do not provide an explicit model of the building, the identification and validation of calibrated simulation models are non-trivial processes. White-box models require building blueprints, significant parameter tuning, and simulation effort. Moreover, since the complexity, non-linearity, and size of the calibrated simulation responsive models, quickly lead optimization problems exceed computation timeframes required in a practical control application. Nevertheless, many researchers have studied the implementation of optimal controllers that use those calibrated simulation models, interfaced with different optimization toolboxes (Corbin et all, 2013).

In general, black-box models cannot ensure reliable prediction for operating points outside the range covered by the training data, and thus extensive and adequate data training is needed to guarantee prediction accuracy. However, state that these models are faster to develop and implement if sufficient data are available, they are often adopted as control-oriented models capable of ensuring an accurate system representation.

Grey-box modeling is proven to be an effective method to model the thermal response of a building (Bloem, 1994). One of the critical targets in development of a grey-box model for an MPC application is identifying a suitable model is agreement with the physical response of the system and at the same time has a complexity that can embed the information contained in the data, which means that the model should neither be under-fitted nor over-fitted (Bacher & Madsen, 2011). In buildings, grey-box models commonly use the R-C network analogy with an electric circuitry to describe the thermal process dynamics of a building zone. Modular construction of the R-C circuit can be followed to describe the behavior of a multi-zone building as a combination of single zones. Toolboxes for the automatic generation of control-oriented R-C models were also recently developed (Sturzenegge, *et al,* 2012). A forward selection strategy is used to find the best model by an iterative process, using the most meaningful and adequately complex model (Andersen, 2000).

In most of the cases, grey-box models were formulated using a state-space representation of Linear Time Invariant (LTI) systems. A discrete state-space model is usually formulated as follows:

$$\{x(k+1)=Ax(k)+B_u u(k)+B_v v(k)+Gw(k)$$

$$y(k)=Cx(k)+D_u u(k)+D_v v(k)+d(k)$$

(2.1)

Where:

u(k) is the vector of manipulated inputs or controlling variables (e.g., the HVAC system control inputs),

v(k) is the vector of measured disturbances affecting the system (e.g., weather),

x(k) is the vector of the system states (e.g., the building temperature nodes),

y(k) is the vector of the outputs,

d(k) is the unmeasured random noise on the outputs, and

w(k) is the unmeasured random noise on the measurement of the states.

The terms A, Bu, Bv, C, Du, Dv, and G are state matrix, manipulated input matrix, measured disturbances matrix, output matrix, and direct transmission matrix for manipulated inputs, direct transmission matrix for measured disturbances, and the matrix of the unmeasured random noise on the states respectively. The parameters contained in these matrices can be estimated using system identification techniques. In building applications, similarly to other industrial processes, the output is not a function of manipulated inputs, resulting in a zero Du matrix. The outputs y(k) can be either measured (e.g., the indoor air temperature) or unmeasured (e.g., the internal wall temperature). An alternative to the output-feedback formulation discussed above is the state-feedback formulation, which assumes that all the states are measured. This formulation is frequently adopted in building applications.

Some authors prefer not to include the HVAC system model in the MPC formulation and therefore solve a higher level optimization problem, which returns, for example, the building set-points to be utilized. Other authors focus on the mathematical description of the HVAC system and its energy components. This was possible either integrating it with the building model and solving a complete optimization problem, or considering separately from the building, and therefore introducing the building (or the precinct) demand as an external disturbance with a forecasted profile in the optimization problem. Figure 2.6 reports the fraction of papers found in the literature that use different control-oriented building models and approaches to the HVAC system modeling.

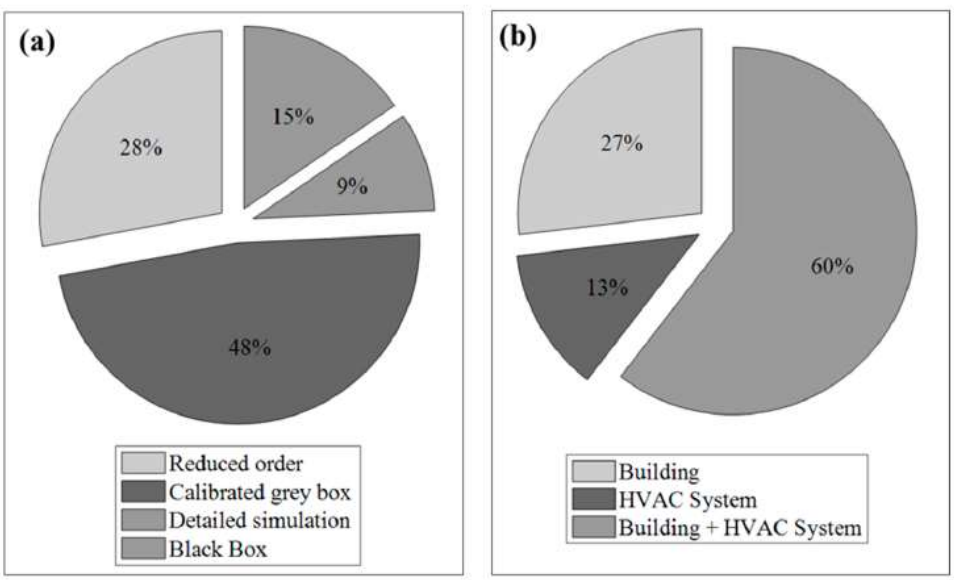


Figure 2.6. (a) Proportion of reviewed literature papers using either white, grey or black-box model as control-oriented building model; (b) proportion of literature papers considering in the control-oriented model either the building only, the HVAC only, or both
Source: Gianluca, 2018

In the first case, the model takes into account the mutual interaction between building and HVAC system in the optimization of the energy problem but leads to a higher computational effort. In the second case, considering for example Air Handling Units (AHUs) and Variable Air Volume (VAV) boxes for example, the problem acquires a non-linear nature, specifically bi-linear, where one of the states (e.g., the room temperature) multiplies one of the controlled inputs (e.g., the system air flow rate) (Kelman & Borrelli, 2011). A similar configuration can also be found in the regulation of Fan Coil Units (FCU) (Borrelli, 2012)

Additional complexity can also derive from an intermittent nature of the energy delivery, which leads to the formulation of an optimal controller of a hybrid system, due to the combination of continuous and Boolean variables in the optimization problem (Siroky, Cigler & Ferkl, 2013). A general framework of the alternative scenario dealing with HVAC system modeling in MPC problems is provided in Figure 2.7

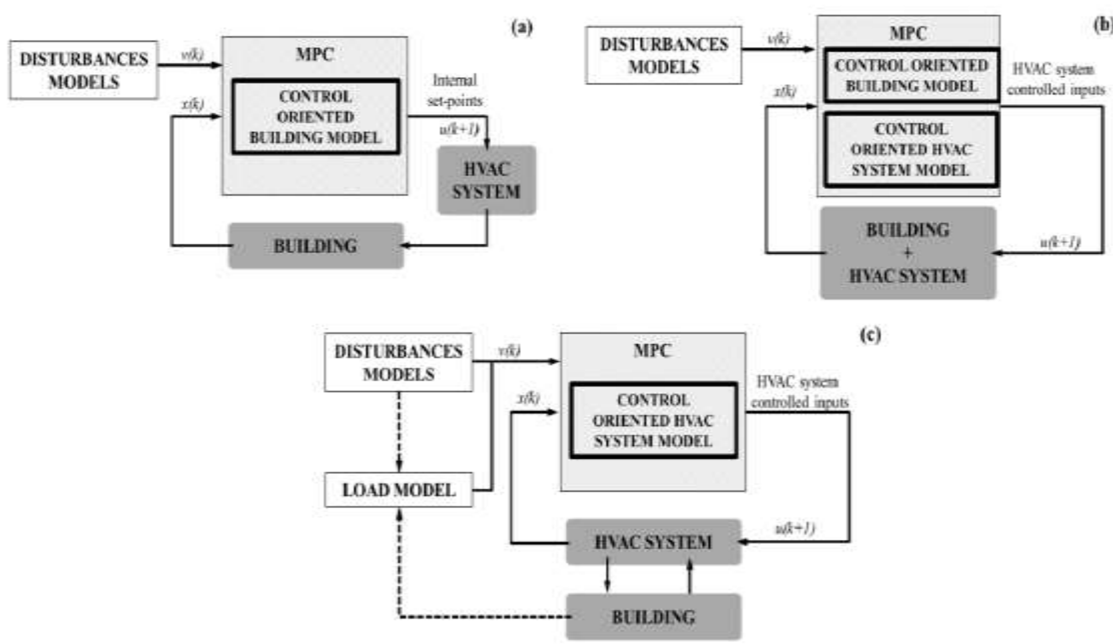


Fig 2.7. The possible alternative scenario of HVAC system modeling in MPC problems. (a) HVAC systems not considered in the MPC formulation; (b) MPC integrating both building and its HVAC system; (c) building not considered in the MPC formulation Source Gianluca, 2018

A. The Prediction Models of Disturbances

Disturbances can be either measured or unmeasured. The *measured* disturbances are generally part of the dynamic building model, and their impact on the system response is directly captured by the model. The *unmeasured* disturbances can have a small or significant effect on the system response, affecting the uncertainty and the accuracy of the model response.

The measured disturbances can be considered as *ideal* measurements or as measurements *affected by uncertainty* (white noise, stochastic noise, etc.). Signal processing tools generally help in discriminating the signal noise from the signal itself.

There are three main categories of measured disturbances affecting an MPC problem for HVAC system and building energy management:

i. Climatic disturbances (e.g., external temperature, humidity ratio, Relative Humidity (RH), wet-bulb temperature, dew-point temperature, solar radiation, wind velocity, ground temperature.

ii. Occupant behavior related disturbances (e.g., occupied/unoccupied, variation in the scheduled comfort set-points, internal heat gains/loads, adjacent zones set-points).

iii. Grid and energy distributor related disturbances (e.g., Time of Use (ToU) or real-time prices, peak load penalties).

In other cases, the building demand can be treated as a single disturbance where the climatic conditions, the occupant behavior and factors affecting the building energy demand are lumped together (De Cursi, 2015).

The most straightforward way to determine disturbances affecting a building is to utilize commonly available disturbances patterns, such as Representative Meteorological Year (RMY), Typical Meteorological Year (TMY), and International Weather for Energy Calculations (IWEC) weather files or building demand and occupation patterns (ASHRAE, 2013). In this case, the disturbances can only be used when assessing seasonal macro trends, but would not be accurate enough to be utilized for the short term predictions used by optimization methods. For this reason, considering the disturbances to be equal to the ones provided in these datasets can be used to assess, at a design stage, the simulated controller performance only, but cannot be used for implementation on a real-time controller.

A more accurate representation of the disturbances affecting the building and its HVAC system can be achieved for example by analyzing historical data gathered from the BAS. In this case, the disturbances will be modeled around an existing system, and they can be used for predicting the performance of an MPC controller when compared to existing standard control logic. For the real-time applications, accurate short-term predictions are necessary, and two primary possible methods of forecast can be adopted:

i. *Online predictions* rely on the availability of an internet connection and the possibility to acquire forecasts from a third party modeling source, that can provide accurate prediction using complex models (Capozzoli, 2016) (e.g., weather forecast or future energy prices).
ii. *Offline predictions* do not need an internet connection, and they only rely on the data which has been measured on site, but they require a model that can predict the future disturbances behavior. These methods are compulsory for the forecast of occupancy related disturbances that are specific to each case study (Mady, 2011).The simplest method for offline predictions is based on a rule of thumb that states that "the conditions of the next hours would be only slightly different from those of the previous time period" (Oldewurtel, 2010). More accurate offline prediction methods are those based on statistical or machine learning models (Florita, & Henze, 2009).

A further prediction method often used in the literature combines the predictions of both offline and online methods. Indeed, combining the predictions of external models with data gathered on-site can be useful to calibrate external forecasts reducing the uncertainty due to discrepancies between the locations of weather stations and building site and to address the risk of sudden internet service interruptions. Furthermore, a more straightforward online forecast can be used to adjust an offline prediction. For example, in (Khakimova *et al,* 2017) minimum and maximum daily forecasted temperature were used to correct the trajectory of an offline prediction; or in (Kim & Augenbroe,) the Support Vector Machine (SVM) method was used to forecast day-ahead electricity tariff prices based on past spot market prices and grid load levels.

Figure 2.8a shows the forecasting methods used by previous scientific works and Figure 2.8b summarizes the scenarios concerning the type of disturbances subject to these predictions.

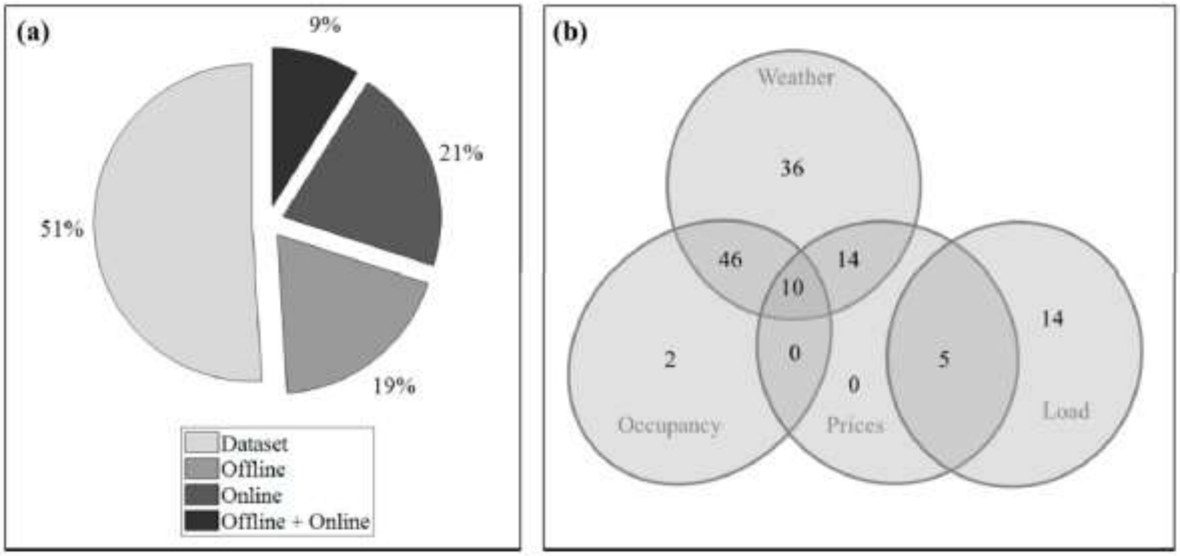


Fig 2.8. (a) Proportion of literature papers using as disturbance forecast method either online prediction, offline prediction or a combination of the two; (b) number of scientific paper grouped according to the combination of forecasted disturbance variables.
Source: Khakimova *et al*, 2017

B. The Controlled Systems

The MPC framework is suitable for the management of buildings, regardless of their typology and classification (e.g., residential, educational, Public, institutional). Figure 2.9a shows that theoretical and experimental studies available in the literature cover very heterogeneous building classifications.

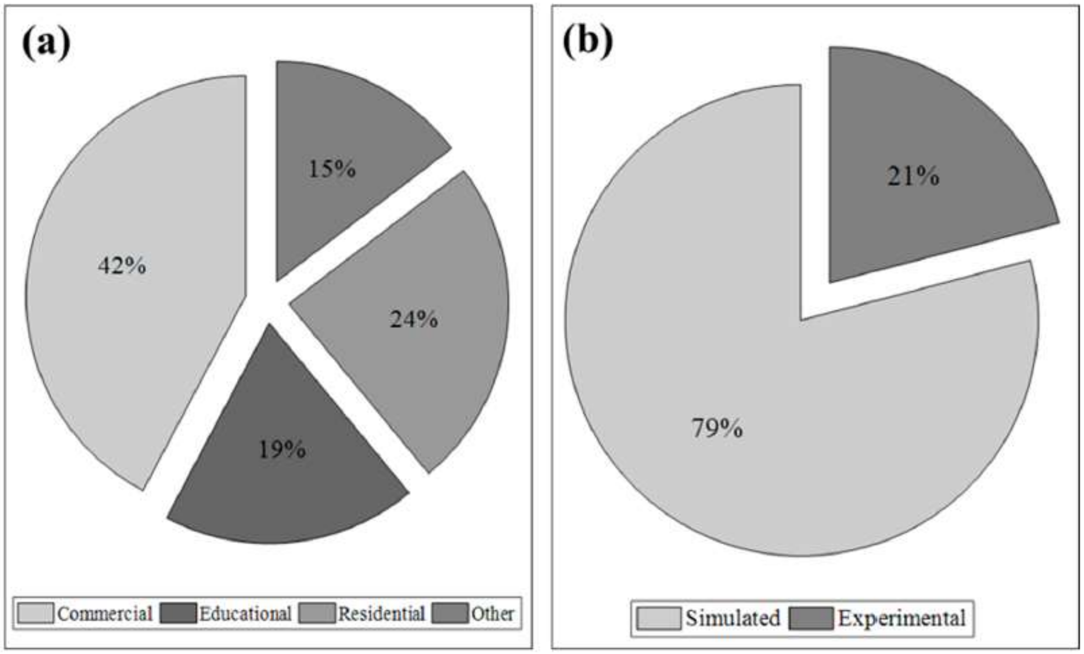


Fig 2.9. (a) Proportion of building typologies considered for MPC scientific literature studies; (b) proportion of simulated versus experimental cases of MPC for building and HVAC system in the scientific literature
Source: Gianluca, 2018

The prototyping and testing of an MPC algorithm can be achieved by implementing the controller on an *experimental* case study or a *simulated surrogate building model*. In any experimental case study, simulations (even if using simplified models) are still necessary during controller design to properly set up the controller parameters and ensure reliable performance under different boundary conditions.

When the MPC algorithm is applied experimentally, an adequate BAS and integration platform is necessary. Firstly, the correct sensors integrated into the BAS are required to monitor the variables needed for the model embedded in the MPC to estimate the response of the system, and that adequate control inputs are associated to the process components. The MPC algorithm, especially in a research study or testing phase, is not embedded in the local controller of the building, but a separate computer performs the online optimization and exchanges information with the BAS at each control time-step employing a communication protocol. The computation of the solution and therefore the communication can be either local (using a computer and a communication protocol, such as Modbus, Bacnet, Obix, etc.) or the optimization can be done off-site, where there is a remote server and the exchange of information is done over the internet. A typical schematic of a real experimental implementation of MPC is shown in Figure 2.10

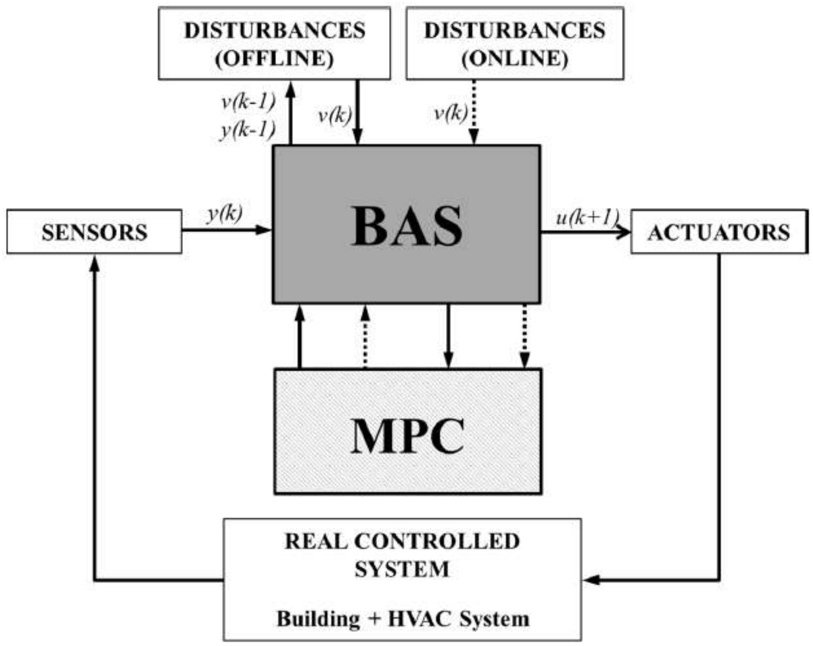


Fig 2.10. Schematic of MPC implementation in a real controlled system. Dashed lines represent possible connections by the internet.
Source: (EIA). ***2012***

In most of the cases available in the literature, surrogate simulated building models have been used to test MPC performance. On the one hand, when the building is ideal or monitoring data is not available, the surrogate simulated building model follows a forward approach. This one is the typical case of the theoretical studies on the MPC performances or the evaluation of MPC at building design stage. In particular, for theoretical studies, the building can be represented by an archetype that allows to carry out simulations to obtain performance indicators on the MPC algorithm on a building category. On the other hand, when there is an existing case study building, where operative data can be gathered in the field, the surrogate simulated building model can be built using either a forward approach or a data-driven approach. This scenario occurs when it is necessary to investigate the possible benefits achievable through the MPC algorithm compared to an existing logic already implemented in the BAS.

The most common issue when testing an MPC algorithm on a simulated building is that it is quite challenging to integrate an MPC controller into a building simulation software, leaving the MPC algorithm in most cases on a different external software platform., The two platforms must be interfaced at each control time-step with each other to evaluate the performance of the controller. In this interface, the surrogate building model sends information on the current states and disturbances to the controller, which computes the optimization and responds with the set of actions that the surrogate building model has to apply at the next time-step. Sometimes, when a detailed simulated surrogate building model is not available, simulation studies can be performed utilizing the control-oriented building model also as surrogate building model to test the closed-loop performance of the MPC controller and speed up the procedure.

C. Constraints in MPC Model of HVAC

One of the main advantages of utilizing MPC to control building systems is the possibility to include physical constraints into the formulation of the control problem, embedding them in the optimization algorithm. Table2.1 summarizes the possible constraints features.

Table 2.1: Constraints features in an MPC formulation

Formulation	Position	Restriction	Time Variation	Kind
Equality	System states	Hard	Constant	Rate
Inequality	Actuators	Soft	Time varying	Range

Source: Energy Information Administration (EIA). *2012*

Constraints can be formulated both as equalities or inequalities, according to how they relate to their counterpart of the real system. When the problem constraints are rigid and it is mandatory that they are satisfied, they are defined as hard constraints, while they are identified as soft constraints if they represent a flexible boundary and it is not strictly required that they are satisfied.

Generally, soft constraints are formulated using a slack variable that can move the boundary of a certain amount, with an associated penalty in the cost function. The higher is the cost associated with this slack variable, and the closer the solution of the problem will be to the one where the constraints are considered to be hard. From a time perspective, constraints can be either constant or time varying limits that change according to a schedule, the occurrence of events or variations of the problem boundary conditions.

Constraints can be allocated to system states and system inputs. Constraints on systems states are generally used to handle the occupants' comfort (e.g., maximum or minimum bounds for the indoor temperature (Lindelof, *et al,* 2015), or the allowable temperature range affecting an active building component (e.g., TES tank operating range (Halvgaard & Bacher, 2012). The constraints allocated to system inputs refer to physical limitations or imposed bounds on the system actuation components, or input variables. The system input constraints can include maximum and minimum limits both for the range (e.g., minimum or maximum power of a heat pump (Halvgaard & Bacher, 2012). or a terminal unit (Moroşan, *et al,* 2010), valve/damper position limits (Siroky *et al*, 2011) and for the rate of change of their operation (e.g., boiler or heat pump response rate (Halvgaard *et al.*2012) valve/damper/pump/fan change rate (Siroky *et al* 2011). Because of their physical meaning, constraints on actuators are typically formulated as hard constraint, while the constraints on the system states can be softened in some cases (Sturzenegger, *et al*, 2016). For example, softening a constraint on an indoor temperature operation range, represents an undesirable situation that might be considered acceptable and advantageous under specific circumstances.

Additional terms that affect how the controller states behave at the end of the prediction horizon are the terminal constraint and the terminal weight. The terminal constraint imposes the desired state configuration to be attained at the end of the prediction horizon, while the terminal weight acts as an incentive (but not a necessary condition to satisfy) to the same goal. Both are often used to guarantee closed-loop stability. For example, a terminal constraint can be used to ensure that a TES tank continuously stores a minimum level of energy to satisfy the demand of the following day (Yudong *et al,* 2009).

D. Control Goals and Objective Functions

The construction of the optimization function depends on the global objectives that it is desired to achieve in the controlled process. One of the primary goals is ensuring that the controller meets the constraints and operates reliably. The stability of the controller and minimization of the control effort (variation of control inputs in two subsequent time instants) are two typical objectives of the optimizations.

Other key objectives could be defined by the preferences the building occupants, the requirement of stakeholders or energy managers. In the first case these requirements are mostly related to comfort factors (e.g., target tracking for indoor temperature regulation, maintaining the internal ambient temperature in bounds ensuring the thermal comfort, minimizing occupants' thermal discomfort hours), whether in the latter the drivers are mostly economic factors (e.g., reduction of overall energy demand or greenhouse gases emissions, minimization of the operational costs, maximization of RES productivity). Other factors commonly considered in the objective function are the constrained on-line system operations optimizations or the peak load shifting or shaving. The cost function has to be chosen based on the requirements of the specific application.

The MPC cost function aims at reducing a multi-objective problem into a scalar objective. This is achieved by weighting and adding the various terms in the cost function of the following exemplary form:

$$\begin{aligned} \min \sum_{k=1}^{N_p} \left[W_x \left|\left| x(k) - x(k)_{ref} \right|\right|_{n_x} + W_y \left|\left| y(k) - y(k)_{ref} \right|\right|_{n_y} \right] \\ + \sum_{k=0}^{N_{p-1}} \left[W_u \left|\left| u(k) - u(k)_{ref} \right|\right|_{nu} + W_{\Delta u} \left|\left| u(k) - u(k-1) \right|\right|_{n_{\Delta u}} \right] \end{aligned} \tag{2}$$

Where:

x is the vector of system states,

y is the vector of outputs, and

u is the vector of manipulated variables or control inputs.

Typically, only x or y is employed in the cost function, the first one when the control-oriented building model is formulated as state-feedback, while the second one in output-feedback formulations. The discrete index k denotes time steps along the prediction horizon.

The term $u(k) - u(k - 1)$ indicates inputs increment over the prediction horizon and is an indication of the control effort.

The subscripts ref. were adopted to show the reference trajectories or set-points.

Wx, Wy, Wu, and WΔu are the weight matrices, which can vary along the prediction horizon.

Np is the prediction horizon.

If the prediction horizon Np is larger than the control horizon Nc, then the control inputs following Nc are assumed constant.

The terms n indicate the norm dimensions in the cost function.

The solution of the minimization of the objective function under constraints yields an optimal control sequence u*.

This is a trajectory of the optimal control moves along the prediction horizon that optimizes the problem requirements according to the cost function weights and subject to the constraints defined by the user.

Only the first control input u*(0) is applied to the controlled building. Afterward, the receding horizon moves one control time-step ahead and the optimization procedure is repeated. Alternative formulations of the objective function are possible according to the problem peculiarities.

When formulating an MPC algorithm, the occupant comfort is generally considered as a pre-determined set-point or set-point trajectory to track or as thermal bounds. This is the simplest way to ensure a positive thermal sensation of the occupants. This formulation avoids adding computational effort to the optimization problem due to non-linearities.

Moreover, it allows simple implantation of sensors' feedback to the controller in experimental applications. The set-point trajectory can be constant in time (Wallace, 2012) or time-varying (Hilliard *et al*, 2016) This set-point can be included in the formulation of a tracking MPC problem, entering in the objective function as a state reference xref(k) or a system output reference yref(k). It is also possible to include set-points as thermal bounds, and therefore as hard or soft constraints, weighted in the cost function.

In order to better assess the occupants' comfort, detailed thermal sensation indices can be introduced in the MPC formulation. For example, the Predicted Mean Vote (PMV) or the Predicted Percentage of Dissatisfied (PPD) are the most widely recognized indices to evaluate thermal comfort (International Organization for Standardization, 2005)

Even if it provides a more detailed indication of the human thermal sensation than set-points or thermal bounds, the introduction of PMV in an MPC problem has significant drawbacks (ASHRAE, 2016). Firstly, since PMV is intrinsically nonlinear, it affects the formulation of the MPC by dramatically increasing the computational effort of the optimization. In general, it is introduced as a further non-linear function in the MPC objective function. Therefore, this formulation requires the adoption of non-linear optimization methods that cannot guarantee that the optimization will reach the optimal solution. Several studies the possibilities of implementing the comfort indices evaluation into MPC formulations (Castilla, *et al*, 2014) Some authors use a comparison between PMV and Actual Mean Vote (AMV) to merge information from occupants' feedback and data from sensors (Chen, Wang & Srebric, 2015) to improve the decision of their thermal comfort.

The weighting matrix Wu assigns a cost to the control inputs when comparison to references defined in the array uref(k). In the economic MPC formulation, it can be directly related to the energy prices of the different energy sources adopted in the process. A typical example is trying to minimize the energy demand of an HVAC system. Since the model generally considers the thermal delivery to the building, it is necessary to convert this energy to the electrical demand of this equipment. This fact can be achieved either by including a constant or linear representation of the Coefficient of Performance (COP) of the studied unit in the control-oriented model or in the linear cost function (Mayer, Killian & Kozek, 2015).

E. Elemental MPC Controller Formulation

The most comprehensive state-space representation of a linear system with p inputs (Larsen, 2014), q outputs and n state variables is represented as follows:

$$x(k+1) = Ax + Bu(k) \quad (1)$$

$$y(k) = Cx(k) \quad (2)$$

where

$$x(k) \in R^n,\ u(k) \in R^p,\ y(k) \in R^q \quad (3)$$

The follow-up of such representation is that the system will be observable and controllable.

As previously mentioned, the MPC is an optimization based control law, and in an elemental MPC controller the performance measure is nearly each time a quadratic cost.

Through the representation of the positive definite matrices as:

$$M = M^T > 0 \quad (4)$$

and the performance weights is given by:

$$W = W^T > 0 \quad (5)$$

The optimal control input has to be identified in order to minimize the infinite horizon performance cost:

$$J(k)=\sum_{j=k}^{\infty} x^T(j \mid k) M x(j \mid k)+u^T(j \mid k) W u(j \mid k) \quad (6)$$

In an unconstrained scenario, the solution to this equation is given by the linear quadratic (LQ) controller. Yet, in a constrained scenario, no analytic solution exists. As an alternative, the objective in the MPC is to establish a prediction horizon N and approximate the problem with a finite horizon cost:

$$J(k)=\sum_{j=k}^{k+N-1} x^T(j \mid k) M x(j \mid k)+u^T(j \mid k) W u(j \mid k) \quad (7)$$

The finite horizon is essential since it is due to it that it is possible to solve the problem, but simultaneously, other complications are brought by the finite horizon. By utilizing the model from (1) and (2), it is possible to predict the state $x(k+j|k)$, given a future control sequence $u(\cdot|k)$and the current state $x(k|k)$. In such a case, no state estimation is obligatory and it is assumed that $C=I$, therefore, $x(k|k) = x(k)$. Consequently, the prediction is represented as:

$$x(k+j \mid k)=A^j x(k \mid k)+\sum_{i=0}^{j-1} A^{j-i-1} B u(k+i \mid k) \quad (8)$$

By utilizing such predictions, it is possible to define the following optimization equation:

$$\min_u \sum_{j=k}^{k+N+1} x^T(j \mid k) M x(j \mid k)+u^T(j \mid k) W u(j \mid k) \quad (9)$$

Which is subject to:

$$u\,(k+j \mid k) \in U \quad (10)$$

And

$$x(k + j \mid k) = Ax(k + j - 1 \mid k) + Bu(k + j - 1 \mid k) \quad (11)$$

and thus, it is possible to design a basic MPC controller.

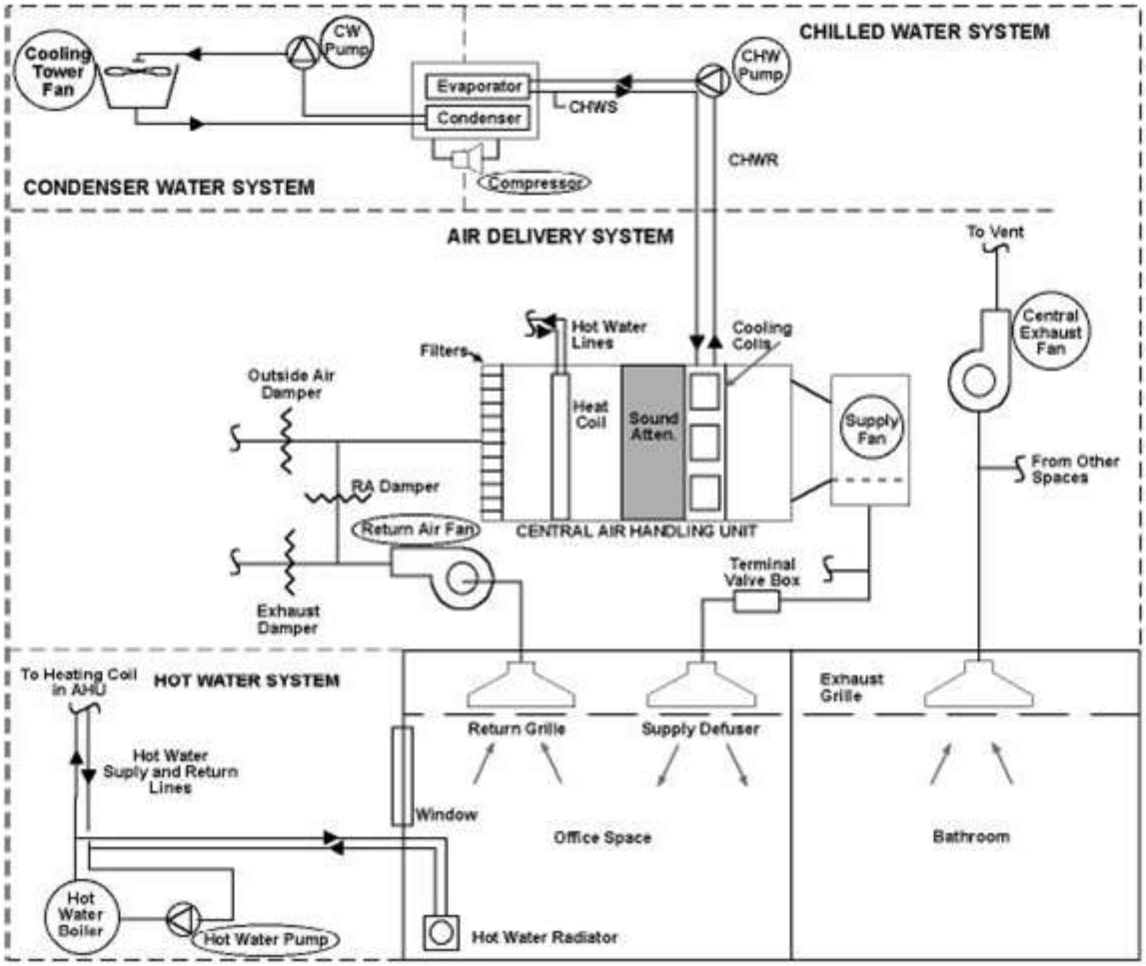
2.1.4. HVAC System Types

HVAC system types in Public buildings are broken down into four broad categories for the purposes of this study: central, packaged, individual AC and uncooled. Central systems are defined as those in which the cooling is generated in a chiller and distributed to air-handling units or fan-coil units with a chilled water system. Heating in central systems is generated in a boiler and distributed to local fan-coil units, radiators, or baseboard heaters via a steam or hot water system. Packaged systems include rooftop units or split systems which have direct-expansion cooling coils, with heat rejection remote from the cooled space. Individual AC systems involve self- contained packaged cooling units which are mounted in windows or on an external wall such that cooling occurs inside and heat rejection occurs outside. Uncooled buildings of interest are heated but not cooled.

A. Central HVAC Systems

Central systems are defined as any HVAC systems which use chilled water as a cooling medium. This category includes systems with air-cooled chillers as well as systems with cooling towers for heat rejection. Heating in these systems is usually generated in a boiler and is distributed in hot water or steam piping.

A central system serving office space is depicted in Figure 2.11 below. The space which is conditioned by the system is in the lower right part of the figure. The system is broken down into three major subsystems: the air-handling unit, the chilled water plant, and the boiler plant.



Note: Power-using components are circled

Figure 2.11: Schematic of a Central System
Source: Huang, 2011

The air-handling unit conditions and supplies air to the conditioned space. Air is taken by the unit either from outside or from the space itself through a return air system. The three dampers are controlled to mix the air according to the chosen control strategy. When the enthalpy of outdoor air is lower than that of the return air, it is more economical to use the outdoor air for cooling of the building than to circulate return air (this is called economizing). When the outdoor air is warmer than return air, or when the outdoor temperature is very low, a minimum amount of outdoor air will be mixed with the return air in order to provide fresh air ventilation for removal of indoor contaminants such as carbon dioxide. The air is filtered and conditioned to the desired temperature (the air may require preheating rather than cooling, depending on outdoor conditions). Preheating and cooling are done with heat exchanger coils which are supplied with a heat exchange medium, typically steam or hot water for heating, and chilled water for cooling.

Air flow to the conditioned space may be controlled, as in the case of a variable air volume (VAV) system, with a terminal valve box. The air is finally delivered to the space through a diffuser, whose purpose is to mix the supply air and the room air. The terminal box may or may not have a reheat coil, which provides additional heat when the space does not need to be cooled or needs less cooling than would be delivered by supply air at the terminal box's minimum air quantity setting. Constant air volume (CAV) systems, which are not allowed by energy codes in many applications, do not reduce air delivery rates and are dependent on reheat coils to control the delivered cooling.

Air leaves the conditioned space either through the return system, or through the exhaust system. In many installations, the ceiling plenum space is used as part of the return ducting in order to save the cost of return ductwork.

The chilled water system supplies chilled water for the cooling needs of all the building's air-handling units. The system includes a chilled water pump which circulates the chilled water through the chiller's evaporator section and through the building. The system may have primary and secondary chilled water pumps in order to isolate the chiller(s) from the building: the primary pumps ensure constant chilled water flow through the chiller(s), while the secondary pumps deliver only as much chilled water is needed by the building. The chiller is essentially a packaged vapor compression cooling system which provides cooling to the chilled water and rejects heat to the condenser water. The condenser water pump circulates the condenser water through the chiller's condenser, to the cooling tower, and back. The cooling tower rejects heat to the environment through direct contact of condenser water and cooling air. Some of the condenser water evaporates, which enhances the cooling effect.

The heating water system indicated in Figure (central HVAC) includes a boiler and a pump for circulating the heating water. The heating water may serve preheat coils in air-handling units, reheat coils, and local radiators. Additional uses for the heating water are for heating of service water and other process needs, depending on the building type. Some central systems have steam boilers rather than hot water boilers because of the need for steam for conditioning needs (humidifiers in air-handling units) or process needs (sterilizers in hospitals, direct-injection heating in laundries and dishwashers, etc.).

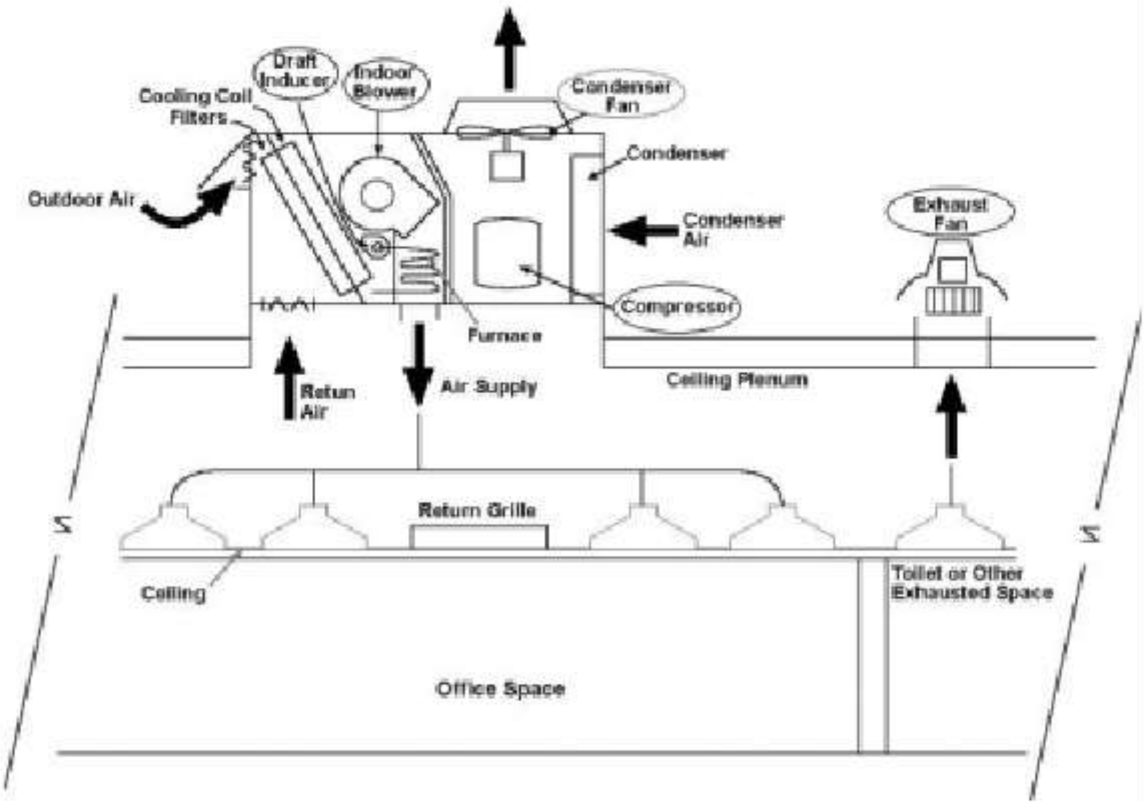
For the purposes of this study, the central system category has been further broken down into the following.

i. Central systems with VAV air-handling units
ii. Central systems with CAV air-handling units
iii. Central systems with fan-coil units for delivery of cooling (Fan-coil units are small typically unducted cooling units).

B. Packaged HVAC systems

Packaged systems include both unitary systems such as rooftop units, and split systems. Essentially, these are systems which do not used chilled water as an intermediate cooling medium. The cooling is delivered directly to the supply air in a refrigerant evaporator coil. Packaged units have either a gas furnace or an electric resistive heating coil for heating, or they are designed as heat pumps (in which the refrigeration system pumps heat from the outdoors into the building).

A packaged system serving office space is depicted in Figure 2.12



Note: Power-using components are circled.

Figure2.12: Schematic of a Packaged System
Surce: Naidu, 2011

The figure shows a rooftop unit used for cooling an office. Again, air is circulated from the conditioned space through the unit and back. Rooftop units can use outdoor air for cooling when outdoor temperature is cool enough, using the outdoor and return dampers to mix the air. The air moves through a filter, through the evaporator coil, through the indoor blower, through a furnace coil, and is supplied to the space through ductwork and supply diffusers. The figure shows air being returned through the ceiling plenum. Some air is pulled from the space through exhaust fans.

Cooling for the unit is again provided by a vapor compression cooling circuit. However, cooling is delivered directly to the supply air, and the heat is rejected in a condenser coil directly to the ambient air. Heating for the rooftop unit in the figure is provided with a furnace.

Most small rooftop units' use draft inducing fans to move combustion products through the furnace coil. Some larger units use forced draft fans which push combustion air into the furnace. Heat can also be provided by resistance electric heat or by the vapor compression circuit (operating as a heat pump).

In a split system, the two sides of the unit shown in the figure are separated, with refrigerant piped between them. A condensing unit, consisting of the refrigerant compressor, the condensing coil, and the condensing fan, is located externally. The indoor unit, consisting of the evaporator and indoor blower are located near or in the conditioned space. Inclusion of a furnace or provision for intake of outdoor air will depend on proximity of the indoor unit to the outside.

C. Individual Room Air Conditioning

Individual room air conditioning includes window AC units, packaged terminal air-conditioners (PTAC's), packaged terminal heat pumps (PTHP's), and water-loop heat pumps. Window AC units similar to those used in residences are frequently used in Public applications. PTAC's or PTHP's are used primarily in hotels and motels. The unit is mounted on an external wall, and a hole in the wall provides access to outdoor air, which is used for ventilation, heat rejection, and heat pumping (for the PTHP).

Water loop heat pumps (also called California heat pumps) are similar to PTHP's except that water piped to the unit takes the place of the outdoor air. This allows more flexibility in placement of the unit, allows pumping of heat from warm to cool parts of the building through the circulated water loop, but requires installation of the water loop system. The water loop requires a cooling tower and a boiler for heat rejection or heat addition when the building thermal loads do not balance

2.2 Conceptual Framework

It is estimated that by 2056, global economic activity will have increased fivefold, global population will have increased by over 50%, global energy consumption will have increased nearly threefold, and global manufacturing activity will have increased at least threefold (Ilha,; Oliveira, ;Gonçalves, 2009). Globally, the building sector is arguably one of the most resource-intensive industries. In order to achieve a sustainable future in the building industry, Asif *et al*. (2007) suggest adoption of multi-disciplinary approach covering a number of features such as: energy saving, improved use of materials, material waste minimization, pollution and emissions control *etc*. There are many ways in which the current nature of building activity can be controlled and improved to make it less environmentally damaging, without reducing the useful output of building activities. To create a competitive advantage using environment-friendly construction practices, the whole life-cycle of buildings should, therefore, be the context under which these practices are carried out. A review of literature has identified the three general objectives (Resource Conservation, Cost Efficiency and Design for Human Adaptation) which should shape the framework for implementing sustainable building design and construction while keeping in mind the principles of sustainability issues (social, environmental and economic). Thus based on this existing literatures the Conceptual Frame work for the work on developing a model for a sustainable energy consumption of the HVAC systems in Hotels can be summarized in Fig 2.13 given

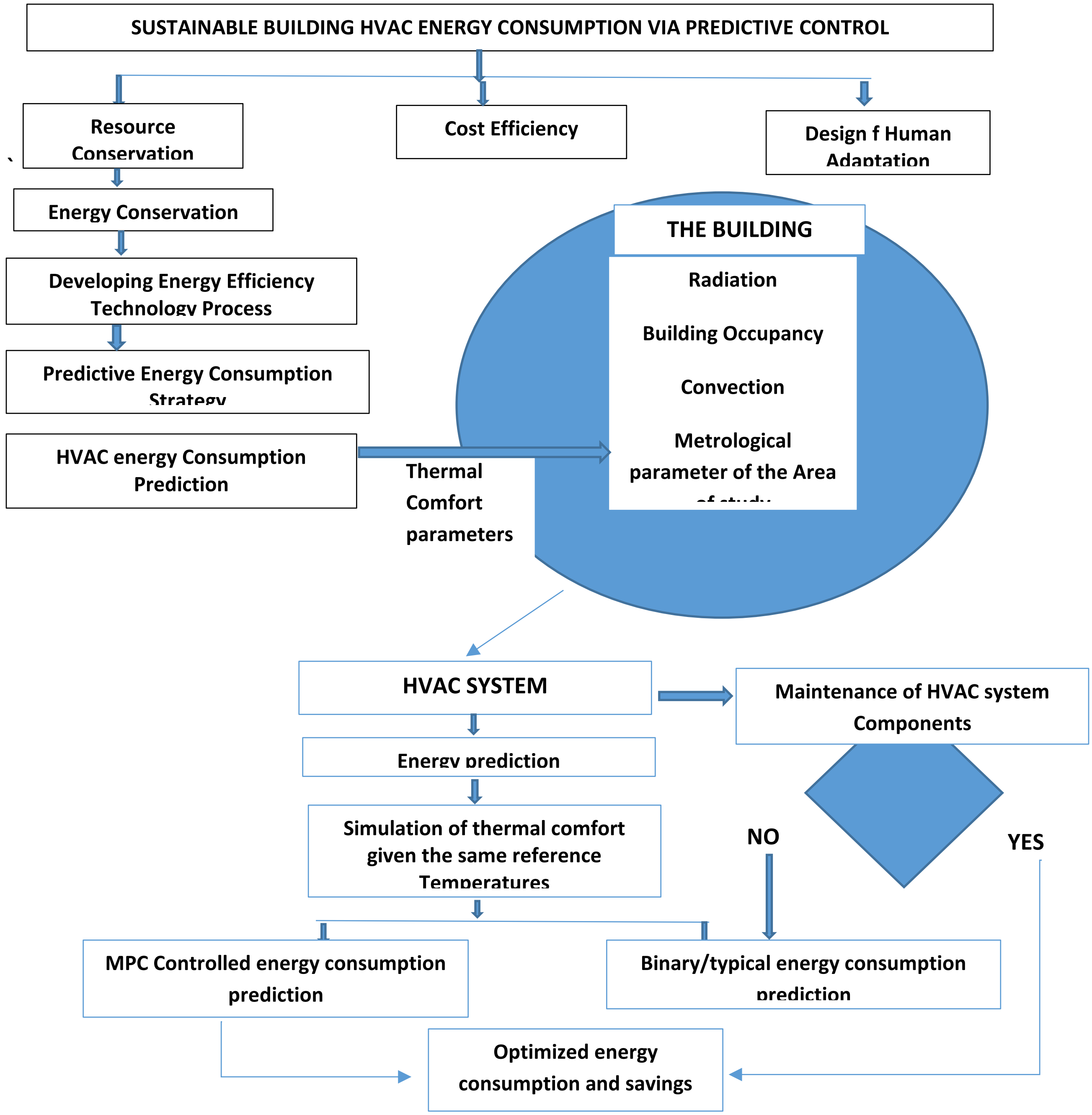


Fig 2.13 Proposed Conceptual Framework
Source: field Survey, 2018

2.2.1 Strategies and Methods of Sustainable Implementation

In order to achieve a sustainable future in the building industry, Asif *et al* (2007), suggest adoption of multi-disciplinary approach covering a number of features such as: energy saving, improved use of materials, material waste minimization, pollution and emissions control etc. There are many ways in which the current nature of building activity can be controlled and improved to make it less environmentally damaging, without reducing the useful output of building activities. To create a competitive advantage using environment-friendly construction practices, the whole life-cycle of buildings should, therefore, be the context under which these practices are carried out. A review of literature has identified three general objectives which should shape the implementation of sustainable building design and construction while keeping in mind the principles of sustainability issues (social, environmental and economic) identified previously. These objectives are:

a) Resource conservation
b) Cost efficiency and
c) Design for Human adaptation

2.2.2 Resource Conservation

"Resource conservation" means achieving more with less. It is the management of the human use of natural resources to provide the maximum benefit to current generations while maintaining capacity to meet the needs of future generations (Wilson *et al*, 1998). The concept has become a major issue in debates about sustainable development. Halliday (2008), observe that certain resources are becoming extremely rare and the use of remaining stocks should be treated cautiously. The author called for the substitution of rare material with less rare or renewable materials.

Bold statements about the need for radical improvements in the use of materials and energy resources have achieved recognition in policy circles. The argument is that productivity improvement is necessary to minimize impacts on the capacity of natural systems to assimilate waste materials and energy (Halliday, 2008). According to Graham (2003), the building industry is a major consumer of natural resources, and therefore many of the initiatives pursued in order to create ecology sustaining buildings are focusing on increasing the efficiency of resource use. He stated that the ways in which these efficiencies are sought are varied. He cited examples ranging from the principles of solar passive design which aim to reduce the consumption of non-renewable resources, the consumption of energy production, life cycle design and design for construction. Methods for minimizing material wastage during building construction process and providing opportunities for recycling and reuse of building material also contribute to improving resource consumption efficiency. Calls to be resource efficient have been born from concern for increasing depletion of non-renewable natural resources. Since the non-renewable resources that play major role in a construction project are energy, water, material and land, the conservation of these non-renewable resources has vital importance for a sustainable future. Resource conservation yields specific design strategies and methods, as defined in Figure 2.14.

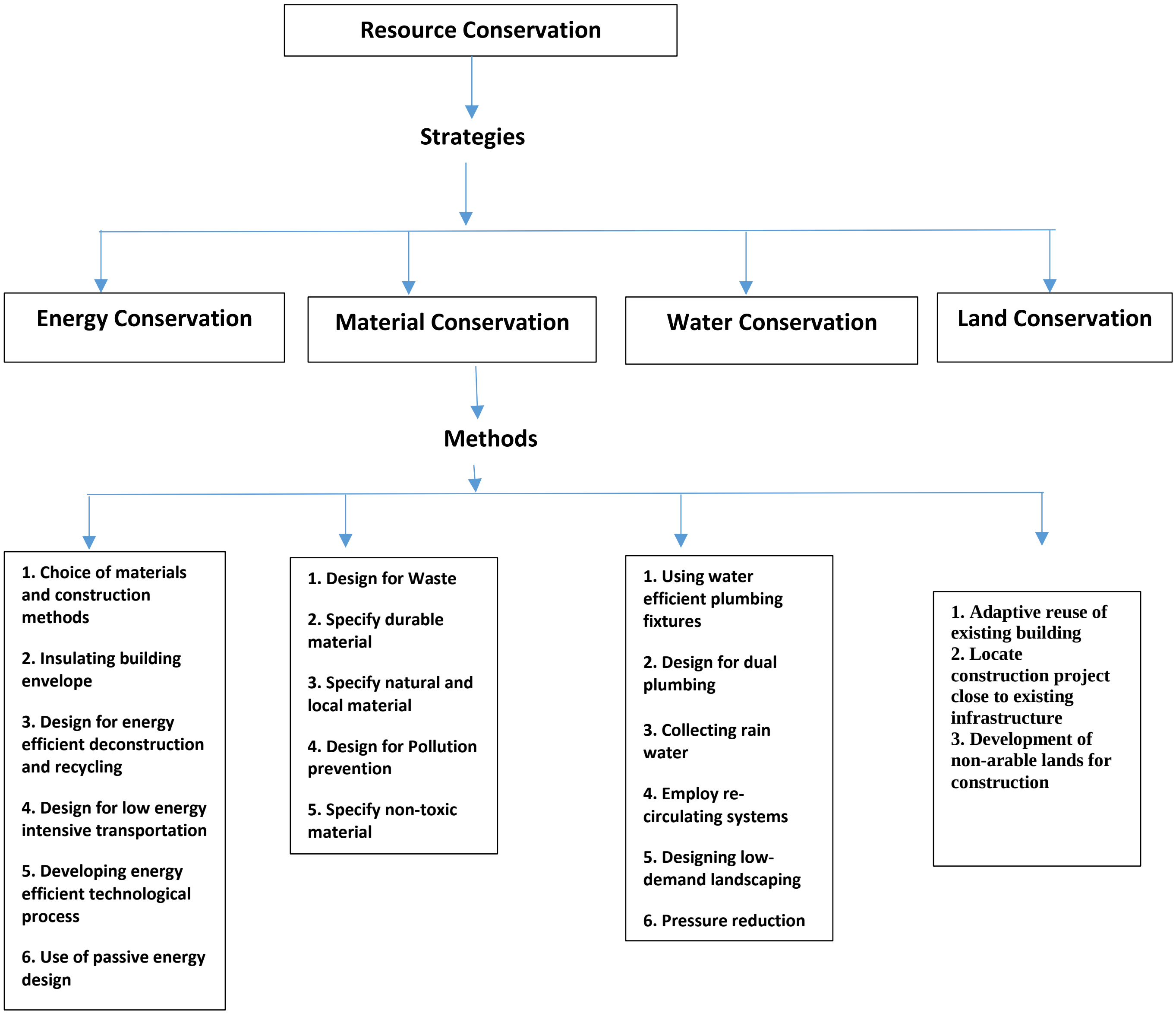


Figure 2.14. Strategies and Methods to achieve resource conservation
Source: (Halliday, 2008).

2.2.3 Energy Conservation

Energy use is one of the most important environmental issues and managing its use is inevitable in any functional society. Buildings are the dominant energy consumers. Buildings consume energy and other resources at each stage of building project from design and construction through operation and final demolition (Schimschar *et al*, 2011). According to Lenzen and Treloar (2002), the kind and amount of energy use during the life cycle of a building material, right from the production process to handling of building materials after its end life can, for example, affect the flow of greenhouse gases (GHGs) to the atmosphere in different ways over different periods of time. Their consumption can be largely cut back through improving efficiency, which is an effective means to lessen greenhouse gas emissions and slow down depletion of nonrenewable energy resources (Lee & Chen, 2008).

With this realization, increasing more attention is being paid to the improved energy conservation in building sector over the years, partly because the sector harbors a considerable potential of primary energy saving and reduction of emissions, having a negative impact on the environment (Sasnauskaite *et al*, 2007).

Energy use in a life cycle perspective includes energy needed for both operational and embodied energy. The operational energy requirements of a building can be considered as the energy that is used to maintain the environment inside that building (Dimoudi & Tompa, 2008). Thormark (2006) life cycle analysis of building shows that operational energy accounts for 85–95% of the total energy consumption and CO2 emissions of a building which comes from occupancy through heating, cooling, ventilation, and hot water use. This will include energy from electricity, gas, and the burning of fuels such as oil or coal.

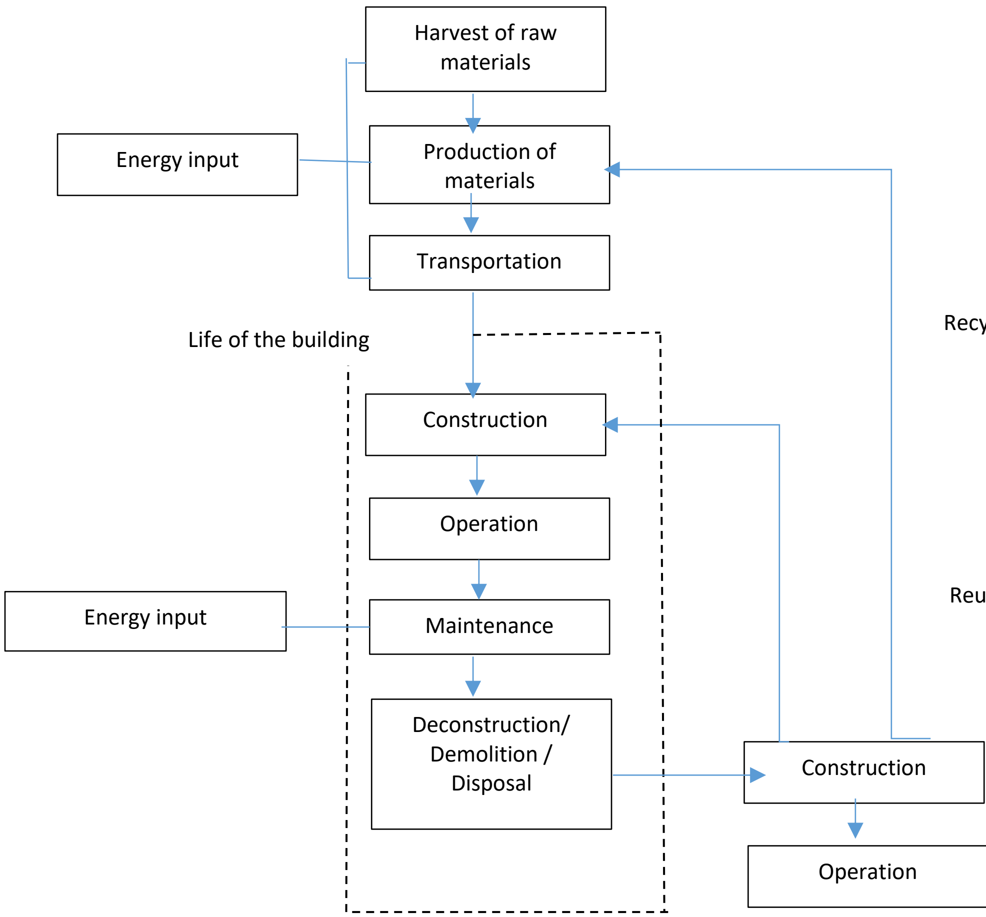


Figure 2.15. Stages of energy input during the life of a building.
Source: Thormark, 2006

As the energy needed for operation decreases, more attention has to be paid to the energy use for the material production, which is the embodied energy. The embodied energy of a building is the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy that is required to manufacture the materials and components of the building (Huberman and Pearlmutter, 2008). This indirect energy will include all energy required from the raw material extraction, through processing and manufacture, and will also include all energy used in transport during this process and the relevant portions of the energy embodied in the infrastructure of the factories and machinery of manufacturing, construction and transport. The energy life of a building can therefore be considered to be made up of numerous inputs of operational and embodied energy throughout a building life cycle as shown in Figure 2.15.

Therefore the main goal in energy conservation is to reduce the consumption of fossil fuels, as well as increasing the use of renewable energy sources. This could be achieved by the consideration of the following methods (Figure 2.14)

1. Choices of materials and construction methods are important to reduce energy consumption of a building through reduced solar heat gain or loss, thus reducing air-conditioning loads. Choosing materials with low embodied energy will help to reduce energy consumed through mining, processing, manufacturing and transporting the materials. For instance, aluminium has a very high embodied energy because of the large amount of electricity consumed to mine the raw material. True low energy building design will consider this important aspect and take a broader life cycle approach to energy assessment.

2. Insulating the building envelope is the most important of all energy conservation measures because it has the greatest impact on energy expenditure. A well designed and installed insulation can reduce the amount of heat lost through the building envelope by at least half (Al-Homoud, 2005).

Draughts and heat loss will be eliminated with an air-tightness strategy, where existing vents and chimneys will be blocked, floors and ceilings will be insulated, and walls will be coated with modified plaster. Heat recovery in high temperature areas such as kitchens and bathrooms, will achieve optimum energy efficiency through a mechanical ventilation unit that takes heat from these areas and uses it elsewhere in the house.

3. Designing for energy efficient deconstruction and recycling of materials cut energy consumption in manufacturing and save on natural resources. Buildings designed for deconstruction will include the disentanglement of systems, and reductions in chemically disparate binders, adhesives or coatings—or thermal/chemical/mechanical means to better separate constituent materials (El Razaz, 2010). They will include a construction blueprint and also a deconstruction blueprint. They will have bar codes for materials so that the deconstruction contractor will have “handling” instructions for the material or component

upon removal. These buildings will have self-supporting and self-stabilizing components, component accessibility designed in, and built- in tie-offs and connection points for workers and machinery. Most importantly, buildings that facilitate reuse and recycling will use non-hazardous materials, bio-based materials, high quality and highly recyclable materials. Design for deconstruction offers possibilities for the design of buildings that will close the loop of materials-use in building, and help make the transition towards a zero-energy building industry.

4. Designing for low energy intensive transportation reduces emissions causing pollution by affecting the amount of fuel used. The reduction of energy consumption in buildings has little impact on the national energy consumption if the urban and rural transportation systems waste energy. An efficient community layout that places schools, shops, and other services close to homes and business, making it easy to get places without driving and offering attractive bicycle and walking paths, can greatly reduce vehicle miles travelled per household (Carlisle *et al*,2008). This would in turn reduce the amount of energy needed for transportation—while improving quality of life—even before any expenditures are made for vehicles. Therefore the design of low energy houses should be combined with an urban design that allows the use of public transportation and bicycles. If the cities maximize public transportation, the use of bicycles and minimize the use of private cars the result would be lower costs for energy and road construction, less traffic jams and less air pollution.

5. Developing energy efficient technological processes for construction, fit out and maintenance of buildings. A truly integrated approach to energy efficiency in building processes would need to be instigated by the project team right from the beginning to achieve the target energy consumption levels.

6. Use of passive energy design such as natural ventilation, landscaping by vegetation, use of water bodies for evaporation and cooling, orientation of building, etc. can help achieve thermal and visual comfort inside the building, so that there is significant reduction in energy consumption by conventional air conditioning and artificial lightning in a building. Architects and Designers can achieve energy efficiency in buildings by studying the macro and micro

climate of the site, applying solar-passive and bioclimatic design feature and taking advantage of the natural resources on site.

2.2.4. Definitions of Sustainable Consumption

Over the last decade or so, there has been a wealth of social and natural scientific debate about the environmental consequences of contemporary consumption and there is, by now, something of a consensus. It is clear that lifestyles, especially in the West, will have to change if there is to be any chance of averting the long- term consequences of resource depletion, global warming, the loss of biodiversity, the production of waste or the pollution and destruction of valued 'natural' environments" (Shove, 2003).

Based on the classic description and definition of the Brundtland Report (WCED, 1987), sustainable consumption is now defined as: the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not to jeopardize the needs of future generations" (OECD, 2002).

Sustainable consumption is seen as a process involving negotiation and the building of consensus in some areas this process competes with conventional market operations. This means that if new consumption strategies are to be achieved, all actors must be willing to engage in discourse. Hansen/Schrader (1997) point out that the normative judgement of sustainable development and the corresponding sustainable consumption "has to be given additional legitimacy by a societal discourse" and practice.

Sustainable consumption has to be understood as a societal field of action, which could be characterised by three interacting areas of action:

i. the individual area of action (divided in two sub-areas): demand-side area, which includes consumption activities in the context of households as well as of professional procurement activities (of both large-scale private-sector companies and the public sector) and the informal area, in which private consumers undertake informal activities (e.g. unpaid household work), which are not market-oriented and are thus not visible on the level of demand;

ii. the supply-side and structural area of action, which includes the activities of companies and also governmental bodies to provide sustainable products, services and information;

iii. The socio-political area of action, which includes the activities of governmental bodies but also of organisations and associations to form the general framework for governance in both the individual and supply-side or structural area of action. Furthermore, in this area of action societal factors of consumption behaviour such as visions and moral concepts will be formed.

The three areas are interrelated: Consumer behaviour is based on individual decisions, individual behaviour, however, largely depends on supply-side measures, an appropriate infrastructure (e.g. the availability of energy-efficient household equipment) and socio-political factors (e.g. if systems of emissions trading or eco- labels exist).

Eberle, Brohmann and Graulich (2004) look at sustainable consumption as a more ecological but also socially … way of buying and using goods and services. Individual and societal consumption behaviour is embedded in daily routines and influenced by a variety of contextual factors such as specific lifestyles, social environment (neighbourhood, favoured peer groups), systems of infrastructure, habits and routines (Shove and Warde, 1998; Empacher, 2003; Shove 2003): with this in mind, sustainable consumption encompasses a range of very diverse fields of action and needs of change.

There is consensus among experts that the implementation of more sustainable consumption behaviour requires not only awareness among consumers, but also changed social and economic structures: Consumption is a "socially constructed historically changing process" (Bocock 1993,). Several authors (e.g. Fichter, 2005; van-Vliet, 2002) underline the need and notion of new product policies and the important role of consumers in this regard: "people are not simply end- consumers entirely isolated from the production process" (van-Vliet, Chapells

& Shove, 2005) but "they participate in the organisation of production consumption cycles" (van-Vliet, 2002).

On the one hand, every decision of purchase is also a vote for or against certain production conditions (with environmental effects as well as social conditions); on the other hand, "the existence of a suitable supply" (Hansen & Schrader, 1997) is crucial for the transition to more sustainable consumption. "The creation of an awareness that an ignorant 'business as usual' attitude does not only promote inaction but constitutes an active immoral act is hence a necessary prerequisite for a change towards sustainable consumption" (Hansen & Schrader, 1997). Empirical data show that this awareness already exists (in western societies): 75% of German consumers agree with the opinion that users are able to put considerable pressure on producers. In that regard, consumers follow the concept of a "co-producer" (Hansen & Hennig, 1995). The comprehensive (economic) debate during the first years of the 2000s on the function of consumption as utility production – among other areas in the field of behavioural economics (Belz & Egger, 2001; Belz, 2001; Scherhorn, 1994) – reveals numerous points of contact which have to be considered in a strategy for change. When taking all these aspects into account it becomes clear and was stated by Jackson (Kaenzig & Wüstenhagen, 2006) that sustainable behaviour is "a function of partly attitudes and intentions, partly of habitual responses, and partly of the situational constraints and conditions under which people operate." A variety of models and theories deals with aspects of decision making in the consumption sector. Three main disciplines should be stressed here: (Behavioural) economics, social psychology (environmental psychology) and sociology (cultural anthropology, sociology of technology). Their contributions will be briefly described in the next section.

2.2.5. Socio-Economic and Psychological Approaches to customer behavior

The central model of consumption in market economies has traditionally been that of consumer sovereignty. "It postulates that consumers in the market should be sovereign and that they are indeed sovereign, at least partly. Prerequisites for consumer sovereignty are freedom of consumption, on the demand side and (perfect) competition, on the supply side.

Given their preferences, consumers can decide which goods they want to purchase at what price" (Hansen & Schrader, 1997).

New approaches of behavioural economics/rational choice already incorporate empirical results of psychology. The model of bounded rationality assumes – and is backed by empirical data – that individuals have difficulty processing all of the information that is available to them. The main assumption is that decision processes are shortened by rules of behaviour or routines as a result of limited capacities for processing information (Kirchgässner, 1993; Beltz, 2005). The approach of bounded rationality can also be interpreted from an economic perspective since the time- and resource-consuming effort of information can be interpreted as costs. Since information has positive costs, the approach of bounded rationality is compatible with the approach of consumer sovereignty: The individual consumer himself decides on the appropriate strategy for how to optimise information cost. Thus it is not surprising that the recent literature highlights that consumer strategies and instruments addressing the model of rational consumer choice by a more elaborate information policy and price signals show "only limited success in changing unsustainable behaviour" (Kaenzig & Wüstenhagen, 2006). Information has

a) positive costs and b) may lead to a behaviour that is not optimal from an individual perspective. However, with regard to energy consumption this perspective may change due to increasing energy prices since this induces significant financial incentives for energy-saving behaviour. Economic psychologists have found that people are more sensitive to losses than to gains (Kahneman & Tversky, 2002). This is clearly reflected in energy- related decisions where decision makers consistently value the investments higher than the gains from cost savings.

Apart from questions of awareness and social and economic framework conditions, attention has focused on the issue of how to stimulate and consolidate changed – in the sense of sustainability-oriented – behaviour and individual decisions. Sustainable consumption in itself is not behaviour but rather a consequence of behaviour (i.e. decisions). Following the concept of Jager (2000), Martiskainen (2007) associates the different types of behaviour with a four-fold typology which is shown in Table 3.1.

Table 2.2. Typology of consumer behavior

	Automated	Reasoned
Individual determined	Repetition/habit i. conditioning	Deliberation i. planned behavior a) Attitudes b) Behavioral control
Socially determined	Imitation i. Social learning normative conduct	Social comparison i. Planned Behavior a) Social norm ii. Relative Deprivation/ Social comparison

Source: Martiskainen, 2007

Other models are linked to moral aspects of behaviour, norms and values (Stern, 2000; Martiskainen, 2007). Here, participation and the possibility to gain behavioural competence are variables of behavioural change as Kaplan (2000) discussed within his approach of the "Reasonable Person Model"

2.2.6 General Factors Influencing Sustainable Energy Consumption

Existing studies on the adoption of energy-efficient measures in households are typically based on different, partially over-lapping, concepts from economics (including behavioural economics), psychology (including the marketing-related literature on consumer behaviour) and sociology. For lack of survey-based studies exploring the impact of those factors on the actual diffusion of energy-efficient household appliances the findings for energy-saving measures in households in general serve as proxies. Such analyses on the diffusion of energy-efficient activities typically include factors related to the following categories (e.g. Dillman et al., 1983; Olsen, 1983; Walsh, 1989; Fergusen, 1993; Long, 1993; Scott, 1997; Brandon and Lewis, 1999; Barr et al., 2005; Carlsson-Kanyama and Linden, 2007; or, in particular, Sardianou, 2007):

i. characteristics of the household (occupants),
ii. characteristics of the residence,
iii. characteristics of the measure (technology),
iv. economic factors,
v. weather and climate factors,
vi. information diffusion,
vii. Attitudes/preferences towards the environment.

In light of the interdependencies among factors (and categories), causal impact of individual variables (or concepts) cannot always be clearly identified or distinguished. Among others, Curtis et al. (1984) pointed out that energy-saving measures may be divided in:

i. low-cost or no-cost measures which do not involve capital investment but rather behavioural change (e.g. switching off lights, substituting compact fluorescent lamps for incandescent light bulbs) and

ii. Measures which require capital investment and involve technical changes in the house (thermal insulation of built environment, windows with double- or triple-glazing). Purchasing a new appliance usually does not require technical changes in the house, but purchasing expenditures may be high. As for the impact of income, results from most studies imply that higher income is positively related with energy-saving activities/expenditures, e.g. Dillman et al. (1983) and Long (1993) for the US, Walsh (1989) and Ferguson (1993) for Canada, Sardianou (2007) for Greece, and Mills and Schleich (2008) for Germany. Thus, richer households are less likely to face income or credit constraints for investments in energy efficiency. In additions, empirical findings for Canada by Young (2008) suggest that richer households also tend to be associated with a higher turnover rate for household appliances, providing greater chances for energy-efficient appliances to replace older, less energy-efficient appliances. With regard to the impact of education levels on energy-saving activities, empirical evidence is rather mixed. In particular, the econometric analyses by Hirst and Goel (1982) for the US, by Brechling and Smith (1994) for the UK and by Scott (1997) for Ireland confirm that higher levels of education are associated with greater energy-saving activities. Reasons include, for example, that a higher education level reduces the costs of information acquisition. Likewise, education, as a long term investment, may be correlated with a low household discount rate and, thus, be positively associated with energy-saving measures. Such measures often require higher up front cost for investment, while savings in energy costs materialize in the future. Attitudes towards the environment as well as social status, lifestyle (Lutzenhiser, 1992, 1993, Weber and Perrels, 2000) belonging to a particular social milieu group (Reusswig et al., 2004) approving environmentally friendly behaviour tend to be positively related with education. In contrast, the analyses by Ferguson (1993) for the take-up of conservation measures in Canadian households and by Mills and Schleich (2008) for the diffusion of energy efficient light bulbs in Germany do not imply a statistically significant impact of education levels.

As expected from economic theory, most existing studies find that higher energy prices accelerate the diffusion of energy-efficient technologies or are associated with higher expenditure for energy saving measures (e.g. Walsh, 1989; Long, 1993; Sardianou, 2007; Mills and Schleich, 2008).

According to Walsh (1989), who finds that older household heads are less likely to carry out energy efficiency improvements, such investments yield a higher expected rate of return for younger investors. For household appliances (and light bulbs) this argument may be less relevant than for measures improving thermal insulation of the built environment, which tend to have a longer lifetime. Further, as suggested by Carlsson-Kanyama et al. (2005), younger households tend to prefer up-to-date technology, which is usually also more energy efficient.

Lower take-up of energy-efficient technologies by elder households may also interact with older people fewer years of formal education, and less information on energy-saving measures. For example, survey results by Linden et al. (2006) for Sweden indicate that younger people have better knowledge about energy efficient measures than older people. Clustering individuals into different types, findings by Barr et al. (2005) for the UK, Sardinanou (2007) suggest that “energy savers” are older. In general, although depending on the timing of the survey - age may turn out to have varying effects on the take-up of energy-efficient measures, the impact of age may not be linear and depends on the actual measure considered. Household size and the number of children are expected be positively related to the adoption of energy-efficient appliances because more intense use would lead to faster replacement (e.g. Young, 2008). Similarly, the more persons there are in a household, the more profitable it is to acquire information on the energy performance of appliances and to purchase energy-cost saving appliances. For other energy saving measures such as insulation of walls or roof, household size and composition may be less relevant. In terms of empirics, the literature provides mixed results. For example, results by Curtis (1984) imply higher energy-saving activity for households with two to four members than for other household sizes, while the impact of household size on energy-saving expenditures in the study by Long (1993) is negative.

Renting, rather than owning a residence has been found to inhibit the adoption of energy-saving technologies in a number of previous studies (e.g. Curtis et al., 1983, Walsh, 1989, Painter et al, 1983, Scott, 1997 or Barr et al., 2005), as it is difficult for residence owners to appropriate the savings from investments in energysaving technologies from tenants (Jaffe and Stavins, 1994; Sutherland, 1996). As Black et al. (1985) emphasize, this user-investor dilemma holds in particular for energy-saving measures requiring large capital investment such as thermal insulation of the outer walls, roofs, or attics.

Since larger residences have, on average, more appliances and higher levels of energy consumption, they are likely to have greater interest in, and knowledge of, household energy consumption and consumption-saving technologies, particularly if the cost of gathering information is relatively fixed. Larger residences may also have greater economic incentives to invest in energy-saving technologies if appliance use is greater. Some studies, among them Walsh (1983) or Mills and Schleich (2008), find the expected positive relation between housing size and the take-up of energy-efficient measures, while others, such as Sardianou (2008) find no statistically significant correlation.

Unless recently refurbished, older houses should have higher potentials for (profitable) energy-saving measures. Thus, the age of a dwelling is expected to be positively related to the diffusion of energy-efficient measures. This argument holds in particular for measures improving energy efficiency in the build environment.

Because of shorter lifetimes it is presumably less relevant for household appliances, which typically last for around ten years or less (OECD, 2002). Location may also affect the take-up of energy-efficient measures. In particular, urban households may have easier access to information and markets and thus lower transaction costs than rural households. Likewise, larger cities (or utilities in larger cities) tend to be more active in terms of implementing and promoting environmental policies, including policies to raise awareness. The econometric analyses by Scott (1997) for the observed diffusion of several energy-efficient technologies in Ireland also suggest a positive relation. However, since citizens in smaller cities and hence more rural areas may have stronger preferences towards the environment, the direction of the relation is likely to be ambiguous. In general, information diffusion relates to the level and quality of knowledge about (i) energy efficiency measures, of (ii) energy consumption (patterns) and costs for existing and new technologies as well as (iii) knowledge about the environmental impact of the particular technology alternatives. From an economic perspective rational household behaviour presumes that households are well informed about the technological alternatives and their costs (including energy costs). For example, information on energy operating costs is typically transmitted via energy bills, where frequency, design and other marketing elements may be relevant. For

Norway, Wilhite and Ling (1995) cited in Sardianou (2007) reports that more frequent and more informative billing led to energy savings of around 10%. Information on the energy performance of technologies (in particular appliances) is typically transferred via energy-consumption labels. Information about energy efficient technologies is often transmitted via campaigns by local, regional, national and international administrations or institutions, by energy agencies, consumer associations, technology providers and their associations, or by utilities.

Scott (1997) finds lack of adequate information on energy saving potential to be a barrier to several energy efficiency technologies in Irish households. From a behavioural and transaction cost perspective, what matters is not only the availability of information but also the credibility of the source (Stern, 1984). For example, Craig and McCann (1978) find that the response of New York households to information on energy-saving measures was stronger if the information was provided by the state regulatory agency rather than by the utility.

Along similar lines, Curtis et al. (1984) find that a greater variety of sources is positively correlated with energy-efficient activities. While information may improve the level and the quality of knowledge, improved information need not necessarily result in sustained energy savings. In particular, energy savings resulting from technology choices tend to have long-term effects, but behaviour-related savings may only be transitory (e.g. Abrahamse et al., 2005).

Most studies do not allow for a distinction between the relative contribution of factors related to cost savings and attitudes towards the environment. Brandon and Lewis (1999), however, find that environmental attitudes and beliefs are relevant but financial considerations are at least as important

2.3 Review of Related Literature

This section presents the various issues regarding the HVAC energy consumption in building based on the existing literature, and it reviews different energy consumption related issues with particular interest in the energy consumption of HVAC installation in Public buildings. It began with an overview of Energy consumptions in Public Buildings followed by a Framework of Strategies and Methods for Sustainable Implementation, HVAC consumption pattern and factors influencing HVAC energy consumption. Finally, it discusses the Energy Efficiency Techniques for HVAC System and identifies and discusses gaps in the existing related literature

2.3.1. Energy Consumption In Comercial Buildings

According to U.S. Department of Energy (2009), energy consumption from Public and residential buildings accounts for approximately 39% of the total energy consumption in the United States (see Figure 2.16). In addition, the energy consumption of the building industry remained almost constant through the past thirty years, while the energy efficient of the other industry sectors has significantly decreased as shown in Figure 2.17 As energy conservation and efficiency have long been a commonly acknowledged need across the U.S, and become even more popular concepts recently, to improve building energy efficiency has become an urgent challenge facing the building industry.

Figure 2.16 Energy Consumption by Sectors
Surce:(Rodgers 2009)

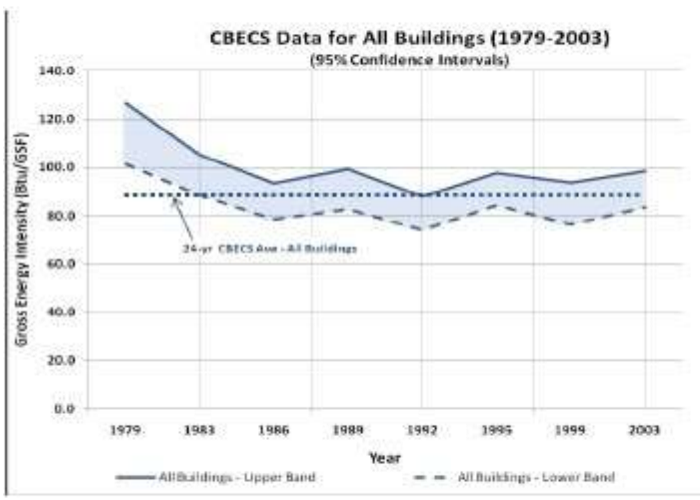


Figure 2.17 Building Gross Energy Intensity, 1979-2003
Surce:(Rodgers 2009)

One of the causes for building energy inefficiency is due to older building systems and a limitation in the integration in the building system design. Current design tasks are frequently performed in isolation and do not involve all impacted stakeholders in a timely fashion, which leads to the missing of many synergistic opportunities that can help improve building energy efficiency. On the contrary, the integrated design approach aims to fully utilize and synergize th professional knowledge of all related parties. Though isolated successful integrated design practices exist, it still remains a challenge for design teams to perform the integrated design efficiently and effectively. Hence, there is a need to understand and clearly define the integrated design process. HVAC systems are critical to building energy efficiency. According to U.S. Environmental

Protection Agency (EPA) (2008), noted that HVAC systems consume 55% of the energy in a typical office building (see Figure 2.18). The Public Buildings Energy Consumption Survey (CBECS) by U.S. Energy Information Administration shows that HVAC systems consume 33% of the electricity in a building (see Figure 2.19). As integrated design process includes the sub-processes of system design, it is important to focus on the building HVAC systems design process because of its critical role to the building energy efficiency. In addition, consider the low volume of new building projects, it is obvious that in order to improve building energy efficiency, a lot of work needs to be done in terms of retrofitting buildings (Petersdorff *et al*., 2006).

.

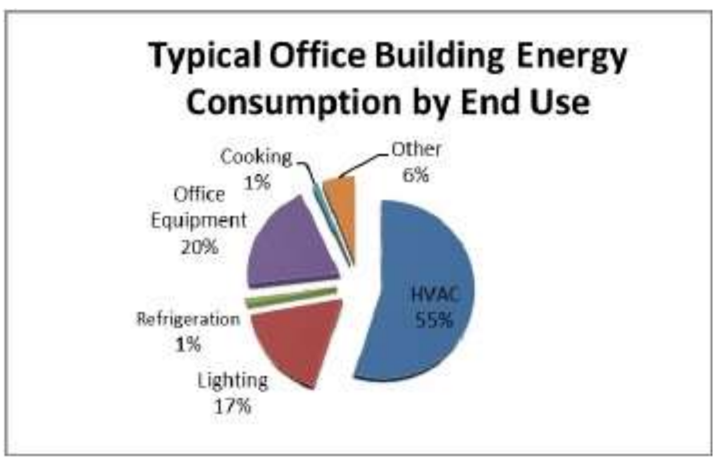


Figure 2.18 Typical Office Building Energy Consumption by End Use
Source: (National Action Plan for Energy Efficiency 2008)

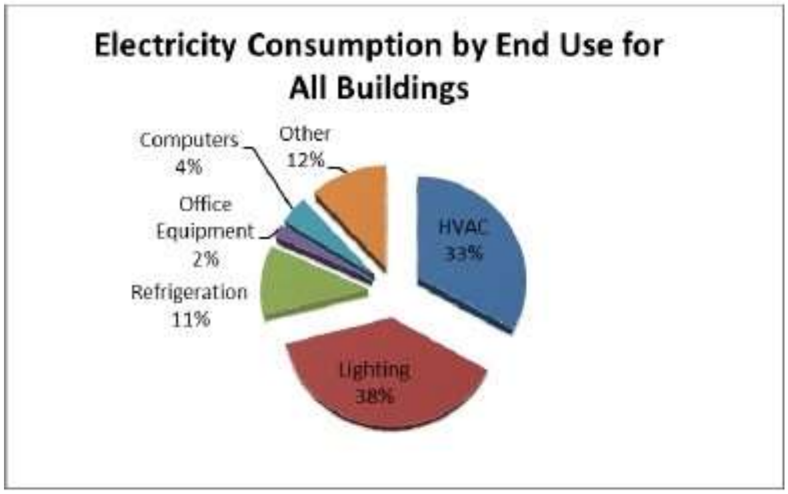


Figure 2.19 Electricity Consumption by End Use for All Buildings
Source: (CBECS, 2008)

2.3.2 Global Perspective of Energy Conservation

Buildings consume a significant portion of energy consumption of the world for heating, cooling, and power. It is estimated that nearly 30% of this consumption could be saved by energy conservation and sustainable building design and operations12, 13. It has been identified from various studies that buildings account for approximately 40% of the primary energy consumption in 15 countries including US, UK, Canada, France, New Zealand and South Africa14. This means that more than 10% of all energy consumed in the world is expended by building air-conditioning systems. Energy inefficiency appears to be widespread in buildings and there is an existence of considerable scope for energy saving.

During the assessment done for buildings thermal indoor climate conducted in Netherlands, where the directives were given in 1979 and 1991 by the Government Buildings Agency (GBA). The criteria formulated in 1991 in the form of 'weighted excess hours' were a subject for debate and it also contained information regarding the project which was started in September 2000 with a goal to innovate these directives.

Studies conducted in South Africa show that, approximately 20% of all available municipal electrical energy is used in Public and office buildings. Extended studies show that air conditioning is responsible for a substantial 50% of energy usage16. Overall energy conservation efforts could reduce the energy demand for air-conditioning in buildings about 40%17. Efforts to improve energy efficiency should include the building and design of the air-conditioning system both. Thus any building and HVAC thermal design tool should be addressed in an integrated manner, for both the building and the HVAC system together along with the control.

2.3.3 Building Envelope

Building envelope through its components plays a major role by gaining or loosing heat to the surroundings. Building envelope can be defined as barrier between the controlled indoor and outdoor environments. It includes exterior walls, windows, doors, floor, ceiling and roof. The performance of the building envelope impacts different sub-systems such as HVAC systems, plumbing and electrical systems. The heat loss or gain due to building envelope can be translated into cooling or heating load used in the design of HVAC system The energy efficiency measures designed for buildings till date target only towards improving present techniques and developing approaches for their practical use, hence there is a pursuit for designing long-term energy policy and systematic measures for achieving energy efficiency.

It is believed that more proficient building energy utilization can be achieved and energy optimization is conceivable by using the present-day techniques effectively in building design and operation. In the similar context the indoor thermal environment control behavior of cooling and heating systems were investigated in Seoul, Korea and compared with the results of previous studies. Twenty four houses in summer, six houses in autumn and houses in winter were used in that study. The result of the study indicated that the development of an HVAC system has created an expectation of comfort and has been shifted their thermal comfort zone warmer in winter and cooler in summer. It is well known fact that by making significant reductions in carbon emissions of building sector will prove to be beneficial for energy efficiency of the existing stock. The UK Government in its White Paper on energy policy and the European Union Directive both have stressed the importance in helping for improvements required in building regulation. Some of the technological solutions were available and well understood but they were often not applied. The regulatory provisions have been discussed in the ways by which it could be modified or new mechanisms can be developed so as to have a greater impact on the performance of buildings.

2.3.4 Design of Buildings for Energy Efficiency

The impact of natural aeration on building depends on design of numerous components of the building like facade, HVAC and control system18. Erhorn et al. has been given a tool to improve energy efficiency in educational buildings called Energy Concept Adviser. The tool has shown many similar design, operation and maintenance features in most countries for educational buildings. Studies have shown that during retrofit, energy saving measures was rarely applied, because the decision-makers lack the knowledge for potential energy saving measures. The ECA is a tool that assists educational building decision-makers when the construction project is still in the design phase. The ECA includes suggestions of energy systems to use and

Wit et al. study addressed doubts in building performance valuation and their probable impact on design decisions. Design evolution involves a chain of design decisions which are supported by input supplied by the various domain experts at large to the design team. The research throws light on the domain expertise of the building responsible for those inputs which prolong rational decisions in respect to energy use, thermal comfort, HVAC system sizing etc.

According to Hui building energy simulation is important for the study of energy efficiency in buildings. The study explained the fundamental concept of energy simulation in building design and the properties of simulation design tools. Efficient simulation practice in the context of integrated building design systems has been discussed. The research conferred some of the building energy simulation techniques rapid building energy simulation tool, developed specifically for building designers. Conceptual building designs can be modeled quickly and without formal training.

Another research presented an overview of the concepts of energy efficiency in view of the principles of sustainable development. It is important to optimize energy consumption, particularly within the building area. The research has identified the importance for the existence of computational resources to support designers and users in order to optimize the use of electric energy in buildings. The research has evaluated the computational resource and presented proposals to update this computer source by the use of a critical analysis made by specialists. The result of consultation with experts confirmed the importance of computational resources in the project development. Conclusively the computational resources for management of electric energy use in buildings permit to obtain the energy diagnosis, induced rationality in design criteria and use of energy.

The Zero Energy Building (ZEB) concept has gained international attention during last years and is now seen as the future target for the design of buildings. However, before international standards, the ZEB concept requires clear and consistent definition and a commonly agreed energy calculation methodology. The following issue required special attention before the development of new ZEB definition:

i. the metric of the balance,
ii. the balancing period,
iii. the type of energy use included in the balance,
iv. the type of energy balance,
v. the accepted renewable energy supply options,
vi. the connection to the energy infrastructure and
vii. the requirements for the energy efficiency.

Studies have been presented and discussed possible answers to the above mentioned issues in order to facilitate the development of a consistent ZEB definition and a robust energy 25 of building simulation tools and building design. The research presented the development of a strategy to provide computational support during the building design process for rational design decisions regarding the selection of energy saving building components. The strategy of prototype support environment has shown the way to support interaction between building design and building simulation.

2.3.5 Thermal Comfort Conditions and Energy Consumption

Almost half of the energy used in our society is consumed by the building sector - the design, construction, and operation, and demolition of our built environment. Much of that energy is used to cool and/or heat buildings. Air conditioning accounts for 44% of a building's energy consumption. Knowing this, designers can help reduce the energy consumption patterns of a building by improving air conditioning systems.

The American Society of Heating, Refrigerating, and Air Conditioning Engineers (AHSRAE) Standard 55, Thermal Environmental Comfort for Human Occupancy, specifies "the combination of indoor thermal environmental factors and personal factors acceptable to a majority of occupants."

There are two approaches to deciding what this combination of factors should be:

a. Analytical: People are put in a temperature-controlled environment and their responses are monitored. This method favors highly controlled environments and the results are used to develop a model that can be used to predict optimum comfort.

b. Behavioral: People are monitored in their normal environments and their responses are related to the conditions they experience. The results are analyzed statistically to develop an understanding of the interaction between people and buildings.

These two approaches produce different results, especially in variable conditions. The analytical approach uses computer software programs that control conditions to make the most people happy. In the behavioral approach, a psychrometric chart is applied. Prior to discussing this latter application in more depth, it is important to consider the history of heating and cooling systems, and what we can learn from our past.

2.3.6 Thermal comfort defined

Initially buildings used to be designed to provide shelter for human beings by preventing them from harmful environment and the dangers surrounding them. At that time, usually little attention had been given to comfort of building in comparison with human comfort. ASHRAE defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment" Due to its subjectivity, thermal comfort is different for every individual. It is maintained when the heat generated by the human metabolism is allowed to dissipate at a rate that maintains thermal equilibrium in the body. Any heat gain or loss beyond this generates Comfort substantial discomfort. Essentially, to maintain Thermal comfort, heat produced must equal heat lost. It has been long recognized that the sensation of feeling hot or cold is dependent on more than just air temperature. In fact, there are six primary Thermal comfort variables:

i. Ambient temperature (air temperature)

ii. Radiant temperature (the temperature of the surfaces around us)

iii. Relative humidity (measurement of the water vapor in an air -water mixture)

iv. Air motion (the rate at which air moves around and touches skin)

v. Metabolic rate (amount of energy expended)

vi. Clothing insulation (materials used to retain or remove body heat)

Understanding these six variables, is essential to making informed decisions when planning and designing a building air conditioning system. However, it is equally important to understand how these systems impact a building’s energy load.

The rationale of a HVAC system is to offer conditions for human thermal comfort. A comfortable environment can be created by simultaneously controlling temperature which includes mean radiant temperature and air temperature, humidity, air cleanliness and distribution within the occupant's vicinity. In addition to the above factors, behavioral factors like clothing level, activity, posture and location, opening a window, etc can also affect the feeling of thermal comfort. Although wide variation exists in the climatic conditions, living conditions and cultures throughout the world, the temperature favored by the people under such conditions of clothing, activity, humidity and air movement were found to be similar (Camacho, 2007).

2.3.7 Historical Perspective of Thermal Comfort

Prior to the development of mechanical air conditioning systems, societies used natural heating and cooling methods – such as shading, thermal mass, and natural ventilation – to achieve thermal comfort. Such methods have been used for thousands of years. For example, the ancient Babylonians used evaporative cooling to condition their dwellings as far back as 2,000 BC. Individuals would spray water onto exposed surfaces at night; the combined evaporation and drop in night time temperatures provided a simple and effective method to get relief from the heat. Ancient Indians would hang wet grass mats on the windward side of their homes to achieve a cooler indoor temperature.

Society moved away from these methods when mechanical cooling became available in the early 1900s. In 1902, the first mechanical cooling system was built.6 Four years later, the first office building was designed for air conditioning.7 In 1929, the first room cooler went on the market and 1931 marked the first time that year-round central air systems became available for homes.8 By 1947, the window air conditioning unit was being mass-produced and after World War II mechanical systems flourished with the large-scale and rapid development of homes.9 Due to these achievements over the course of the 20th century, the mechanical air conditioning industry led the market in growth in energy use in buildings.

While the advent of air conditioning made it possible to have a comfortable indoor environment in any climate, it also led to design that completely ignored varying climatic conditions. For example, New York-style town-homes were built in New Orleans. This caused buildings that had functioned efficiently in one environment to consume excessive amounts of energy in another. Essentially, we began to build less efficient buildings that used more energy.

Before the 1970s energy crisis, occupants accepted and expected the experience of occasional high humidity periods. This variation in humidity rarely factored into building material choices, which have a huge impact on overall structure and indoor air quality. During this time, buildings were constructed loosely, with poor insulation. This construction resulted in an added sensible load, keeping the AC units running frequently.

After the 1970s energy crisis, stringent building codes began to arise through the Energy Policy Act to improve building efficiency. ASHRAE Standard 90 Energy Standard for Buildings addressed energy efficiency, Standard 62 Ventilation for Acceptable Indoor Air Quality addressed ventilation, and Standard 55 addressed issues of thermal comfort. These more stringent codes also required that mechanical equipment become more energy efficient. With these codes in place, an unintended consequence was that equipment continued to be optimized for sensible cooling, but still ignored the moisture load.

The following factors emerged from these developed standards and changes made to the manner in which we designed and constructed our buildings:

a. The sensible load in a building was reduced, however, the moisture level stayed the same. This caused relative humidity problems. Though the changes in standards after the 1970s energy crisis made buildings and equipment more efficient, the focus on sensible loads (temperature) meant that humidity was often ignored in system design.
b. With increased ventilation requirements more moisture was added with ventilated air .
c. With increased indoor air quality awareness drier conditions were expected by the occupants.

Because of the emergent standards, indoor air quality conditions decreased as a result of unaddressed moisture loads. While the energy crisis resulted in more energy efficient buildings and equipment, we were left with less dehumidification. This is problematic from an indoor air quality standpoint as increased moisture can cause mold or mildew to grow inside the building, which is a health hazard for occupants and detrimental to the life of building materials.

As a result of these changes, one important lesson emerged: we should design to control humidity and not just temperature. Peak dehumidification load is different from the peak temperature load, but it is not often accounted for in mechanical design. Peak temperature load only occurs 2% of the year. When designing for this maximum peak dehumidification and part load conditions are often not considered.

While air conditioning systems had previously been designed for a specific building, over time they became standardized. Now, we are witnessing a desire to return to using passive systems, often in tandem with specifically designed mechanical systems. New energy efficient methods that consider the occupants in a space, rather than designing the building and air conditioning system without thought for who is using the space (or how it is used), are being employed more frequently. Additionally, these systems are adapted to the local climatic context of the building, accounting for both temperature and humidity not only peak temperature but peak humidity and part load conditions as well. One method with which to properly design an HVAC system is to apply the concept of psychrometrics to system design, since psychometrics considers the factors of local climate, human occupancy and comfort, and varying temperature and humidity controls.

2.3.8 Factors Affecting Thermal Comfort

The factors that lead to discomfort inside the building are being controlled and maintained. In fact there are numerous factors that affect the comfort, however a few important of them are briefly described here. The environmental factors controlling thermal comfort are temperature, mean radiant temperature, operative temperature and relative humidity. The personal factors controlling thermal comfort are clothing and the nature of activity. By investigating thermal comfort conditions in outdoor urban spaces, it has been concluded that there are some complexity issues involved, which demonstrates that a quantitative approach was insufficient in describing comfort conditions outdoors. The paper focused on the issue of psychosomatic adaptation: naturalness, expectations, experience (short-/long-term), time of exposure, perceived control and environmental stimulation, and presented an attempt to try and64 thermal comfort; however the most important of them are follows:

(a) Temperature: It is the determinant of thermal activity in a body. The action depends on the velocity of the molecules and other particles by which all the matter is composed. It is perhaps the most important environmental factor which determines the perception of comfort. Generally, humans are sharp to react to this parameter.

(b) Mean Radiant Temperature (MRT): The factor by which comfort is affected is coined as mean radiant temperature (MRT). MRT is the uniform temperature of any imaginary black enclosure with which any person is also assumed to be a black body, and exchanges the same heat by radiation as in the actual environment. In other idiom, MRT is the average of all room surfaces weighed according to emissivity (Andersen *et al,* 2000). MRT becomes more important when the radiant heating or cooling ability of any surface can be calculated in the context of its area in proportion to the area and temperature of other surfaces of the room.

(c) Operative Temperature: It is the uniform temperature of a radiant black enclosure where an occupant exchanges the same amount of heat by radiation and also with convection as in the actual non-uniform environment. Numerically, operative temperature can be defined as the average weighted heat transfer coefficient of the air (Nassif, 2013)

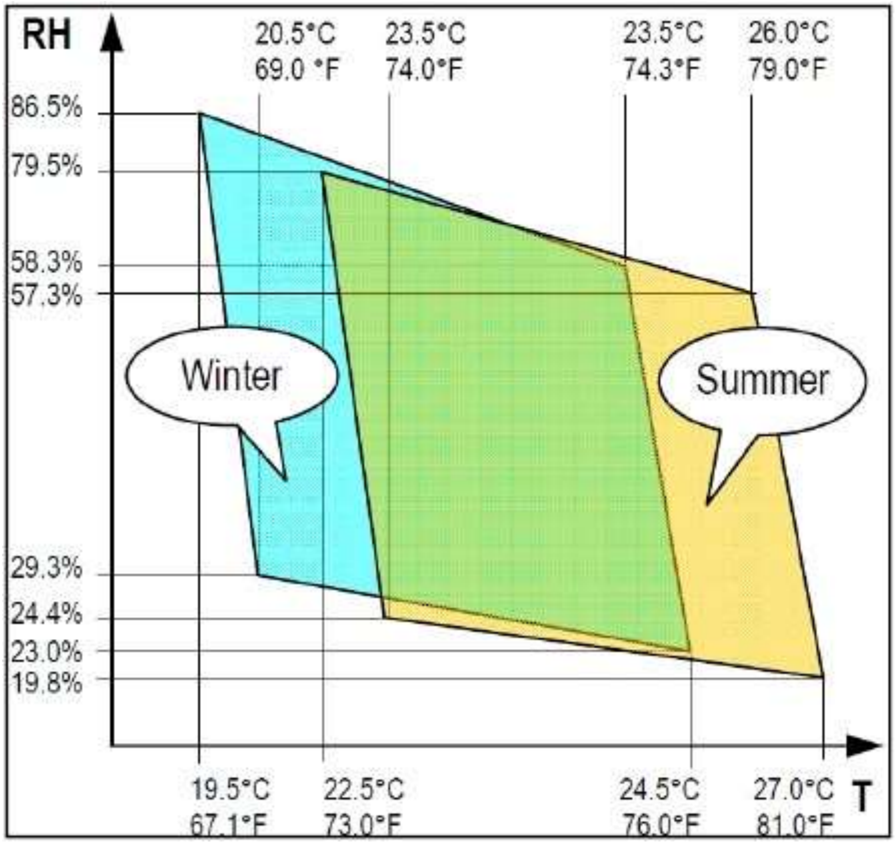


Figure 2.20: Relative humidity Vs temperature diagram based on thermal comfort zon efor summer and winter
Sources (ASHRAE,1992)

(d) **Relative Humidity**: Relative humidity (RH) is also an important factor that affects comfort. Fundamentally RH is the amount of water vapor held in the air as a percent of the maximum amount of water that air can hold at a specific temperature and pressure. Experiments show that in winter, a relative humidity of 30% seems to be suitable for comfort. In summer, visa-vise 50% sounds to be ideal for accomplishing the comfort69. When relative humidity decreases from 50% to 20% or visa versa, the difference in comfort is not being actually detected by human body. On the other hand, in winter seasons the body feels uncomfortable until the relative humidity (RH) reaches up to 60% or higher.

(e) Clothing: An individual can alter his or her comfort conditions through adding or subtracting clothing with regard to indoor situations. By considering the studies carried out by energy investigators working at Kansas State University, it provides evidence that the most comfortable condition is wearing of light clothing for office wear (0.4-0.6 clo) (Bacher and Madsen, 2011) which corresponds to an air velocity of less than 35ft/min and air temperature of 24°C at 50% relative humidity.

2.3.9 ASHRAE Standard for Thermal Comfort

The ANSI/ASHRAE standard 55-1992, Thermal Environmental Conditions for Human Occupancy Standard describes an acceptable thermal environment under conditions in which 80% or more of the occupants will find the environment at indoor space environment and also the occupant's personal factors which can provide thermal environmental conditions acceptable to 80% or more of the occupants. As numerous methodologies are present in establishing thermal comfort zones of buildings, there is a need to have one standard reference of interest for researchers. The ASHRAE model is the most important and widely used thermal comfort model.

The model is based under the conditions of the effective temperature, designed for the occupants wearing typical clothing. The model recounts the effective temperature with the operative temperature which would influence the MRT. Though the model initially was designed for a specific value of clothing and activity level, but now in the model alteration to operative temperature to suite different clothing and activity level can be accommodated. The model does not set minimum value for air movement but recommends values not exceeding 0.15 m/s and 0.25 m/s during winter and summer

2.3.10 Thermal Comfort Relative to the Psychrometrics

Before defining and applying the concept of psychrometrics, it is important to understand what an air conditioning system is, and what its inputs/outputs are. Psychrometrics is the study of the physical and thermodynamic properties of air-water vapor mixtures and according to Willis Carrier, inventor of modern air conditioning, it is “the control of the humidity of the air by either increasing or decreasing its moisture content. Added to the control of humidity is the control of the temperature by either heating or cooling the air, the purification of the air by washing or filtering the air, and the control of air motion and ventilation. In order to improve our air conditioning systems, we must examine all the variables involved in thermal comfort: humidity, temperature, air purification, air motion and ventilation.

Psychrometrics is used to help select the proper air conditioning equipment and determine the environmental conditions that affect human thermal comfort. It is also useful to help understand: a building’s regional climatic context and better address, human occupancy and use, and structural considerations. The study and analysis of psychrometric properties is especially important in applications where moisture and heat transfer in air are critical.

Most of psychrometrics is embodied in the psychrometric chart (Figure 2.20). An understanding of how to apply the psychrometric chart will help to diagnose air temperature and humidity concerns. The chart is a tool for visualizing the airconditioning process and helps inform climate-specific designs. It uses three main categories: temperature, moisture, and relative humidity, to inform the design of energy efficient and properly sized HVAC systems.Understanding the chart helps with visualizing environmental control concepts such as how hot air can hold more moisture, and conversely, how cooling moist air to its dewpoint will produce condensation.

The three principal boundaries of the psychrometric chart (Figure 2.21) are a dry-bulb temperature scale on the horizontal axis, a humidity ratio (moisture content) scale on the vertical axis, and an upper curved boundary which represents saturated air, or 100 percent relative humidity. The chart also shows other important properties such as enthalpy (the energy content of an air-water mixture, expressed in BTUs per pound of dry air) and specific volume (the space occupied by a given mass of air). The versatility of the chart lies in the fact that knowing any two of these properties fixes a point on the chart from which all the other properties can be determined. The use of the chart is simple and the following sections discuss its applications by dissecting the components of the graph piece by piece.

Temperature

There are two main sources of building heat: internal and external. Internal sources include people, lights, appliances, equipment; external sources include solar load, conduction, ventilation, and infiltration. Temperature increases from cold to hot along the x-axis of the psychrometric chart. The temperature measured in this case is the 'dry bulb' temperature, which is that of an air sample as determined by an ordinary thermometer. It is called "dry-bulb" since the sensing tip of the thermometer is dry and does not take the moisture content of the air into account.

Moisture

Moisture in the air is an important consideration of air conditioning system design, and thus an integral element of the psychrometric chart. Like temperature, there are also two main sources of moisture: internal and external. Internal includes evaporation, desorption, and people (breath, clothes); external includes ventilation, infiltration, and permeation. Internal moisture sources are as important to consider as outside moisture sources, since each person emits 0.25 pounds of moisture per hour, therefore100 people at a moderate activity level produce three gallons of water per hour. Moisture is measured through a humidity ratio measurement, which is found on the y-axis, with lines of constant humidity ratio running horizontally across the chart. The humidity ratio is the weight of water per unit of dry air. This is often expressed as grains of moisture per pound of dry air, with 7,000 grains of moisture per pound of water (Fiorentini, 2015)

Humidity

The ASHRAE user's manual states that HVAC systems that have dehumidification must be designed to control relative humidity when analyzed for either of the following design conditions:

i. At the peak outdoor dew point design conditions and the concurrent (simultaneous) indoor design latent load, or,
ii. At the lowest space sensible heat ratio expected to occur at the concurrent (simultaneous) outdoor condition.

Relative humidity provides an indication of how close the air is to its saturation point. It compares the amount of water in the air to the amount of water that the air could potentially hold at that temperature. This affects the perceived temperature of an environment, as well as mold growth and stability of building materials. On the psychrometric chart, lines of constant relative humidity are represented by the curved lines sweeping up from the bottom left and to the top right of the chart.

Wet-bulb temperature is determined by circulating air past a wetted sensor tip, which is affected by air saturation. In practice, this is the reading of a thermometer whose sensing bulb is covered with a wet sock evaporating into a rapid stream of the sample air. (Note: WBT will be the same as DBT when the air sample is saturated with water, since no water can evaporate in those conditions.)

The line for 100 percent relative humidity, or saturation, is the upper, left boundary of the chart. This is also the dew point temperature. Dew point temperature indicates the temperature at which water will begin to condense out of moist air. A rule of thumb is that the annual night time temperature for a given region is that area's dew point temperature. See Figure 6 for a map of the daily average dew point temperature for October in the continental United States. High levels are represented by the red areas and range down through the spectrum to low levels in the purple and blue areas.

There are different ways to remove moisture from the air in a building: cooling below the air's dew point, desiccants that adsorb or absorb water, and compression to condense water out of the air. Whichever method is used it is important to analyze both its performance and annual energy use at all of the building loads.

Another way to remember the inputs for proper HVAC design is to remember to consider both the sensible and latent heat of a given building. Sensible heat refers to the temperature load of a given space. Latent heat is basically the moisture load of the building. It is the energy given up or taken up by the air as water changes phase, such as vapor condensing into liquid. It considers the moisture content, which engineers often forget about when designing and sizing HVAC systems. The latent load is crucial because it is a significant load and also accounts for the outdoor moisture at peak and part load conditions as well as moisture from the people in the room (Indoor and outdoor moisture loads). If latent load is not considered it may lead to increased moisture in the space that could create higher relative humidity, discomfort and building deterioration. Combining the latent and sensible heat gives the total heat load.

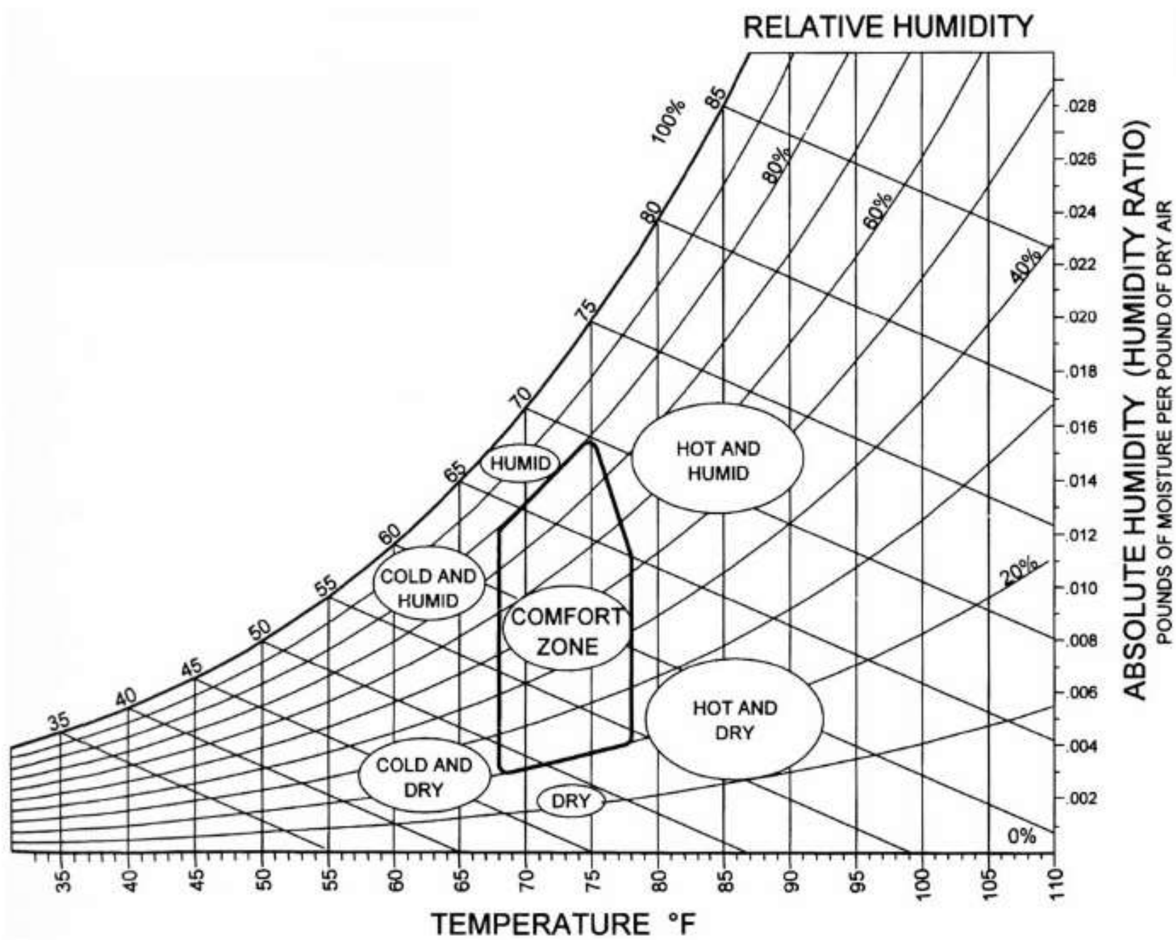


Figure 2.21 Psychrometric Chart

Source: ASHARE. (2011)

2.3.11 Thermal Comfort, Psychometric Chart and Building Design

It is important to mention that these heating and cooling systems do not operate in a vacuum. Aside from understanding a building's potential moisture content, another issue arises with proper building site orientation. Proper orientation, materials, and design affects heat gain and loss of a building, as well as ventilation and cooling loads. Therefore, it is important to also consider the location and orientation of a given building on a given site in addition to the proper sizing of an HVAC system.

Looking back at history provides a broader understanding of how various building cultures designed for their climates, considering proper orientation with regard to air flow and other thermal comfort conditions. Today, maintaining thermal comfort for building occupants is one of the most important goals of building design engineers. While we can employ adaptive strategies to cope with our changing thermal environment (removing clothing, unconsciously changing posture, moving to cooler locations away from heat sources), problems arise when this choice (to remove jacket, or move away from heat source) is not available, and people are not able to adapt. Therefore, we need to consider the following factors in building design and construction:

a. The role of cooling in comfort, productivity and energy use for different climates
b. Strategies for reducing reliance on AC and reduction of its energy use
c. Adaptive behavior in buildings: mechanical cooling and passive controls
d. Standards for comfort and energy use in buildings
e. Thermal comfort in the context of energy performance regulations
f. Improving building simulations
g. Improving building envelope, design and materials to reduce loads
h. The role of renewable energy in cool buildings
i. Impacts of climate change, urban heat islands and rising fuel costs
j. Practical issues for low or zero carbon cooling

Current best practices in building design and construction result in homes that conserve much more energy than average new homes. Constructing homes in smart ways results in the use of minimal resources to cool and heat the house as the seasons change. Employing these methods can significantly reduce energy costs. Some of these best practices and guides include:

i. Passive houses: using the sun‘s energy for heating and cooling living spaces, the building itself, or some element of it, taking advantage of the natural energy potential of materials and air that have been exposed to the sun.
ii. Superinsulation: an approach to solving thermal envelope problems through design, construction, and retrofitting. A super insulated house can include thick insulation and/or an air tight envelope.
iii. Windows and lighting: Utilization of properly designed and installed high efficiency windows and lighting.
iv. Self-sufficient homes: also known as off-grid, where the building generates and consumes its own power/energy.
v. Zero energy buildings: produce on average as much energy as they consume; designed to use zero net energy from the utility grid.
vi. Earths hips: passive solar houses built out of recycled tires and usually built into the ground.(Luis ,Ortiz. and Pout, 2008)

Maintaining thermal comfort for building occupants is one of the most important goals of HVAC design engineers. If we can understand the variables of thermal comfort in our regional climatic contexts, and the mechanisms by which they operate in relation to human physiology, then we can design buildings that provide comfort in more rich and economical ways than a standard HVAC solution. The psychrometric chart offers much insight into the integration of physiological properties, the properties of the local climate context, and other factors which allow us to design comfortable environments in a holistic manner

2.3.12 HVAC System

HVAC system is a tool to provide healthy, comfortable, productive comfort conditions, which is an essential component of human life. It is very essential to properly design, operate and maintain the HVAC system. HVAC issues related to energy conservation play a vital role for the design of new Public buildings as well as for redesigning existing buildings.

The foremost rationale of heating ventilation and air-conditioning system is to generate a contented and healthy indoor environment, by controlling the indoor temperature, humidity level, air circulation and air quality. The prompt consideration is required on important factors like performance, efficiency, quality and morale of individuals to improve the quality of indoor environment. A well-designed HVAC system is also a crucial constituent for competent performance of buildings. The majority of the HVAC systems in utilization today were poorly designed for 34 than 60% of the energy delivered to the building is consumed by HVAC system in some countries due to the harsh climatic conditions For example HVAC systems in USA alone consume more than 25% of the total primary energy 35,-36%. As a result there is a pressing necessity for improved HVAC designs.

The energy usage due to HVAC systems represents 40% of the total energy consumed by typical office buildings. The major characteristics of HVAC equipment to determine the condition of the equipment, their operating schedule, their quality of maintenance, and their control procedures should be obtained by the energy auditor. A large number of energy efficiency measures can be considered to improve the energy performance of HVAC systems.

The majority of the HVAC systems are designed for human comfort which consists of number of fans, pumps, compressors, heat exchangers, cooling towers valves and dampers as well as a pipe and air duct assemblies of different sizes and with different operating characteristics. Many industrial applications do have other objectives besides human comfort like to provide control of space temperature, humidity, air system will be much enhanced and more cost effective if human comfort and the demands of industry are satisfied simultaneously.

A simplified building HVAC system model was presented by Bertagnolio et al. He included simplified models of building zones and HVAC equipment. The simplified building zone model was presented on an R and C network, whose parameters were adjusted through a frequency characteristic analysis. And then it was contrasted with other detailed models, using the BESTEST procedure. The study also discussed the application of the experimented model to the audit of Public buildings.

a Equipment Selection: The capacity and operating conditions for each component of the system can be determined with the help of calculations and the method of control. The selection of equipment’s can be done with the help of manufacturer's catalogs. Many equipment test codes have been written by ASHRAE, American Refrigerator Institute (ARI), Air moving and Conditioning Association (AM CA), and other societies and manufacturer groups. Comprehensive lists of these codes are mentioned in ASHRAE handbooks.

b Distribution Systems::Air ducts and piping are two kinds of HVAC distribution systems. Air ducts include supply air, return-relief air, exhaust air, and air-conveying systems. Air ducts are used to convey air to and from desired locations. Piping is used to convey steam and condensate, heating hot water and other heat transfer fluids. Energy is required to force the fluids through these systems should be considered when systems are evaluated or compared.

c Thermal Zoning: It is a technique commonly used for greater design flexibility and energy economics in HVAC systems. In this approach a building is subdivided into a series of zones, where the set conditions can be maintained properly for a specific space and the equipment needs service only in the areas that require heating and cooling. By combining zoning with night temperature set-back controls and a time clock is an effective means of achieving occupied and unoccupied building controls. Though it is common to have many zones within one building, the number of occupied and unoccupied modes permissible in one day is normally limited to two each in any one zone, in other words the system can switch from occupied to unoccupied mode and back to occupied mode twice daily (Sekhar et al 2007). employed simulation to evaluate five most commonly used HVAC systems in Public buildings which were selected on basis of their thermal and energy performance. The results of simulation showed that the two coil induction unit had lowest consumption and performed better in providing thermal comfort, followed by VAV system with small fluctuation over the building. CA V system consumed 10% more than VAV system and at the same time gave degraded performance. Hence packaged system had experiments revealed the strategies for terminal VA V system in Public building.

Research showed that use of floating supply temperature offered improved comfort conditions and energy performance. Operation stability is found when cooling effect dampers are used rather than conventional box dampers to modulate the air flow. The comfort conditions of the building have been improved when use of multiple space temperature sensors has been extended along with incorporation of lighting and HVAC.

2.3.13 Description of General HVAC Systems

A Heating, Venting and Air Conditioning (HVAC) system is a set of infrastructures, devices and actuators that are devoted to the conditioning of the air in buildings, i.e., to the control of the temperature, humidity and CO_2 levels.

A variety of HVAC systems are found in office buildings which differ from each in size, occupancy activities, building age, geographic location and climatic conditions 44 etc. ASHRAE has categorized the air-handling unit systems as all-air system, all-water system and air-and-water system. HVAC systems could also be categorized on basis of energy efficiency into highly efficient, moderately efficient or generally inefficient categories.

(a) **Constant Air Volume Systems**: By maintaining the constant airflow single-duct constant volume systems change the supply air temperature in response to the space load. It is the simplest among all-air systems which consists of a supply unit serving44 when not required without affecting the operation of adjacent areas. They can also be designed as a multi-zone system with or without provision for reheat. They provide more space control for areas of unequal loading.

At a fixed cold air temperature the conditioned air is supplied from a central unit, which can be generally varied to reduce the amount of reheat required and the associated energy consumption.

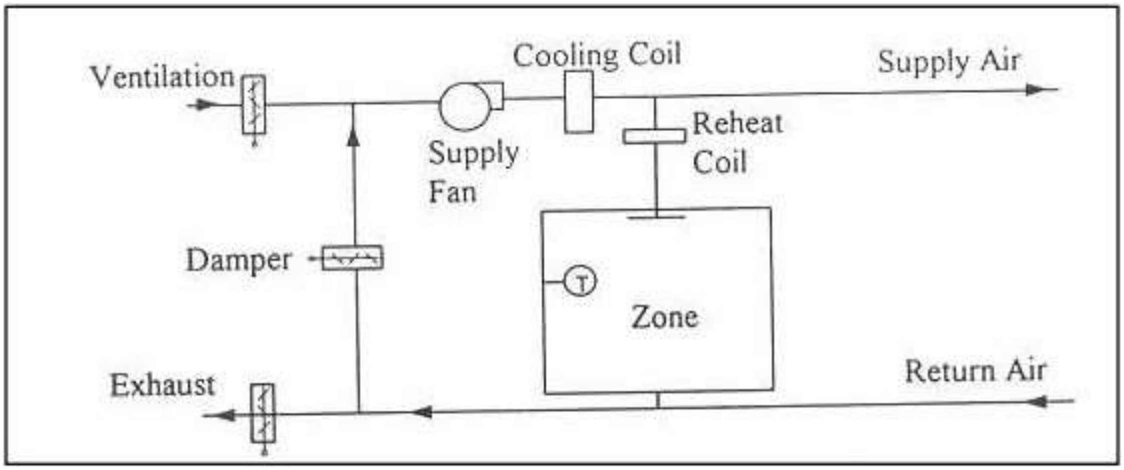


Figure 2.22: Constant air volume reheat system

Source: ASHARE. (2011)

The CAV-RH system as shown in figure 2.1 is a multi-zone system which uses a central supply fan to provide a constant volume of conditioned air to the reheat coils of multiple zones. To provide reheating for the purposes of maintaining the zone temperatures terminal heating coils are controlled by the individual zone thermostats. The demand for most zones is cooling rather than heating hence main supply i.e. fan which continues its operation during all scheduled occupied hours.

The supply of air temperature is fixed by the user and the design air flows are computed, based on the peak load for each zone. The building load calculation for CAV-RH system is supported on the peak load during occupied hours. But when zone cooling load is not at a peak, the required zone temperature is maintained by means of reheat coils. During unoccupied hours, a night set-back temperature is specified and the system operates in the same manner.

(b) Variable Air Volume (VAV) Systems: It is one type of all-air system, which provides cooling and heating through the air supplied by the system. The airflow in variable air volume system is generally regulated through a variable speed controller. The room temperature requirements are regulated with help of room thermostat which normalize the reheat coil control valve and the volume damper position47. The cooling need in the building is satisfied with a certain air flow at a certain supply air temperature with the help of variable air volume

(VA V) system under100 % outdoor air condition. To minimize the system energy use, an optimal supply air temperature can be set dependant on the load, specific fan power (SFP), chiller coefficient of performance, outdoor temperature and the outdoor relative humidity. Hung et al. conducted the study on the performance of flow controllers in VAV systems. Under the guidance of simulations and field measurements, it was found that the flow controllers were competent enough to provide a constant zone air temperature48.

(c) Variable -Air-Volume with Reheat: A VAV-RH system as shown in figure 2.2 is a multi-zone system, where the flow of air temperature is kept stable and the volume of air delivered to each zone is speckled according to the load oscillation in the zone. The thermostat in every zone modulates the terminal damper, allowing the static pressure builds-up in the distribution duct work when the terminal damper is closed and is used to modulate the VAV supply fan inlet vanes. If the modulating terminal damper is pre-set to allow for a minimum amount of cooled air into the zone for the purposes of ventilation requirements, some source of reheating is required to evade over-cooling which can be accomplished with the help of a coil placed downstream of the VAV terminal damper (VAV-RH).

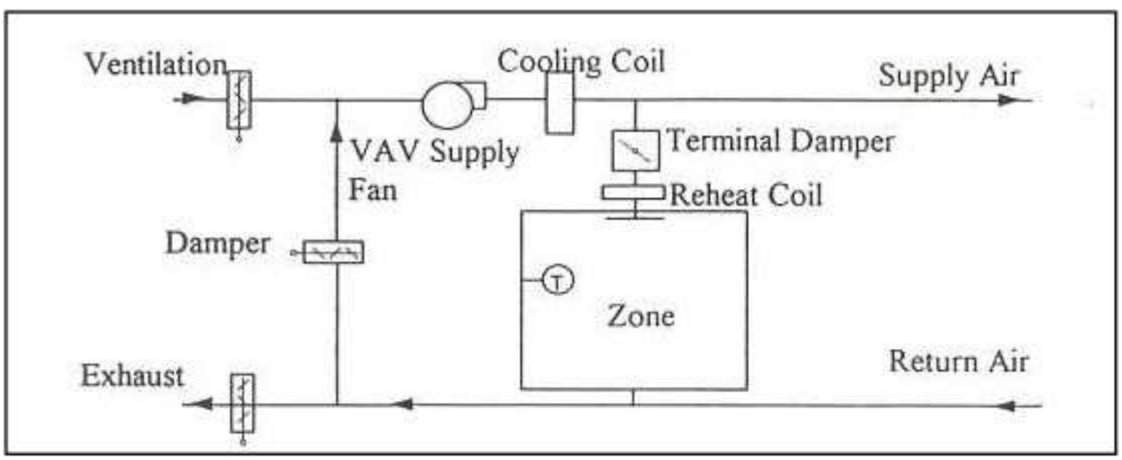


Figure 2.23: Variable air volume reheat system

Source: CBESC, 2008

(d) Split Systems: The name indicates that systems are "split" into two parts first is the air-handling units located inside the building and second is the condensing units located outside.

These systems can operate with or without distribution ductwork. Such systems are very well accepted in low-rise Public buildings because of their lower cost and ease of installation.

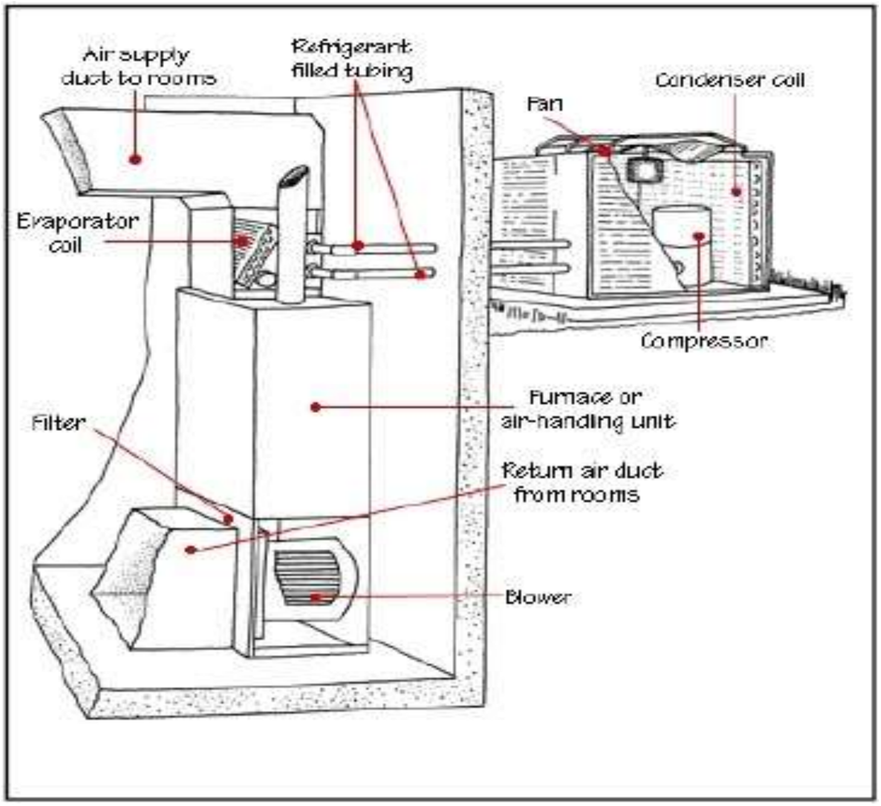


Figure 2.24: Split system
Source:CBESC, 2008

(e) Heat Recovery System: There are several types of heat recovery systems used in Public buildings. M ajor annual H VAC energy savings and cost savings may be realized in Public, industrial or institutional buildings by using the most viable heat recovery system. On the basis of major application at the source on the waste heat and its place of use (heat sink), heat recovery systems could be generally classified as: process-to-process, process-to comfort comfort-to-process; and comfort-to-comfort. The procedure in this kind of categorization could be in a power generation, cogeneration or steam generation system; internal combustion engine and /or turbine drive; cooling of engines or compressors; or any other industrial or Public process which can offer a source of waste heat and can not be openly part of the HVAC system providing comfort in the building.

2.3.14. Chillers

A chiller is a refrigeration system that cools water. Air conditioners and dehumidifiers stipulate the air whereas a chiller, using the identical refrigerating operations, cools water, oil, or some other fluid which is capable to cool a broad range of operations. Centrifugal chillers are applied for cooling huge buildings in a centralized air conditioning system. They use centrifugal impellers to move the refrigerant within the chiller circuit. In general refrigeration circuit, there is a compressor, a condenser, an expansion device, and the evaporator where as in centrifugal chiller, the impeller is the compressor which rotate at very high speed and is capable of pressurizing the refrigerant gas so as to increase its temperature.

Centrifugal chillers are usually designed for low-pressure refrigerants like R-123a. M odern centrifugal chillers make use of electronic microprocessors to control the diverse parameters and timing in order to run smoothly as these chillers sometimes surge when running are very sensitive to sudden changes in loads. There are other additional types of chillers which use screw compressors and reciprocating compressors and are usually smaller in size. These chillers are available in sizes ranging from 70 to 2,500 tons factory- assembled and up to 9,000 tons field-assembled. It is imperative to know that chillers are actually part of a complicated system, and any inefficiencies or over-efficiencies in pumps, cooling towers, and controls also have the potential to waste significant amounts of electricity, and even modest improvements in efficiency may yield substantial energy savings and attractive paybacks.

It is again important to select chiller efficiencies carefully because buying a too efficient chiller can raise costs so high, that the investment may not even yield a reasonable payback period. To maximize cost-effectiveness, it is recommended that the entire chilled water system should be analyzed in addition to exercising care in specifying the efficiency of the chiller itself. It is cost effective to replace an existing chiller with a new and more energy efficient chiller. In recent years, significant improvements in the overall efficiency of mechanical chillers have been achieved by the introduction of variable speed centrifugal chillers

The performance of a chiller can be measured in two ways i.e. capacity and efficiency. Capacity is the total refrigeration capability of the chiller. Efficiency is measured as the energy output per energy input. Some chillers are efficient at full the energy usage for cooling systems; the energy efficiency of the equipment should be improved under both full load and part load conditions.

The analysis of a five-star hotel for annual energy consumption was done using energy simulation software with experimental validation to identify the utility of chillers. The result of simulation has shown that an energy savings, up to 15.4 % annually, can be expected in the selected high-rise building if the chiller plant, especially the chilled water distribution system can be renovated with variable speed driven pumps.

Zuo et al. has developed a M odelica library for the advanced simulation of building energy and control systems. It offers benefits compared to conventional approaches for integrating models from different domains, and for simulating systems with largely varying time responses such as building energy systems and control algorithms. Zuo et al. demonstrated these features using an example of chilled water .

2.3.15 Energy Efficiency Techniques for HVAC System

Iqbal et al. investigated the impact of alternative energy efficiency measures on energy requirements in office buildings in hot-humid climate of Saudi Arabia. Different types of HVAC systems have been used to evaluate different feasible and practical operational energy efficiency measures using the energy simulation software of Visual DOE 4.0. HVAC play a majr role in the control the indoor envirnment. and energy management. Many energy efficiency measures can be applicable to the HVAC system of interest depending on the facility occupancy.

A. Operational Techniques for Energy Efficiency

(a) **Time-Scheduled Operation**: This technique consists of starting and stopping of the systems based on the time and type of day. Type of the day refers to weekday, weekends and any other days that has a different schedule of operation. This is the simplest technique in function to maintain and operate.

(b) **Optimization of Start/Stop**: M echanical system installed in buildings are not required 24 hrs therefore they should be shut down during un occupancy and restarted prior to occupancy in order to cool down or heat up depending upon the requirements on a fixed schedule. This feature has the capability to automatically start and stop the system to minimize energy required to maintain the desired environmental conditions during occupied hours. This technique was devised to achieve higher energy efficiency for reducing building utility costs by decreasing the time duration for the operation of the HVAC system supply fan (Gondhalekar, 2013). Theoretically, without sacrificing thermal comfort, a delay in start-up and an early shut down of the equipment can also potentially increase energy efficiency. The thermal capacity of the building mass allows for reduction in supply fan operation, therefore it is expected that more massive buildings have higher potential for getting benefit from this technique.

Start/stop optimization program can monitor outdoor and indoor temperatures and keeps the equipment on at optimized time to conserve energy (Gondhalekar, 2013). Stop time optimization is often incorporated to shut down the equipment before the occupants leave but not so early that the building becomes uncomfortable before the unoccupied mode of operation.

(c) **Advanced Thermostat Settings**: One way to conserve electrical energy in the building is to reduce the cooling requirement of each zone. Advanced thermostat can be programmed and has the facility to set desired room temperatures for different periods of the day and for different days of the week. They offer better settings than ON-OFF timers or manual shutdown. These types of thermostats can be programmed for the entire week within the range of 5°C or higher offset condition during the period of no occupancy to save energy in the building.

(d) **Demand Control**: It helps in the reduction of electrical load which will add to setup peak electrical demand. There can be numerous ways to reduce electrical load. The most commonly used method is by continuously monitoring and predicting the electrical load, when these predictions exceed the preset limits certain scheduled electrical loads are shut off to reduce the rate of consumption and predicted peak demand. To reduce the peak demand the loads are turned off on priority basis, so that the initial load drop action can be achieved efficiently.

(e) **Outside Air Economizer**: Using outside air economizer cycle can be a good energy efficiency technique. It utilizes the outside air to satisfy all or portion of requirement for building cooling. The outside air is introduced into the building through the mechanical system during the cooling cycle in replacement for the recirculation air.

(f) **Use of Single Water Pump**: It is found that during the non occupancy period of the building in summer season, the building cooling demand can be met comfortably with the help of a single chiller. By making use of single water pump with a higher chilled water temperature setting to 8°C can be used satisfactorily. Operation of the system with one chilled water pump can reduce the motor power around 7KW. There are additional advantages, such as reduction in pumping heat and improved chiller performance, due to the increased temperature of leaving chilled water.

(g) **Chilled Water Reset**: The energy generating chilled water in a reciprocating or centrifugal electric driven machines are predisposed by different constraints including the temperature of chilled water leaving the system. When chilled water temperature was selected at peak design times, under absence of effective humidity control, this temperature could be elevated during operating hours, in-order to satisfy the greatest cooling requirement.

(h) **Condenser Water Temperature Reset**: The other parameter which affects the energy consumption through air-conditioning system is the temperature of condenser water entering the machine. In application heat rejection system is designed to produce a precise condenser water temperature at peak wet bulb temperature. Optimization of system can be attained by resetting the temperature to its initial value by which the outdoor wet bulb temperature produces a lower condenser water temperature.

(i) **Night Purge**: The night purge technique was designed to reduce energy thermal energy requirement. During the unoccupied periods air conditioning is not required. For that period outdoor air is supplied into the building to cool the building for reduce the cooling load at the beginning of the occupancy. Fundamentals for applying this energy efficiency measure, the controller is required to monitor and control the outdoor and indoor air-temperatures as well as the supply fan. When the controller applies Night Purse the outdoor air schedule should allow the outdoor air damper to open fully.

The controller should activate the main supply fan when the outdoor air reaches a set temperature to blow outdoor air inside the building. The supply air continues until the outdor air temperature falls to a predefined temperature (Ascione, 2016).Thugh the night purse can be used fr this study, but its possible to rojecy in anther context for regulating this operation in warm & humid climate where the relative humidity may not exceed a specified value.

B. Design Techniques for Energy Efficiency

A comparative study of energy utilization of different building heating systems for diverse meteorological regions of Iran has illustrated that how heating systems in buildings have been stimulated. A research oriented computer code was developed where parameters like the climate, existing heating equipment in buildings, consumer behavior and their interactions were considered for simulating energy consumption in conventional systems for instance like heaters, radiators and fan-coils. The study has revealed that by changing heater to radiator it renders energy conservation up to 50% under all climatic condition and by changing radiator to fan-coil it decreases energy consumption in climatic condition with cold and dry winter (Ascione, 2016).

(a) **Cold Deck Temperature Reduction**: A regular way to reduce fan energy in dual systems is by reducing the set-point temperature of the cold deck which in turn reduces the air quantity which is required to meet the space loads. This type of energy efficiency evaluation was simulated for the agriculture building by reducing the cold deck set-point temperature. Reduced air handling energy requirements account for the modest saving in electrical fan energy.

(b) **Occupancy Sensors**: Studies show that in many cases, offices are not occupied for the majority of the working day, even though lighting and air handling for those offices are maintained throughout. By means of occupancy sensors, the energy associated with lighting and conditioning of these offices during unoccupied periods could potentially be abolished. The application of occupancy sensors to reduce air handling and lighting energy usage for only the office areas can be simulated by multiplying the DOE-2 office occupancy schedule defector by 70%, 50% and 30% to reresent these different occupancy schedule defector by 70%, 50% and 30% to represent these different occupancy levels77. By using occupancy sensors fr reducing air handling and lighting energy many significant savings results are attained but there is of course a capital and maintenance expenditure associated with implementing this measure.

(c) **Dead Band**: Dead band programs set the heating and cooling design temperatures so that they cannot be separated by a dead band where neither heating nor cooling is required 78. For example by conducting an experiment in an office set at 18°C for heating and 25°C for cooling there is a 7°C dead band. The temperature in the dead band is allowed to drift and no energy except fan power for fresh air is consumed by the HVAC system.

A cautious control of HVAC systems can result in significant energy savings. For example electricity can be saved by reducing pump or fan operation time and intensity. Reduction of outside air intake will also save the energy used by cooling and heating equipement 79. An econmizer section on air handling units by using outside air free cooling reduces the load on the cooling equiepment.

2.4: Study Gap

The twin issue of scarcity of electricity supply (Ntsoane, 2005) and high carbon emission by building is a major concern in Nigeria. This key concern has reinforce the importance of energy efficiency as a way of reducing emission of carbon dioxide to the atmosphere while also improving access to electricity via demand reduction.

Towards this end it is worth noting that despite the fact that energy efficiency efforts has been frustrated by the perceived low price, institutional barriers, resistance to change and lack of overall investors' confidence due to lengthy payback period. Nigeria energy efficiency strategy underlines its commitment to reduce demand reduction. Energy efficiency studies therefore becomes a strategic importance in Nigeria towards achieving energy security

The building sector consumes 30-40% of world's energy and is therefore a natural focus in energy efficiency (UNEP, 2007). It is however notable that most of the buildings energy consumption period (Junilla, 2004). It is therefore logical that any energy and by extension electricity demand reduction in building must lay emphasis on the operation and occupation period.

In Nigeria, energy efficiency studies in HVAC systems is lacking, as all existing researches are geared towards renewable energy methods with little or no attention given to pattern and way of energy consumption by end-use facilities. Also, there is no existing qualitative or quantitative data on the effect of maintenance of HVAC systems and its energy implication in the Hotels in Nigeria nor in Owerri the research area. Hence, this research seeks to establish both qualitative and quantitative data of the effect of maintenance of HVAC installation and its energy implication in the area of study. The focus of this study is further supported by Holness (2008), who asset that hotel buildings forms the bulk expenditure in the building industry.

Also, in Nigeria and Africa at large, the focus of energy efficiency research in buildings has mainly been in the area of renewable and green building implementation as evidenced by Reinnk (2007) and Ntsoane (2005).

A sustainable approach to the energy consumption of HVAC system in buildings can lead to large energy savings. Much research has been done on sustainability but none has so far presented conclusively the exact saving potential that can be offered by a sustainable energy consumption of the HVAC system in Nigeria.

A refocusing from the potentials of renewable energy use to a sustainable energy consumption of HVAC system which have proven to be a major end-user energy demand facility will help in reducing the pressure on the energy demand. This is supported by research clams that link energy saving to retrofitting of several components. It is demonstrated by assertions by Wendes (1994) that use of various fan volume control methods at an average of 60% peak air flow in VAV systems lead to energy saving of 13% to 78%.

In addition HVAC energy efficiency research has often been simulation based only, and geared towards heavy commercial uses as evidenced by Matthew *et al* (2002); Buys (2002) and Claasen (2003). Research in the sustainable energy consumption of HVAC system in buildings that will not only be simulated but further explore the type and installation condition of the HVAC system in buildings in Nigeria has remained untouched, leading to a gap in knowledge. In addressing this issue, this research focuses on existing Hotel buildings in Nigeria

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

This chapter describes the research procedure, methods and tools used in the study. It sets out to bring in various stages and phases that were taken during the course of this study. The chapter describe the research design, target population, data collection and the method of data analysis.

3.1 Research Design

According to Opoku, (2005) described research design as the arrangement of research problems in to a structural format that will subsequently guide the researcher of how to collect and analyze his research data. Basically, research design is an outline of what the researcher intends to do, beginning from writing of objectives, hypotheses and its operational implications to collection and analysis of data. Therefore, the nature of the hypothesis, variables involved, and the constraints of the real world all contribute to the selection of design. A good research design, is a prerequisite for a good and comprehensive research as affirmed by Creswell, 2009, 2012, 2013 and Opoku, 2005).

Categorically, there are different research design, (i.e. qualitative descriptive research design and quantitative descriptive research design. These two mentioned research design are commonly used in research. The set of data needed for this study is both qualitative and quantitative in nature. Therefore, the most appropriate design for this study is a mixed research design approach. A mixed design approach according to Bian (2011), focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. The choice of this research approach is based on the nature of the hypothesis, variables involved as well as the Constraints of the real world

3.2 Population, Sample and Sampling Technique

3.2.1: Population of the Study

A population can be defined as the complete set of subjects that can be studied: people, objects, animals, plants, organizations from which a sample may be obtained (Shao, 1999). Simply put, population is the entire group or set of cases that a researcher is interested in generalizing. Simply put, population is the entire group or set of cases that a researcher is interested in generalizing.

Therefore, the population of this study constitutes all the hotels in Owerri municipal. According the Jumai Hotel reservation outlook, there are a hundred and sixty-one (161) hotels within Owerri municipal even though are several others within the state (see google map attached in appendix III).

3.2.2: Sample, Sample size and techniques

Sampling is the selectin of part of the whole population for study whereas a census is the study of the whole population (Rao, 2000). The techniques/Strategies for determining sample size according to Glenn (2013) are

i. Using of census for a small population
ii. Using a sample size of a similar study
iii. Using published table
iv. Using a formula to calculate the sample size (e.g. Yaro Yamani Formular)

O'Leary (2004) further underlines the importance attached to proper definition of population being studied. In this particular study, the population being studied are public buildings with particular interest in the Hotels in Owerri Municipal. In the context of this study the public buildings allowed relatively unrestricted access and these could include educational and research facilities, car parks entertainment halls and offices. However dues to lack of access and the need to maintain uniformity of data the study opted for only Hotel buildings in owerri municipal. There are one hundred and sixty-one (161) hotels (see appendix III) within owerri municipal. Hence the study

However, Cochran's sample size calculation procedure was employed to determine the appropriate sample size in this study. To do this, Cochran's return sample size formula is first determined using the formula presented in equation 1 (Cochran, 1977)

$$\mathbf{N_0= (z^2pq)/d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

Where;

n = the desired sample size

z = the ordinate on the Normal curve corresponding to or the standard normal deviate, usually any of the following determined based on the 'margin error formula'

i) A 90% level of confidence has $\alpha = 0.10$ and critical value of $z\alpha/2 = 1.64$.

ii) A 95% level of confidence has $\alpha = 0.05$ and critical value of $z\alpha/2 = 1.96$.

iii) A 99% level of confidence has $\alpha = 0.01$ and critical value of $z\alpha/2 = 2.58$.

iv) A 99.5% level of confidence has $\alpha = 0.005$ and critical value of $z\alpha/2 = 2.81$.

P= the proportion in the target population estimated to have particular characteristics (normal between the range of 0.1 to 0.5

q = 1.0-p

d = degree of accuracy corresponding to the confidence level and Z selected.

For the purpose of this study, a confidence level of 95% was adopted owing to the fact that the questionnaire was geared towards evaluating perception on monitoring.

Consequently, the sample size is determined as thus,

z = 1.96, d = 0.05 where p = 0.5, q =0.5

N_o= (1.962X0.5X0.5)/ (0.05)2= 384

z = 1.96, d = 0.05 where p = 0.5, q =0.5

N_o = (1.962X0.5X0.5)/ (0.05)2= 384

Therefore a total of three hundred and eighty-four questionnaires were administered to the various respondent's staff and occupants of the Hotels inclusive).

Thus, after calculating using Cochran's formula for sample size of 384 respondents (see Equation 3.1), the number of hotels from which the various respondents were drawn was deduced from the formula for calculating sample sizes given a known population.

$$\mathbf{n= (N/ (1+N (\alpha^2)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. (3.2)$$

Where;
n = the desired sample size
N = the Known Population size
Given that the number of hotels in Owerri Municipal is 161 Hotels, the formula below can be adopted. Consequently, the number of hotels is determined as thus,

N = 162, α = 0.05
Hence,
Sample size n = [(161)/ (1 + 161 $(0.05)^2$) = 114.7
Hence = 114.7
Thus the study considered 115 Hotels within Owerri Municipal and as such the three hundred and eighty-four (384) respondents were drawn from this one hundred and fifteen (115) hotels. The Table 3.1 shows the major roads linking the various areas in Owerri Municipal and the corresponding areas along the road where the various hotels for this research were selected.

Table 3.1: Major Roads Linking Various Areas In Owerri Municipal Where The Hotels Were Selected

S/N	MAJOR ROADS IN OWERRI MUNICIPAL	Area of coverage	Number of hotels to be sampled
1	Port Harcourt Road	Obinze, Avu, Oforola and Ihiagwa, New Owerri	20
2	Naze-Aba Road	Nekede, Agbala and Ulakwo	19
3	Egbu Road	Egbu, Awaka, Ihitta and Emekuku	19
4	Owerri-Orlu Road	Akabo and Obazu, ikenegbu, Prefab, Akwakuma, orlu	19
5	Okigwe – Road	Orji, and Amatta,, Ugwu orji	19
6	Irete-Onisha Road	Orogwe, Amakohia and Ogbaku Egbeada	19
	Total		**115**

Source: Google map, 2018

In choosing the population frame for the respondents and hotels, for this study, multi-stage sampling technique was employed. In this case, samples are selected in stages (i.e. selection of the areas to be studied first, followed by hotels and then respondent). The respondents are the Staff of the hotels this approach is so in a bid to gather pertinent information concerning the management, scheduling, controls, operations and maintenance of the HVAC systems. . Nineteen (19) Hotels were selected from each of the five (5) areas identified from the connecting roads within Owerri Municipal with exception of the Port Harcourt Road where twenty (20) were selected as it links more areas.

3.3 Data Collection Methods

As earlier stated in section 3.1 of this work, that the data set needed for this research is both quantitative and qualitative (i.e. Mixed design research). Applying the mixed research design approach in collating the data set needed to address the research objectives and questions will involve the following (arranged according to the research questions):

i. What are the types and characteristics of HVAC installation commonly used in the study area?

This question sought descriptive knowledge of the HVAC systems installed in the facilities/buildings in the area of study. The common type of HVAC systems commonly use in the Hotels Owerri Municipal and the functionality status of the various component of the HVAC system. The approach towards answering it is thus via observation and interview as it was the most suitable mechanism to collect qualitative data needed.

ii. To what extent does HVAC installation maintenance affect energy consumption of the system in the Hotels in Owerri Nigeria?

The essence of this question was to establish the frequency of maintenance, the factors that inform the maintenance of the HVAC system and the effect of the maintenance on the energy consumption Therefore, this question required both qualitative and quantitative data. Qualitative data needed were garnered using physical observations and focus group discussion whereas the qualitative data needed were garnered using questionnaire.

iii. What are the variations of the HVAC installations in the study area with the standard requirement as stipulated by ASHRAE Standard 62.1 and 62.2?

The objective of this question was to determine how and to what extent the HVAC systems installed in Owerri Municipal vary from the provisions of ASHRAE standards 62.1 and 62.2 respectively. This question requires qualitative data only. Data here, were gathered using a well-structured Checklist that stipulates the standard requirement for HVAC installations.

vi. What are the key strategies for saving or reducing energy wastage using the HVAC installation system in Owerri Nigeria?

This question were best answered by a quantitative and qualitative approach to measure the suitability of the various energy saving strategies identified from literatures as it applies the area of study. Thus the approach to answering this question is totally reliant on literature review. Hence the major findings from the quantitative and qualitative approaches will combined, corroborated, and validated using triangulation techniques.

iv. Does the Model Predictive Control (MPC) HVAC model for simulation have the capability of predicting and optimizing of Energy Consumption of HVAC Installation

This question were set out to determine the MPC algorithm that were used to design the Model so it can accommodate the peculiarities of the hotels and the possible disturbances to thermal comfort while predicting and optimizing the energy consumption. Model Predictive Control (MPC) simulation model was used to predict the energy consumption of the HVAC Binary and MPC Systems as it also take into cognizance various disturbance for thermal comfort. The Simulation model is built using the MATLAB software interface and is consistent with Grey-box model of ASHRAE Classification of Modeling of Building and the HVAC System. Model simulation was considered to be most suitable mechanism to collect the data needed as the models are calibrated using real data gathered on field and estimated using system identification methods to measure HVAC energy consumption

The general approach adopted in answering the research questions can be summarized in Table 3.2.

Table 3.2: Approach Adopted In Answering the Research Questions

Sub Questions	Details Of Data Required	Data Collecting Instrument	Data Source	Method Of Analysis
Q1. What are the types and characteristics of HVAC installations commonly used in Hotels in Owerri Nigeria?	Description of the current standard, practice and type of HVAC system in the selected hotels	Physical observation and A questionnaire structured to be consistent with the literature review	Building operators/staff of the hotels	Narrative analysis based on theoretical framework and a descriptive statistics using weighted mean
Q2. To what extent does HVAC installation maintenance affect energy consumption of the system in the Hotels in Owerri Nigeria?	The details of the maintenance of the components of the HVAC systems measured in their order of severity. And Comparism of the frequency of maintenance of the various HVAC component to identify the component given the highest priority	A physical observation guided by the use of the checklist and a well structure questionnaires which is consistent with literatures	Building staff/operators, , Document e.g HVAC manuals	Narrative analysis based on theoretical framework, descriptive statistics using weighed mean
Q3. What are the key strategies for saving or reducing energy wastage using the HVAC installation system in Owerri Nigeria?	Description of the current HVAC energy control strategies and measure that can promise a better control of energy consumption.	Observation and responses from the questionnaires	maintenance officers, a walk through in Hotel HVAC contents	Narrative analysis based on theoretical framework, descriptive statistics using weighed mean
Q4. Are there variations between HVAC installations in	variations of the HVAC installations in the study area with the	A checklist structured to be consistent with the ASHRAE	A walk through with The hotel management or	Narrative analysis based on

the study area and the standard requirement as stipulated by ASHRAE Standard 62.1 and 62.2?	standard requirement as stipulated by ASHRAE Standard	standard and existing literature	maintenance officer	theoretical frame work
Q5. Does the Model Predictive Control (MPC) HVAC model for simulation have the capability of predicting and optimizing of Energy Consumption of HVAC Installation?	Predict the energy consumption of the HVAC installation given the details of the HVAC installations and the	A Model Predictive Control Software was used for the Simulation of the thermal indoor environment and consequently predict the energy consumption	The Nigerian metrological services (for information on temperature, RH and Humidity ratio), NREEEP (grid and energy distribution)the Hotel operative (occupancy related disturbance) And the HVAC Manuals(information of the HVAC) all for the MPC HVAC build up build up	Decretive statistic using weighted mean and charts t represent the result of the findings

Source: Survey 2018

In addition, with the primary data listed earlier, the following secondary data were collected:

i. National Energy Efficiency Action Plan (NEEAP): Information about the nation's goal on energy efficiency and sustainability in Nigeria.

ii. The National Renewable Energy Efficiency Policy (NREEEP) this is a department under the Ministry Of Power Federal Republic Of Nigeria. These ministries/Departments were provided Grid and energy distributor related disturbances that were used for the MPC Simulation build up

iii. Nigeria Meteorological Services: This agency provided information on weather and temperature, relative humidity ratio of Owerri municipal was used for the MPC simulation build up.

3.4 Data collection and Instruments

3.4.1 Design and Administration of Questionnaires

The questionnaire were structured to be consistent with the major aspect of the research such as the research questions and the objectives of the research. The questionnaire was administered to occupants and/staff of the hotels. The questionnaire were used to investigate issues relating the management, operations, control, maintenance and installation of the HVAC systems in the Hotels and was however, be was prepared in five point Likert scale. A brief summary of the key issues interrogated by the questionnaire are discussed below

i. Management: Questions in this section explored issues concerning the ownership and use of buildings, accountability for energy management, energy consumption budgets and energy conservation measures in the hotels.

ii. Operations: Schedules of operation. The questionnaire sought to establish the buildings and HVAC systems schedule of operation in hours per day and days per week. In addition , it also seek to know if the operation of the HVAC system is in any way liked to the operation of the whole building. The duration of use of the HVAC systems by the occupants when they lodge the hotels was also be sought for. Regarding the operations the questionnaire also sought to establish the pattern of the facility use even with seasonal variation throughout the year.

iii. Controls: occupants and staff were also be asked if they are familiar with the control setting /operation of the HVAC system and if there is any instruction or pre-couching on the use of HVAC by the hotel attendance when they lodge in them.

iv. Maintenance: the staff were ask if there are energy consumption meters place for the building, further inquiries were made to identify if this energy consumption meters have sub meter for different installations in the building. The questionnaire sought to establish details of maintenance planning and the type of maintenance arrangement used in the facilities. The questionnaire also seeks to investigate the response time need to correct faulty HVAC system. Issues such as age of equipment or retrofit and whether the maintenance management was done in-house or outsourced were asked in the questionnaire.

v. Installation and commissioning: the questionnaire seeks to establish if the HVAC systems have maintenance manuals, commissioning hand-over notes and as built drawings.

3.4.2 Checklist

A checklist was adopted to investigate if there is variation with the HVAC system installation in the hotels from the general provision of ASHRAE Standard 61.1 and 62.2 for thermal comfort and HVAC installations. In view of this, the checklist was used to investigate the HVAC system installations conformity to the following key aspects:

i. The installed Equipment

ii. The airflow through the heat exchanger

iii. Water flow through the water exchanger

iv. System Documentation

v. Customer education

3.4.3 Walk-through survey/Physical or Direct Observation.

It involves observing the workplace relationships among workers/people and work processes/procedures and recording, describing, analyzing and interpreting the research subjects‟ behavior (Okolie, 2011). The observations/walkthroughs was conducted during the administration of the checklist in the hotels to physically observe the condition of the HVAC installations in the various Hotels. The visual documentation of these situations were captured in photographs which were presented as plates.

3.4.4: HVAC Energy Consumption Simulation Using MPC

The Energy consumption of the HVAC system was predicted with the use of the Model Predictive Control simulated. This HVAC Model Predictive Control simulation is a system based software built with a MATLAB interface. It belong to the ASHRAE class of the Grey-box Simulation Model.

Inputs to the models for prediction and calibration include the most significant climatic disturbances and occupancy related disturbances, as well as controllable inputs such as the thermal energy delivered by the HVAC. Common inputs to the thermal model include outdoor temperature, solar radiation, internal gains (solar or occupancy related) and heating or cooling energy delivered by the HVAC. In order words, the three main categories of measured disturbances affecting an MPC problem for HVAC system and building energy management:

i. Climatic disturbances (e.g., external temperature, humidity ratio, Relative Humidity (RH), wet-bulb temperature, dew-point temperature, solar radiation, wind velocity, ground temperature.

ii. Number of occupants related disturbances (e.g., occupied/unoccupied, variation in the scheduled comfort set-points, internal heat gains/loads, adjacent zones set-points).

iii. Grid and energy distributor related disturbances

The measured response is generally the indoor air temperature. The simulation process offers a great benefit of predicting energy consumption using a computer based software. However the process can be cumbersome, and as such six (6) of the Hotels each of the area were simulated and inferences were drawn from it.

3.5 Method and Instrument of Data Analysis

From the data collected, the results were analyzed to determine the direction of the study. Data obtained from the interview were analyzed using Content Analysis that is, presenting who say what, to whom, why, to what extent and with what effect in quantitative or qualitative manner. The techniques or processes involved in this analysis were:

1. Documentation of the data and the process of the data collection

2. Organization/categorization of the data into concept

3. Connection of the data to show how one concept may influence the other

4. Corroboration/legitimization by evaluating alternative explanation, disconfirming evidence and researching for negative cases

5. Representing the account (reporting the finding).

The data collected for this study was subjected to various statistical analyses using the computer based software "Statistical Package of Social Sciences" (SPSS). The results of the analysis were presented in the forms of table for the purpose of easy comparism and clear expression of the findings. Also, Data obtained through questionnaires were analyzed using mean score, standard deviation, Relative Importance Index and t-test to test the research hypotheses. All analysis was done using Statistical Package for Social Science (SPSS) version 19. Further, the analyses were presented in tables and chart.

The Mean Score were computed using this formula:

Mean-score = $\mathbf{(X_1W_1+X_2W_2+X_3W_3+ \ldots\ldots\ldots\ldots X_nW_n)/N}$ ....(3.3)

Where

W = Weight of answer choice

X = Response count for answer choice

N = Total Numbers of the Respondents

From the computation, most significant constraint factor in a subset was one with the highest Mean-Score value. The factor having an average or higher value is considered significant as shown in Equation 1, while the insignificant factors are identified using Equation 2.

Significant constraint factor: $MR > 2.5$ ………………………. (1)

Non-significant constraint factor: MR < 2.5 ……………………….. (2)

Where:

1 < M< 5 on 5-point Likert rating scale

Based on the mean score (M) values of the constraints in a given set, the variable were ranked or rated.

The standard deviation was computed using this formula:

$$\sqrt{EFi(xi - X)/EFi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

Where:

X = Mean

Efi= Means the frequency of the ith item

Relative importance indices (RII) were also used to rank Areas of Emphasis during Project Monitoring. The Relative Importance Index (RII) was calculated for each document according to their frequency of use as suggested for use by Memon et al, (2006) and Othman et al, (2005)

RII ranges between zeros to one. The five-point likert scale ranking was transformed to relative Importance Indices (RII) for each of the construction contract documents. The weighted average for each item was determined and ranks were assigned to each item, representing the perception of the respondents

Relative Importance Index (RII)

$$= \frac{\sum \boldsymbol{fx}}{\sum \boldsymbol{f}} \times \frac{\mathbf{1}}{\boldsymbol{k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

Where,

$\sum$fx = is the total weight given to each attributes by the respondents.

$\sum f$ = is the total number or respondents in the sample.

K = is the highest weight on the likert scale.

Results are classified into three categories as follows (Othman et al, 2005) when;

$RII<0.60$ -it indicates low frequency in use

$0.60 \leq RII<0.80$ -it indicates high frequency in use.

$RII \geq 0.80$ –it indicates very high frequency in use

Finally, the data analysis were presented table's and chart's form. However, the analyses were aided using the SPSS (i.e. Statistical Package for the Social Sciences) software.

3.5.1 Validity and Reliability of the Instrument

Validity and Reliability are used to ensure that the research outcome is accurate and credible. Validity is the degree to which a thing measures what it tends to measure. That is, it is the extent to which the results of a study can be verified against its objective (Okolie, 2011). The instruments especially the questionnaires and interview guide was subjected to content validity test by distributing the instrument to the project supervisor and some key professional in this field of study to validate the questions..

The use of multiple sources of evidence specifically direct observation, interview, checklist, Model simulation and questionnaire entrenched the construct validity and reliability in this study and ensured a triangulation of finding and an eventual high level of accuracy. This is referred to as 'convergence of line of inquiry' by (Yin 1994).

Conversely, Okolie (2011); Anol (2013) defined reliability as the degree to which the measure of a construct is consistent or dependable. That is, the degree to which the findings of a research is independent to accident circumstance. Simply, reliability measures consistency and not accuracy.

CHAPTER FOUR

4.0: PRESENTATION, DATA ANALYSISAND DISCUSSION OF FINDINGS

This chapter presents the results, analysis, discussions and findings of the data collected. Analyses were done according to the instrument used for data collection. Based on this, this chapter is structured into these sections:

i. Presentation and analysis of the questionnaires
ii. Presentation of the checklist observation
iii. Presentation of the algorism of the Model Simulation using Model Predictive Control (MPC)
iv. Test of the Hypothesis
v. Summary of findings

4.1 PRESENTATION AND ANALYSIS OF QUESTIONNAIRE

A total of three hundred and ninety questionnaires were administered to respondents within the area of study. The percentages of responses are presented in Table 4.1 below. From the table it can be gathered that a total of three hundred and forty-two questionnaires were received adequately filled giving a percentage response of 87.7%.

Table 4.1 Questionnaire administered

Questionnaires	Frequency	Percentage of (%)
Number returned	342	87.7
Numbers not returned	48	12.3
Total	**390**	**100**

Source: Field Survey, (2018)

4.1.1 Respondents Profile

Table 4.2 Respondents Profile

S/N	Variables	Characteristics	Frequency (No)	Percentage (%)
1	Gender	a) Male	266	77.7
		b) Female	76	22.3
		Total	**342**	**100**
2	Age Group	a) Below 20yrs	22	6.3
		b) 21-30yeras	156	45.7
		c) 31-40years	118	34.6
		d) 41 and above	46	13.4
		Total	**342**	**100**
3	Job Description	a) Staff	295	86.3
		b) Contractor/Consultant	47	13.7
		Total	**342**	**100**
4	Position	a) Front Desk Clerk	12	3.4
		b) Supervisor of guest Services	46	13.5
		c) House Keeping Supervisor	34	9.9
		d) Kitchen Manager	6	1.8
		e) Executive Chief	56	16.4
		f) Maintenance officer	188	55.0
		Total	**342**	**100**

Source: Field Survey, (2018)

From the result of the analysis, the profile of the respondents is as presented in Table 4.2. Form the Table it can be deduced that a greater percentage of the respondent were male (77.7%) while only 22.3% were female. Similarly, with regards to the age bracket of the respondents, a large percentage of the respondents were between the ages brackets of 21-30years (45.7%). This was followed closely by those within the age bracket of 31-40yrs (34.6%); 41 and above (13.4 %) and below 20years (6.3%).

For the respondents' status in the hotels studies, 86.3% of the respondents were the staff of the hotel with only 13.7% of the respondents attesting that they were contractors/consultants to the hotels studied. Also it can be deduced that a larger percentage of the respondents 55.5%

were the maintenance officers in the Hotels. However the distribution of other workers are; 16.4% are the Executive Chief; 13.5% are the Supervisor of Guest Services; 9.9% are the house keeping supervisor, while 3.4% are the Front Desk Clerks. Details are as presented in the Table.

4.1.2 Data Sheet building Audit

Table 4.3 Data Sheet building Audit

S/N	Variables	Characteristics	Frequency (No)	Percentage (%)
2	Owner of the Hotel	a) Government(Central or Local)	52	15.2
		b) Commercial Private	20	5.8
		c) Public Trust (University, Public Society, government trust)	23	6.7
		d) Private Individual	247	72.3
		Total	**342**	**100**
2	the building used for a different purpose other than a Hotel before now:	a) Yes	108	31.6
		b) No	190	55.6
		c) Don't Know	44	12.8
		Total	**342**	**100**
3	Original Use of the Building	a) Entertainment or assembly hall	76	70.4
		b) Offices or banking hall	32	29.6
		c) Library	-	-
		d) Storage and warehouse	-	-
		Total	**108**	**100**
	Age of building or age of last refurbished with regards	a) 0-10years	176	51.5
		b) 11-20years	133	38.9
		c) Over 20years	33	9.6
		Total	**342**	**100**

Source: Field Survey, (2018)

The details of the Hotels were assessed and the results is as presented in Table 4.3. From the Table it can be deduced that a larger percentage (72.3%) of the Hotels in Owerri are owned by the Private individuals. This is closely followed by 15.2% owned by government (Central or Local), 5.8% of the hotel is owned by Commercial privates.

Enquires on original purpose/use of the building, and the result shows that over 55.6% of the buildings were constructed originally as hotels. However, 31.6% of the respondents attested to the fact that some of the buildings were not constructed originally for Hotel purpose with 12.8% of the respondents claiming not to know anything about the original use of the building. In view, the analysis also indicated that for the buildings which were not originally built as hotels, 70.4% of them were initially built as an entertainment and assembly halls whereas, 29.6% of them were originally offices.

Still on the peculiarities of the hotel building, the age of the hotel and it was deduced that most of the Hotels in Owerri assessed (51.5%) were within the age bracket of 0-10years; 38.9% were within 11-20years while only 9.6% were above 20years of age.

4.1.3 Building Physical Characteristics

Table 4.4 Building Physical Characteristics

S/N	Variable	Option	Frequency (No)	Percentage (%)
2	total number of Floors (above ground floors)	a) 0- 3	289	84.5
		b) 4- 5	53	15.5
		c) 6 and Above	-	-
		Total	342	**100**
	number of guest rooms in the Hotel	a) 0-10	-	-
		b) 11-20	11	3.2
		c) 21-30	102	29.8
		d) 31- 40	169	49.4
		e) 51 and Above	60	17.6
		Total	342	**100**
2	Hotel Having any Building Management System	a) Yes	98	28.7
		b) No	179	52.3
		c) Don’t Know	65	19.0
		Total	342	**100**
3	ever been any energy audit conducted for the Hotel	a) Yes	74	21.6
		b) No	234	68.4
		c) Don’t Know	34	10.0
		Total	342	**100**

Source: Field Survey, (2018)

The physical characteristics of the hotels were assess and the result of the analysis presented in Table 4.4. From the Table it can be deduced that 84.5% of the hotels had a total of 0-3 floors above ground floor. While only 15.5% had a total floor of 4-5 floors above the ground. With regards to the number of guest rooms, a larger percentage of the hotels 49.4% had guest room ranging from 31-40rooms, followed by 29.8% that have 21-30 guest rooms. Details are as presented in the Table.

It can also be established that most the hotels do not have energy management system as opined by 52.3% of the respondents. Also it can also be deduced that most of the hotels have never conducted any energy audit (68.4% attested) other details are as presented in the Table.

4.1.4 Building Operating Characteristics

Table 4.5 Building Operating Characteristics

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	hotel operate throughout the whole year	a) Yes	314	91.8
		b) No	28	8.2
		c) Don't Know	-	-
		Total	**342**	**100**
2	Occupant have the privilege to operate the HVAC at all times through the day	a) Yes	324	94.7
		b) No	18	5.3
		c) Don't Know	-	-
		Total	**342**	**100**
3	how many hours is an occupant privileged to operate the HVAC in a Day	a) 0-3hrs	6	1.8
		b) 4-6hrs	24	7.0
		c) All through the night 9.pm-6.am	312	91.2
		Total	342	**100**
4	operational logs including repair, maintenance summary available	a) Yes	98	28.7
		b) No	232	67.8
		c) Don't Know	12	3.5
		Total	**342**	**100**
	Are HVAC manual available	a) Yes	113	33.1
		b) No	151	44.1
		c) Don't Know	78	22.8
		Total	**342**	**100**
	Are all the rooms occupied every day of the week	a) Yes	288	84.2
		b) No	54	15.8

		c) Don't Know	-	-
		Total	**342**	**100**
	Are the electricity bill for the building available	a) Yes	305	89.2
		b) No	37	10.8
		c) Don't Know	-	-
		Total	**342**	**100**
5	specific staff assigned to management of energy or plant operation	a) Yes	76	22.2
		b) No	266	77.8
		c) Don't Know	-	-
		Total	**342**	**100**
6	type of HVAC system is in use in the building	a) Centralized system	10	2.9
		b) Room Conditioning Unit Packaged HVAC equipment	332	97.1
		Total	**342**	**100**
7	Type of room packaged HVAC equipment	a) Radiators/ Convectors	-	-
		b) Roof Top Units	55	16.1
		c) Self-Contained Air Conditioners and thro wall heat pumps	189	55.3
		d) Remotely cooled contained Air Conditioners and heat pumps	98	28.6
		e) Heat Pump Loop System	-	-
		f) Direct Fired Heating Units	-	-
		Total	**342**	**100**

Source: Field Survey, (2018)

The operation characteristics of the building with regards to the HVAC system was assessed and the analysis of the respondents' opinion is as presented in Table 4.5. From the Table, most of the hotels (91.8%) operate throughout the year. Also, with regards occupants/customers privilege to use the HVAC at all-time of the day, 94.7% of the respondents attested that occupants/customers are at liberty to use the HVAC system any time of the day in the Hotel. Also, enquiry on the number of hours an occupants must be provided with electricity to use the HVAC system in the hotel was conducted and the result shows that, 91.2% of the respondents attested that such privileges are more certain throughout the night.

With regards to the tendency of having the rooms maximally occupied in the hotel, 84.2% of the respondents attested to the act that most of the hotels are maximally occupied every day of the week. The researcher sought to know if there are HVAC manuals provide at the hotel rooms to guide occupants/customer in using the system, the result revealed that a larger number of the hotels (44.1%) do not available such manual; 33.1% claim to provides while 22.8% of the respondent claim not to be aware of such provision.

Also, the respondent were asked the type of HVAC systems in use in the Hotels and to that, 97.1% attested to the fact that the HVAC were majorly Room Conditioning Unit Package HVAC equipment. Further enquires on the type of packaged HVAC equipment in use in the hotels revealed that the most common type use is the self-contained air conditioners and thro wall heat pumps (55.3%). This was closely followed by the remotely cooled contained air conditioner and heat pumps (28.6%) and Roof top Units (16.1%)

Finally from Table 4.5, it can be deduced that there are rarely any specific staff assigned in the hotels to manage the energy or plant operation as attested by 77.8% of the respondents. Other details are as presented in the Table

4.1.5 Energy Management in the Hotels

Table 4.6 Energy Management of the Hotels

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	Who is responsible for energy management	a) Building operators	198	57.9
		b) Maintenance Contractors	132	38.6
		c) Nobody	12	3.5
		Total	**342**	**100**
2	Is there an Energy consumption budget	a) Yes	68	19.9
		b) No	218	63.7
		c) Don’t Know	56	16.4
		Total	**342**	**100**
3	Fraction of energy budget constituted by HVAC system consumption	a) Less than ¼	-	-
		b) ¼ to ½	10	2.9
		c) ½ to ¾	12	3.5
		d) Over ¾	46	13.5
		e) Don’t Know	274	80.1
		Total	**342**	**100**
4	Does the building management review or carry out analysis of energy consumption	a) Yes	232	67.8
		b) No	65	19.0
		c) Don’t Know	45	13.2
		Total	**342**	**100**
5	what time intervals are the energy consumption review carried	a) 0 to 6months	-	-
		b) 7 to 12months	31	9.1
		c) 13 to 1months	109	31.9
		d) Over 18 months	135	39.5
		e) Never done	67	19.5
		Total	**342**	**100**
6	familiar with the operation procedure of the HVAC system installed	a) Yes	278	81.3
		b) No	64	18.7
		Total	**342**	**100**
7	come across any placard explaining operation or any other issue concerning the HVAC system in this Hotel	a) Yes	44	12.9
		b) No	298	87.1
		Total	**342**	**100**
8	How is the maintenance of this building organized	a) Whenever there is faulty operation	166	48.5
		b) On regular basis	30	8.8
		c) Whenever funds allow	146	42.7
		Total	**342**	**100**
9	waiting period taken to repair reported faults in the building	a) Less than 3days	2	0.5
		b) 3days to one week	18	5.3
		c) 1 week to 2 weeks	16	4.7
		d) 2 weeks to 3 weeks	82	24.0
		e) 4 weeks	78	22.8
		f) Over 4 weeks	146	42.7
		Total	**342**	**100**

Source: Field Survey, (2018)

The HVAC energy management processes in the hotel was assessed carried and the result of the respondents are as presented in Table 4.6. From the result, it is seen that 57.9% of the respondent attested that building operators are responsible for the energy management; 38.6% claim it's the maintenance contractor while only 3.5% of the respondent claim not to know who is responsible for the energy management of the hotel.

The result also reveal that most of the hotels do not have energy consumption budget as attested by 63.7% of the respondents; though 19.9% of the responds claim hotel they work have energy budget while 16.4% of the respondents affirmed to the fact that they truly do not know if there exist any of such budget. With regards to the fraction of the energy budget allotted to HVAC energy consumption, 80.1% of the respondent attested that they do not know the Fraction of energy budget constituted by HVAC system to the energy consumption of the building. However, 13.5% of the respondent who claim to know attested that HVAC energy consumption is allotted three-quarter the entire energy budget of the hotel.

Also from the Table 67.8% of the respondents attested that the building management do carry out a review of the energy consumption. However, with regards to the frequency of the review: 39.5% of the respondents' claim it takes over 18months to review the energy consumption; 31.9% claims it takes between 13-18months, 9.1% claim it's between 7-12months, whereas 19.5% claim that the review is never done.

The results also show what informs the maintenance of the HVAC system and from the result it can be seen that 4.5% of the respondent attested to the fact that HVAC systems in the hotel is only maintained when there is a faulty operation of the system. 42.7% claim maintenance are only carried out whenever funds allow while only 8.8 % claim it is carried out on a regular basis

Finally regarding the energy management of HVAC systems, the 42.7% claim the waiting period taken to repair HVAC system when reported takes over four (4) weeks. 22.8% claims it take four (4) weeks; 24.0% claim it take 2-3weeks while 4.7% claim it take a week or two.

4.1.6 HVAC Maintenance

Table 4.7 HVAC Maintenance

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	Is there planned maintenance for HVAC systems in the building	a) Yes	98	28.7
		b) No	234	68.4
		c) Don't Know	10	2.9
		Total	**342**	**100**
2	schedule for the planned maintenance	a) 0-6mnths	22	6.4
		b) 7-12 months	94	27.5
		c) 13-18 months	45	13.2
		d) Over 18 months	156	45.6
		e) Don't Know	25	7.3
		Total	**342**	**100**
3	Who is in charge of HVAC system service maintenance	a) Building operator	138	40.4
		b) Maintenance contractor	204	59.6
		c) Nobody	-	-
		Total	**342**	**100**
5	the elements covered by the maintenance or services contract	a) Services or maintenance duration	34	9.9
		b) Filter Replacement or clean up	45	13.2
		c) Duct clean up	56	16.4
		d) Replacement of faulty units/parts	54	15.8
		e) Refrigerant recharge/change	35	10.2
		f) Purging of system	31	9.1
		g) Review of HVAC system performance and operational/ energy efficiency	87	25.4
		Total	**342**	**100**

Source: Field Survey, (2018)

The opinion of the respondents' on the maintenance of the HVAC systems in the hotels and the result is as presented in Table 4.7. From the Table it can be seen that there is no planned maintenance of the HVAC systems as attested by 68.4%. In line with the maintenance interval, 45.6% of the respondents attested that the HVAC are maintained in interval of over 18thmnths; 27.5% claim it's within 7-12months while 13.2 % claim it is 13-18 months.

The result also shows that most of the HVAC system maintenance are done mainly by maintenance contractors (59.6%) while only 40.4% of the respondents claim it is done by building operators in the Hotels. The researcher also sought to know the elements covered by the maintenance or service contract. From the result it can been seen that 25.4% of claim its ‘Review of HVAC system performance and operational/ energy efficiency’; 16.4% ‘Duct clean up’; 15.8% ‘Replacement of faulty units/parts’. Details of other elements covered by the maintenance service contract are as shown in the table.

4.1.7 Ranking of Maintenance of the HVAC Components

Table 4.8: Ranking of Maintenance of the HVAC Components

S/N	Maintenance of the HVAC Components	WEIGHTNG/RESPONSE FREQUENCY										
		1	2	3	4	5	(∑f)	∑fx	MEAN	Std	RII	RANK
A						Chillers						
1	Check refrigerant level, leak test with electronic Leak detector. If abnormal, trace and rectify as necessary, Inform department in writing on the rectification	50	61	14	173	44	342	1126	3.29	1.33	0.66	4TH
2	Inspect level and condition of oil. If abnormal, trace fault and rectify as necessary. Inform department in writing on the rectification	-	63	51	228	-	342	963	2.82	0.79	0.56	5TH
3	Check the liquid line sight glasses for proper flow	-	106	-	140	96	342	828	2.42	1.19	0.48	8TH
4	Check all operating pressure and temperature	142	08	73	119	-	342	853	2.49	1.34	0.50	7TH
5	Inspect and adjust, if required, all operating safety controls	-	81	14	138	109	342	1301	3.80	1.13	0.76	1ST
6	Check capacity control, adjust if necessary.	50	187	105	-	-	342	739	2.16	0.66	0.43	9TH
7	Lubricate vane/ linkage/ bearings.	-	04	158	110	70	342	1272	3.72	0.80	0.74	2ND
8	Visually inspect machine and associated components, and listen for unusual sound or noise for evidence of unusual conditions.	-	46	94	170	32	342	1214	3.55	0.84	0.71	3RD
9	Check lock bolts and chiller spring mount.	-	238	22	49	33	342	903	2.64	1.05	0.53	6TH
10	Review daily operating log maintained by	77	265	-	-	-	342	607	1.77	0.42	0.35	10TH

Table 4.8: Ranking of Maintenance of the HVAC Components Cont'd

	department's operating personnel Review daily operating log maintained by department's operating personnel											
Cluster statistics		**32**	**106**	**53**	**113**	**38**			**3.06**	**1.21**		
B												
	WATER PUMPS											
1	Inspect all water pumps	88	98	35	46	75	342	948	2.77	1.51	0.55	3RD
2	Check all seals, glands and pipelines for leaks and rectify as necessary.	113	75	67	37	50	342	862	2.52	1.42	0.50	5TH
3	Re-pack and adjust pump glands as necessary	145	43	69	85	-	342	778	2.27	1.25	0.45	6TH
4	Check all pump bearings and lubricate with oil or grease as necessary.	67	98	11	116	50	342	1010	2.95	1.41	0.59	2ND
5	Check the alignment and condition of all rubber couplings between pumps and drive motors and rectify as necessary.	92	78	23	135	14	342	927	2.71	1.34	0.54	4TH
6	Check all bolts and nuts for tightness and tighten as necessary.	14	98	16	167	47	342	1161	3.39	1.16	0.68	1ST
Cluster Statistics		**86**	**82**	**37**	**98**	**39**			**2.77**	**1.39**		
C												
	AIR HANDLING UNITS AND FAN COIL UNITS											
1	Inspect all air handling and fan coil units	75	33	54	79	101	342	1124	3.29	1.52	0.66	1ST
2	Check all air filters and clean or change filters as necessary.	54	114	23	134	17	342	972	2.84	1.24	0.57	3RD
3	Check all water coils, seals and pipelines for leaks and rectify as necessary	88	89	46	98	21	342	901	2.63	1.30	0.53	5TH
4	Check and re-calibrate modulating valves and controls. Adjust and rectify as necessary to ensure compliance to the original specifications	91	73	34	124	20	342	935	2.73	1.35	0.55	4TH
5	Purge air from all water coils.	102	113	12	67	48	342	872	2.55	1.44	0.51	7TH
6	Check all fan bearings and lubricate with grease as necessary.	91	121	8	72	50	342	895	2.62	1.43	0.52	6TH

Table 4.8: Ranking of Maintenance of the HVAC Components Cont'd

7	Check the tension of all belt drives and adjust as necessary.	156	70	15	34	67	342	812	2.37	1.59	0.47	9TH
8	Check and clean all the condensate pans, trays and drains.	78	67	55	97	45	342	990	2.89	1.38	0.58	2ND
9	Check, clean and service smoke detectors. Carry out a system test to ensure that the smoke detector will trip the AHU's.	135	64	43	78	22	342	814	2.38	1.37	0.48	8TH
Cluster Statistics		**97**	**83**	**32**	**87**	**43**			**2.70**	**1.43**		
D	**AIR COOLED PACKAGED UNITS AND PRECISION COMPUTER AIR-CONDITION EQUIPMENT**											
1	Check condenser fan motor load ampere	131	56	43	89	23	342	843	2.46	1.39	0.49	6TH
2	Check fan and motor mounting brackets	123	76	56	87	-	342	791	2.31	1.20	0.46	8TH
3	Check shafts and bearings. Lubricate with grease as necessary.	145	45	54	67	31	342	820	2.40	1.42	0.48	7TH
4	Check the tension of all belt drives and adjust as necessary.	112	34	66	45	85	342	983	2.87	1.59	0.57	2ND
5	Check for refrigerant leaks with electronic leak detector.	109	76	35	77	45	342	899	2.63	1.46	0.53	4TH
6	Check electrical terminals and contactors operation and connection for tightness.	45	66	34	165	32	342	1099	3.21	1.24	0.64	1ST
7	Check compressor motor current	109	49	41	118	25	342	927	2.71	1.41	0.54	3RD
8	Check refrigerant line driers and moisture indicators	90	88	71	77	16	342	867	2.54	1.23	0.50	5TH
Cluster Statistics		**108**	**61**	**50**	**91**	**32**			**2.64**	**1.40**		
E												

Table 4.8: Ranking of Maintenance of the HVAC Components Cont'd

1	Check operation of all modulating and fixed dampers controlling air flow through unit. Lubricate all damper bearings and linkages as necessary.	54	45	78	98	67	342	1105	3.23	1.34	0.65	1ST
2	Check noise level of discharged air from diffusers	77	56	34	87	88	342	1079	3.15	1.53	0.63	2ND
Cluster Statistics		**66**	**51**	**56**	**93**	**76**			**3.18**	**1.43**		
F												

Table 4.8: Ranking of Maintenance of the HVAC Components Cont'd

					VENTILATION							
1	Check and adjust as necessary that the air flow of all fans is in compliance with the original specifications.	81	67	56	94	44	342	979	2.86	1.37	0.57	4TH
2	Check the tension of all belt drives and adjust as necessary	76	45	76	88	57	342	1031	3.01	1.40	0.60	3RD
3	Check and lubricate all fan bearings	91	67	56	101	27	342	932	2.73	1.34	0.55	5TH
4	Tighten motor terminals.	71	34	54	89	94	342	1127	3.30	1.49	0.66	1ST
5	Check starter contacts	34	109	52	78	69	342	1065	3.11	1.32	0.62	2ND
Cluster Statistics		**71**	**64**	**59**	**90**	**58**			**3.00**	**1.40**		
G					**SWITCH BOARD**							
1	Clean and adjust all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months	56	45	112	97	32	342	1030	3.01	1.20	0.60	1ST
2	Check and prove operation of thermal over load and protection devices.	154	35	56	86	11	342	791	2.31	1.35	0.46	4TH
3	Check and ensure tightness of all equipment fastenings and cable terminations within switch boards	132	56	31	77	46	342	875	2.56	1.51	0.51	3RD
4	Vacuum clean all switch board cubicles	112	53	67	78	32	342	891	2.61	1.39	0.52	2ND
Cluster Statistics		**114**	**47**	**66**	**85**	**30**			**2.62**	**1.39**		
H					**PIPING SYSTEM**							
1	Check all piping system for leaks and repair these where they have occurred	67	72	45	97	61	342	1039	3.04	1.41	0.61	1ST
2	Check for damage & deterioration of insulation or sheathings. Rectify as necessary	58	76	79	92	37	342	1000	2.92	1.27	0.58	2ND
Cluster Statistics		63	74	62	94	49			**2.98**	**1.34**		

Source: Field Survey, (2018)

Where: ND= Never Done; RD= Rarely Done; NI= No Idea; OD= Often Done; AD= Always Done

The Likert scale result in table 4.8 presents the ranking of the maintenance of the HVAC component. From the result in the Table, the HVAC component. is divided into various Components namely: Chillers (with cluster mean value of 3.06 and standard deviation of 1.21), Water Pumps (with cluster mean value of 2.77 and standard deviation of 1.39), Air Handling Units and Fan Coil units, Air cooled package units and precision computer air-condition (with cluster mean value of 2.64 and standard deviation of 1.40), Air Distribution System (with cluster mean value of 3.18 and standard deviation of 1.43), ventilation, Switch Board (with cluster mean value of 3.00 and standard deviation of 1.40), and Piping system (with cluster mean value of 2.98 and standard deviation of 1.34). From the cluster mean value it indicates that of all the various component of the HVAC system, the Air Distribution System is the component that is often maintained compared with the other component based on the mean.

However within the various section of the HVAC system the following are the result of the ranking of the various component that make up the sections:

a) In the chillers, the respondent ranked "Inspect and adjust, if required, all operating safety controls" (RII=0.76) as the most carried out maintenance practice for the chillers. This was closely followed by "Lubricate vane/ linkage/ bearings: (RII=0.74), "Visually inspect machine and associated components, and listen for unusual sound or noise for evidence of unusual conditions" (RII= 0.71), and "Check refrigerant level, leak test with electronic Leak detector. If abnormal, trace and rectify as necessary, Inform department in writing on the rectification (RII=0.66) which ranked second, third and fourth respectively. Details of the ranking of other factors that relates to the chillers as a component of the HVAC system is as presented in the Table.

b) In the Water Pumps, the respondents ranked "Checking all bolts and nuts for tightness and tighten as necessary" (RII=0.68) was ranked the first as the most maintained aspect of the water pump. This was also followed closely followed by: "Checking all pump bearings and lubricate with oil or grease as necessary" (RII=0.59) and "Inspection of all water pumps" (RII=0.55), which ranked second and third respectively. Details of the ranking f other maintenance aspect of the Water Pump are as presented in the Table.

c) In the Air Handling Units and Fan coils, Units; “Inspection of all air handling and fan coil unit” (RII=0.66) was ranked first. “Checking and cleaning all the condensate pans, trays and drains” (RII=0.58) was ranked Second while the “Checking all air filters and clean or change filters as necessary” (RII=0.57) was ranked third. Details of the ranking of other maintenance process of the Air handling Units and Fan coil units are as presented in the Table.

d) In the Air Cooled Packaged Units and Precision Computer Air Conditioning Equipment, the respondents ranked “Checking electrical terminals and contactors operation and connection for tightness”(RII=0.64) as the first while the lease ranked maintenance procedure is “Checking fan and motor mounting brackets” (RII=0.46). Details and ranking of other maintenance procedures are as shown in the Table.

e) In the Air Distribution System, “Checking operation of all modulating and fixed dampers controlling air flow through unit. Lubricate all damper bearings and linkages as necessary” (RII=0.65) was ranked the first

f) In the Ventilation Component of the HVAC system maintenance, “Tighten motor terminals” (RII=0.66) was ranked first. While “Check starter contacts” (RII=0.62) and “Checking the tension of all belt drives and adjust as necessary (RII=0.60) were ranked the second and third commonly done maintenance practice on the ventilation component of the HVAC systems in the Hotel respectively. Details of the ranking of other procedure are presented in the Table.

g) In the Switch Board, the respondents ranked “Cleaning and adjusting all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months” (RII=0.60) as the commonly practice maintenance procedure of the Switch board in the Hotels. The details of the ranking of other procedure of the Switch board is presented in the Table

h) Finally in the Piping system as a component of the HVAC system, "Checking all piping system for leaks and repair these where they have occurred" (RII=0.61) was ranked first while "Checking for damage & deterioration of insulation or sheathings. Rectify as necessary" (RII= 0.58) was ranked Second.

4.1.8 Occupants Use of HVAC

Table 4.9 Occupants Use of HVAC

S/N	Variable	Option	Frequency (No)	Percentage (%)
1)	occupants conversant with or informed on operations of controls	a) Yes	98	28.6
		b) No	216	63.2
		c) Don't Know	28	8.2
		Total	**342**	**100**
2)	Are there contact(s) given for persons to get in touch with in case the HVAC system is faulty?	a) Yes	243	71.1
		b) No	99	28.9
		c) Don't Know	-	-
		Total	**342**	**100**
3)	How long does it take the management to act on the report of faulty items	a) < 3days	87	25.4
		b) 4days to 1week	150	43.9
		c) 1 - 4 weeks	65	19.0
		d) < 4 weeks	40	11.7
		Total	**342**	**100**
	sign of vandalism of the control knobs and switches	a) Yes	210	61.4
		b) No	132	38.6
		c) Don't Know	-	-
		Total	**342**	**100**
	occupants informed about the importance of energy conservation and specific implication of HVAC system	a) Yes	98	28.7
		b) No	244	71.3
		c) Don't Know	-	-
		Total	**342**	**100**

Source: Field Survey, (2018)

The occupants' use of the HVAC system was assessed and the result is as presented in Table 4.9. It can be identified that occupants are not informed on operations of control of the HVAC as attested by 63.2% of the respondents. Also, 71.1% of the respondent attested to the fact that occupant are not given any contact to get in touch while in the hotel at the event of the HVAC system malfunctioning. The Table further presents that it takes mostly ‘4days to 1week’ (43.9%) for the management of the hotel to act on any HVAC control reported faults. Similarly, 61.4% of the respondent also opined that there are signs of the destruction of the HVAC control knobs and switched. Finally, it can be seen from the table as attested by 71.3% of the respondents that occupants are not informed about the importance of energy conservation and specific implication of the HVAC system.

4.1.9 Component, Equipment and Measures Values

Table 4.10 Component, Equipment and Measures Values

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	the age of the HVAC system	a) 0 – 3year	58	17.0
		b) 4- 6year	109	31.9
		c) 7-9year	132	38.6
		d) 10years and above	43	12.5
		Total	**342**	**100**
2	How often is the duct cleaned	a) Every 0-6mnths	18	5.3
		b) Every 6-12 months	49	14.3
		c) Every 12-18 months	67	19.6
		d) Every 10-24 months	78	22.8
		e) Irregularly/ unplanned	112	32.7
		f) Never	18	5.3
		Total	**342**	**100**
3	leakage in the duct work	a) Yes	158	46.2
		b) No	184	53.8
		c) Don’t Know	-	-
		Total	**342**	**100**
4	other source of power to the hotels aside the EDDC supply	a) Yes	257	77.2
		b) No	85	22.8
		c) Don’t Know	-	-
		Total	**342**	**100**

Source: Field Survey, (2018)

The HVAC equipment and measures value comprising of the age of the system and the presence of leakages in the system was assessed and the result resented in Table 4.10. it can be seen that most the HVAC systems in the hotels are between 7-9years (38.6%) old and have been in use fr this years. The age distribution are: ‘4-6years’ (31.9%), ‘0-3year’ (17.0%) while HVAC that are ‘10years and above’ (12.5%).

It can also be identified that most of the systems do not have leakages as attested by 53.8% of the respondents. With regards to the frequency of cleaning of the duct, it can be seen that most of the hotels have irregular or unplanned timing in cleaning the ducts (32.7%). Details of variation in the frequency is as presented in the table. The Table also revealed that the HVAC systems are often powered in the hotels by other means (77.2%) aside the Nigerian Enugu Electricity Distribution Company (EDDC) power supply.

4.1.10 Effect of the maintenance of HVAC system on its Energy Consumption

Table 4.11 Effect of the maintenance of HVAC system on its energy consumption

VARIABLES	Yes/High Extent (%)	Not Sure or Inconsequential (%)	No/Low Extent (%)	Mean	Std. Dev.
Maintenance of HVAC system affects Energy consumption	284 (83.0%)	0 (0.0%)	58 (17.0%)	2.66	0.752
Adequate maintenance of the HVAC system will help to reduce energy wastage and optimal use of energy	292 (85.4%)	33 (9.6%)	17 (5.0%)	2.80	0.508
Extent of agreement that energy is consistently wasted due to nature of the maintenance of the HVAC systems	314 (91.8%)	17 (5.0%)	11 (3.2%)	2.89	0.407
Urgent need of improving the maintenance of the HVAC for a sustainable energy consumption	262 (76.6%)	0(0.0%)	80 (23.4%)	2.53	0.848
Cluster Mean	**84.2%**	**3.7%**	**12.1%**	**2.72**	**0.629**

Source: Field Survey, (2018)

Table 4.10 presents the Effect of the maintenance of the HVAC installations on the energy consumption. From the Table it can be deduce that a larger percentage of the respondents opined that the maintenance highly affect the energy consumption of the system (83.0%). Similarly, 85.4% of the respondents identified that adequate maintenance of the system can help reduce the energy wastage and optimize energy consumptions of the HVAC systems. Also, 76.6% of the respondents attested to the fact that there is an urgent need to improve the maintenance of the HVAC installations so as to improve the energy consumption.

4.1.11 Energy Saving and HVAC Control Functionality

Table 4.12 Energy Saving and HVAC Control Functionality

S/N	Variable	Option	Frequency (No)	Percentage (%)
3	The focuses of the energy saving program with regards to HVAC system?	a) Demand reduction by minimum operation of system	67	19.6
		b) Introduction of an energy management system	45	13.2
		c) Demand scheduling	47	13.7
		d) HVAC system retrofit	50	14.6
		e) Energy efficient maintenance program	89	26.0
		f) Duct cleaning	44	12.9
		Total	**342**	**100**
4	the control type/strategies used for HVAC system operation in the building	a) On/off toolbox	198	58.9
		b) Automatic thermostat based control	64	18.7
		c) Variable Fan speed adjuster	10	2.9
		d) Air intake control	13	3.8
		e) Carbon dioxide sensors	-	-
		f) Variable motor speed adjuster	12	3.5
		g) Timers	45	12.2
		Total	**342**	**100**
5	what are the observable faults in the HVAC control	a) Control setting are very low	56	16.4
		b) Control knobs are broken	18	5.3
		c) Control settings are higher than desired	30	8.8
		d) Control sensor faulty	125	36.5
		e) Adjusters are faulty	113	33.0
		Total	**342**	**100**

Source: Field Survey, (2018)

The Energy Saving and HVAC Control functionality of the Hotels were assessed and the result is presented in Table 4.11 from the table, it is seen that the focus of most of the energy saving programme in the Hotels is mainly ‘energy efficiency’ (26.0%). Other major focuses are; ‘Energy demand reduction by minimum operation of system’ (19.6%), ‘HVAC system retrofit’ (14.6%), ‘Demand scheduling’ (13.7%) and ‘Introduction of an energy management system’ (13.2%) arranged in their order of severity.

It can also be seen that the most common HVAC operation control type and strategy used in most of the Hotels studied is ‘On/off toolbox’ (58.9%). Also, ‘Automatic thermostat based control’ (18.7%) identified as the second most common HVAC operation control strategy adopted in the Hotels. Details of other control strategy used are also presented in the table.

The Table also presents the observable faults in the HVAC Control system in the hotels. It is seen that the most common fault often observed in the HVAC control is ‘Control Sensor Faults’ (36.5%). This is closely followed by; ‘Adjusters are faulty’ (33.0%); ‘Control setting are very low’ (16.4%) and ‘Control settings higher than desired’ (8.8%) arranged in the order of severity

4.1.12 Energy Saving Strategies for HVAC Systems

Table 4.13: Ranking Of the Strategies to Be Used To Save Energy When Using HVAC System

S/N	**Control Measures**	**RESPONSE FREQUENCY**									
		SD	**D**	**U**	**A**	**SA**	**(∑f)**	**∑fx**	**MEAN**	**RII**	**RANK**
1	On/off toolbox	-	11	14	271	46	342	1,378	4.02	0.81	3rd
2	Timers	-	-	51	248	43	342	1,360	3.98	0.80	4th
3	Automatic thermostat based control	-	-	-	246	96	342	1,464	4.28	0.86	1st
4	Variable Fan speed adjuster	-	08	143	119	72	342	1,281	3.74	0.75	5th
5	Air intake control	30	50	111	138	13	342	1080	3.16	0.63	7th
6	Carbon dioxide sensors	-	50	105	187	-	342	1163	3.40	0.68	6th
7	Variable motor speed adjuster	-	6	-	265	71	342	1427	4.17	0.83	2nd

Source: Field Survey, (2018)
Where: SD= Strongly Disagree; D= Disagree; U= Undeceive; A= Agreed; SA= Strongly Agreed

Table 4.12, presents the respondents ranking of the energy saving strategies for HVAC systems. From the Table it can be seen that ‘Automatic thermostat’ (RII=0.86) was ranked first as the most promising HVAC energy saving strategy. This was followed closely by ‘Variable motor speed adjuster’ (RII=0.83); ‘On/off toolbox’ (RII=0.81) and ‘Timers’ (RII=0.80) ranked second, third and fourth respectively. Details of the ranking of other strategies is as presented in the Table.

4.2 RESULT OF THE CHECKLIST ANALYSIS

The result of the checklist analysis of a hundred and fifteen (115) hotels assessed in the study area is presented in accordance to the major components of the HVAC system with a section for the general observation of the system (see Appendix VII), from the checklist survey the following deductions can be made out of the survey:

i. The indicators of the general observation of the HVAC installation proves to be unsatisfactory and unacceptable for most of the hotels. However, most of the hotels prove to have a satisfactory state of the Units as their HVAC units were installed on anti-vibration mounts. However, other general observation checks such as: valve tagging, pressure guage installations and automatic air vent installations were grossly unsatisfactory in most of the hotel HVAC installations

ii. The checks conducted on the Fans of the HVAC system accessed also reveal that most of the Hotel only had a satisfactory Duct indication for the fans. However, other fan checks such as: ‘Volume damper installation at FA duct with filter’, ‘Fresh air duct installation’ and ‘Canvas installation at main supply and return ducts’ were in a condition that is unacceptable based on the standard of checks.

iii. For the check conducted on the chillers of the HVAC installations, it can be established that most of the hotel HVAC had very good Gate valve installations and Pipe identifications however almost all didn’t conform to other standard checks like: provision of supporting systems, control sequence and changeover unit installations of the chillers. Details of status of the individual hotels to the chillers checks are in Appendix VII

iv. The check on the HVAC control section showed an obvious deviation from the provision of the standards and as such an unsatisfactory control installations. It's worthy to note that almost all the Hotels a bad temperature sensor connection to (Direct Digital Control) DDC. Similarly, most of the hotel HVAC installations also had faulty Pressure sensor connection to DDC. And finally most of the Hotels had faulty Selector switch connection to DDC. Details of checks conducted on the HVAC installation controls are as presented in the Appendix.

4.3 SIMULATION OF ENERGY CONSUMPTION USING A MODEL PREDICTIVE CONTROL

The HVAC Model Predictive Control is Feedback Control algorithm (see Appendix VII) that uses a model to make prediction about future Energy consumption of the HVAC system. Using this Model, the thermal comfort is simulated to a reference temperature taking into consideration the Disturbances (No of occupant, outdoor evaporation, the ambient temperature, the properties and component of the HVAC system) is simulated and it give a prediction about the energy consumption based on the Control Action you chose (Binary and the MPC Control Action) then one can select the optimal decision with reference to a specified reference temperature. The model is predicts the energy consumption on per square meter basis

The choice of the MPC is because The MPC can handle Multiple –input multiple-output (MIMO) system that have interactions between the input and the output. The advantage of the MPC controller is that it's a multivariable controller that controls the output simultaneously by taking into account all the interactions between system variables. Another strength of MPC is that it can handle constraints. Constraints are important, because violating them can lead to undesired consequences. The process of operation of the Model Predictive Control of the HVAC developed is as shown in the algorism

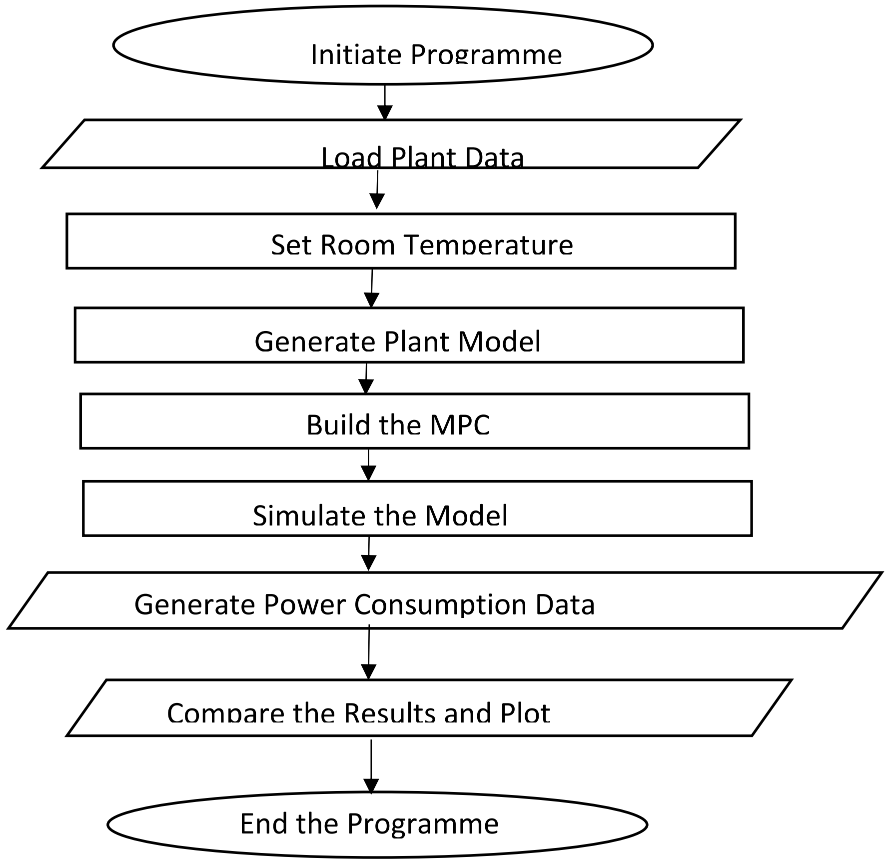


Fig 4.1: HVAC MPC Algorism
Source: Field Survey

Fig 4.2, presents the design of the Binary Control system that works hand in hand with the HVAC MPC System. It is at the binary Control system that the reference indoor temperature is set taking into cognizance the outside air, evaporation, cooling Tower, Chillers, Boiler, Saturation, Ventilated room, filters, fan, coils, Air handling Units and the Ambient temperature. The configuration of the Binary Control systems is presented Fig 4.2

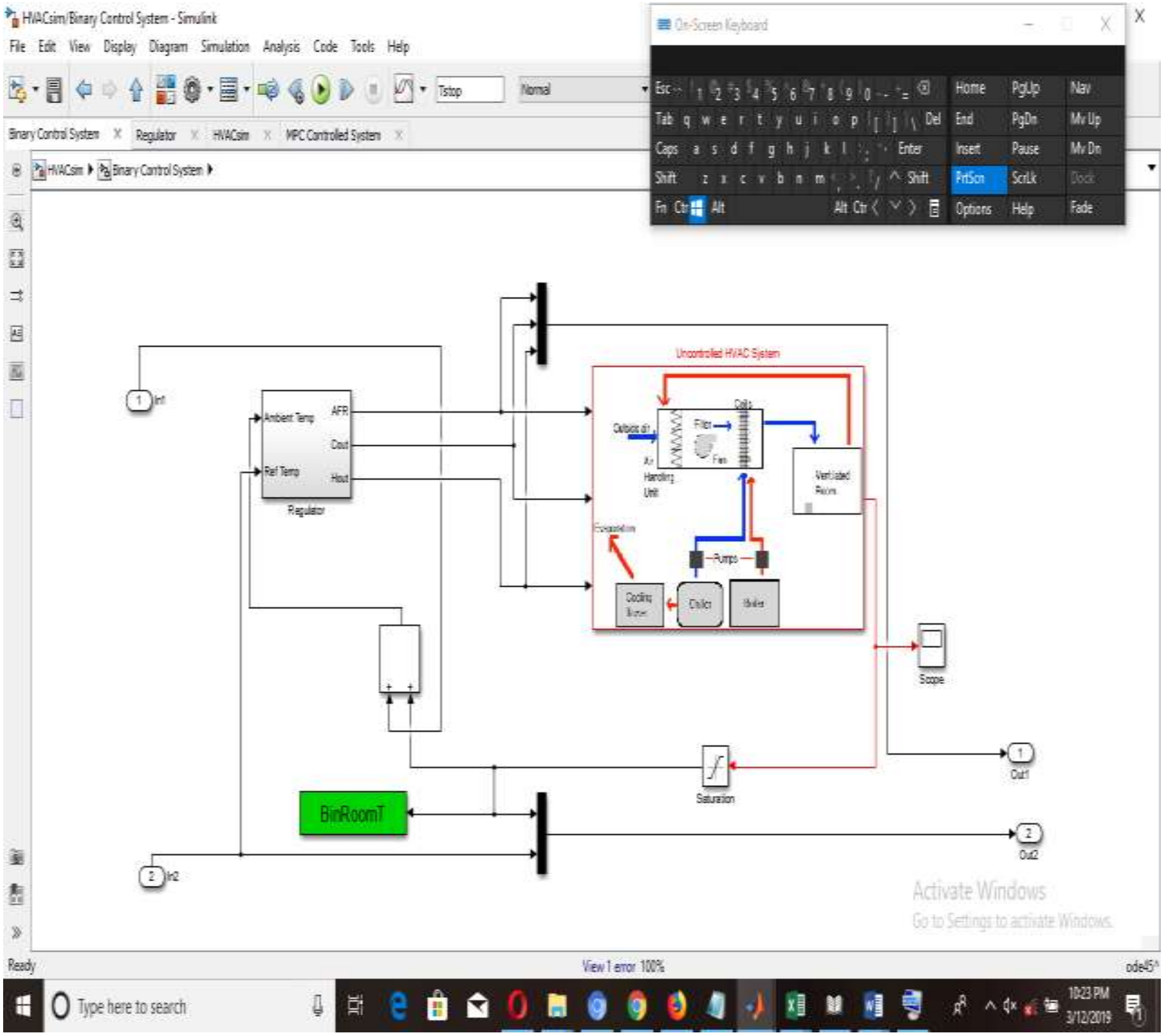


Fig 4.2 The HVAC Binary Control system
Source: Field Survey (2018)

Fig 4.3 Presents the MPC control System which is designed just like the binary systems but has the MPC controller introduced into the binary system. The MPC controller regulates or routes the signal in the model such that the prediction of the HVAC energy Consumption becomes realistic.

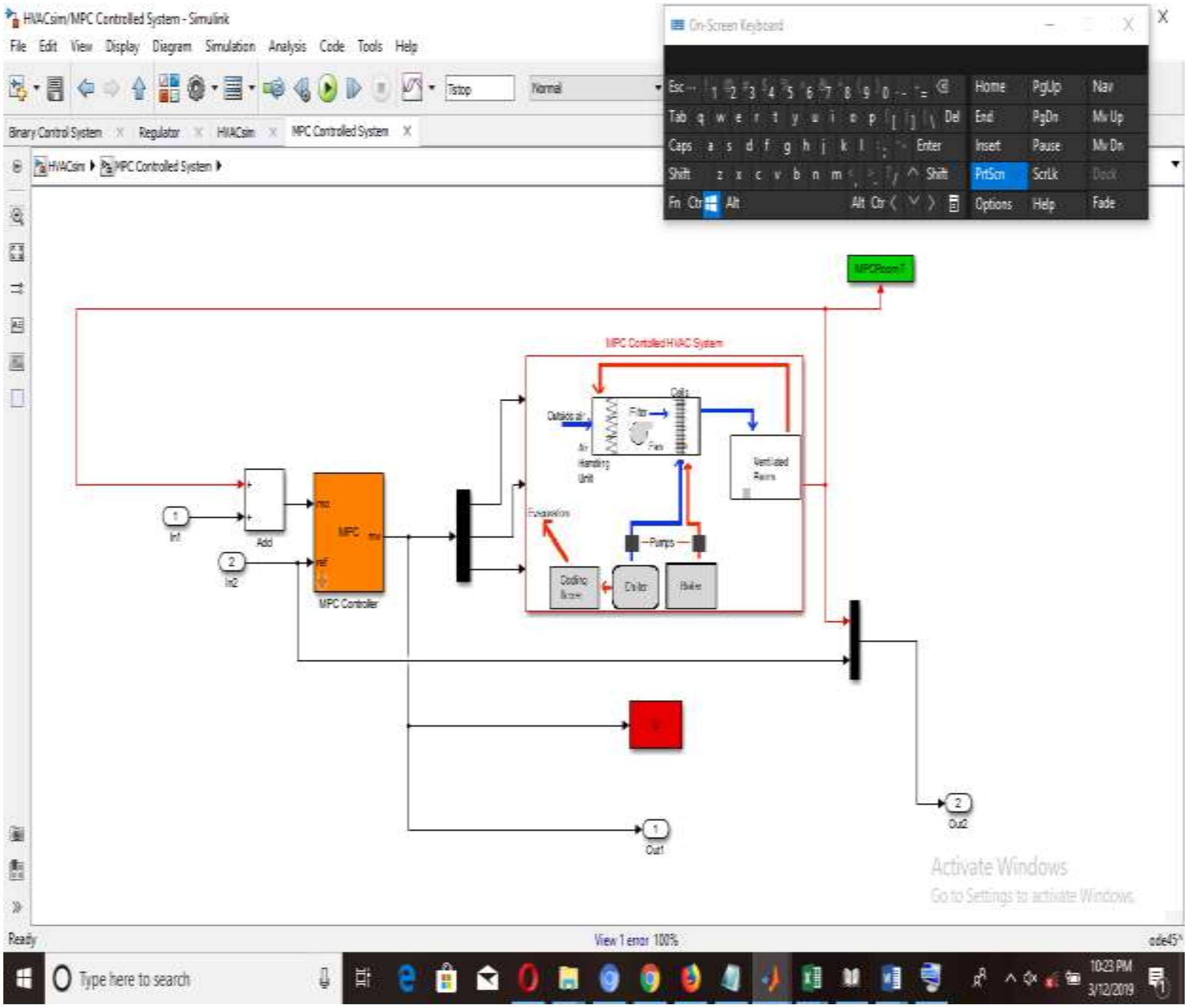


Fig 4.3: The MPC Controlled System
Source: Field Survey (2018)

Fig 4.4 present the regulator which serve as an interface for the two systems earlier mentioned and it is worthy of note to state that the predicted values are not displayed in any of these figs but in the Fig 4.5

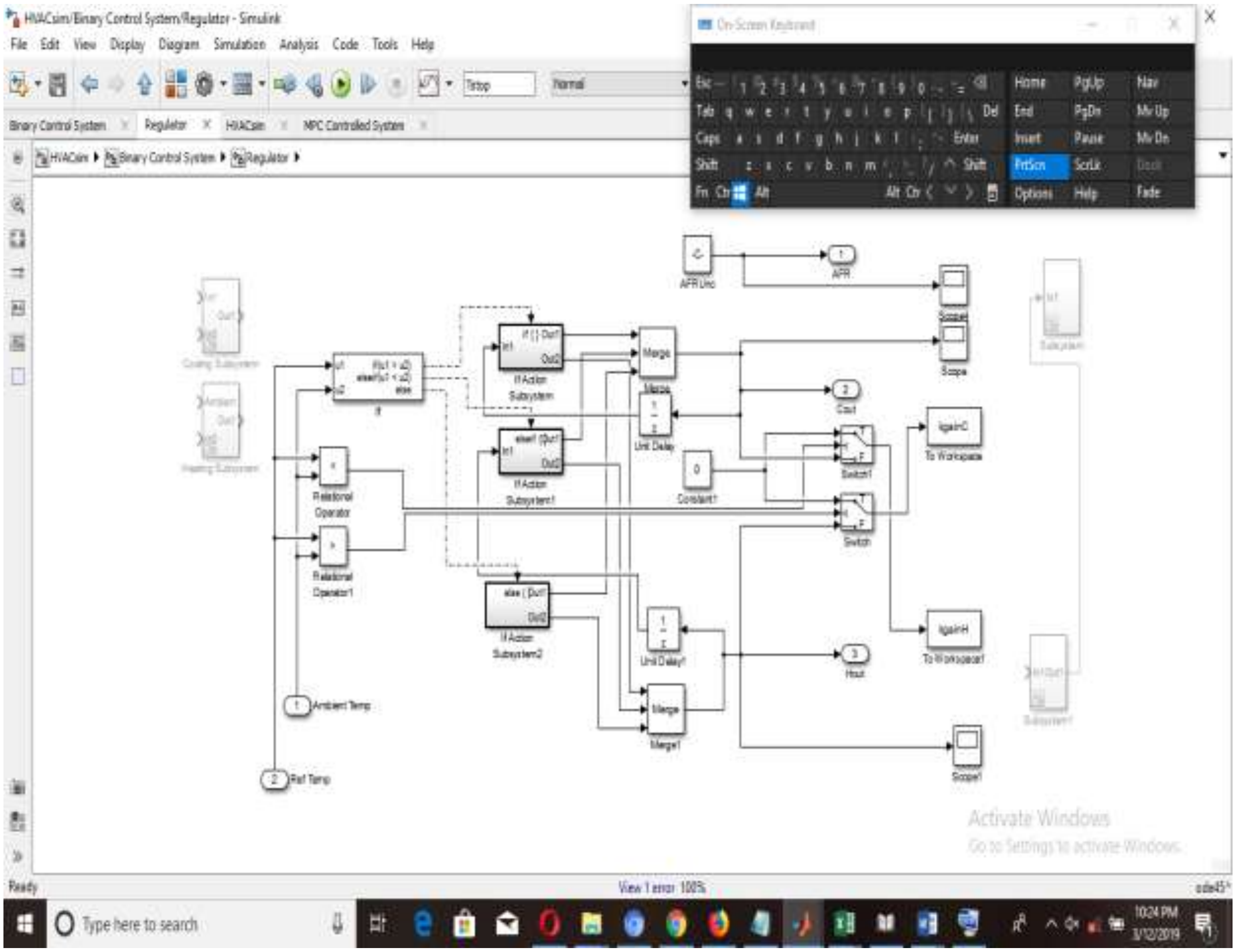


Fig 4.4: The Model Regulator
Source: Field Survey (2018)

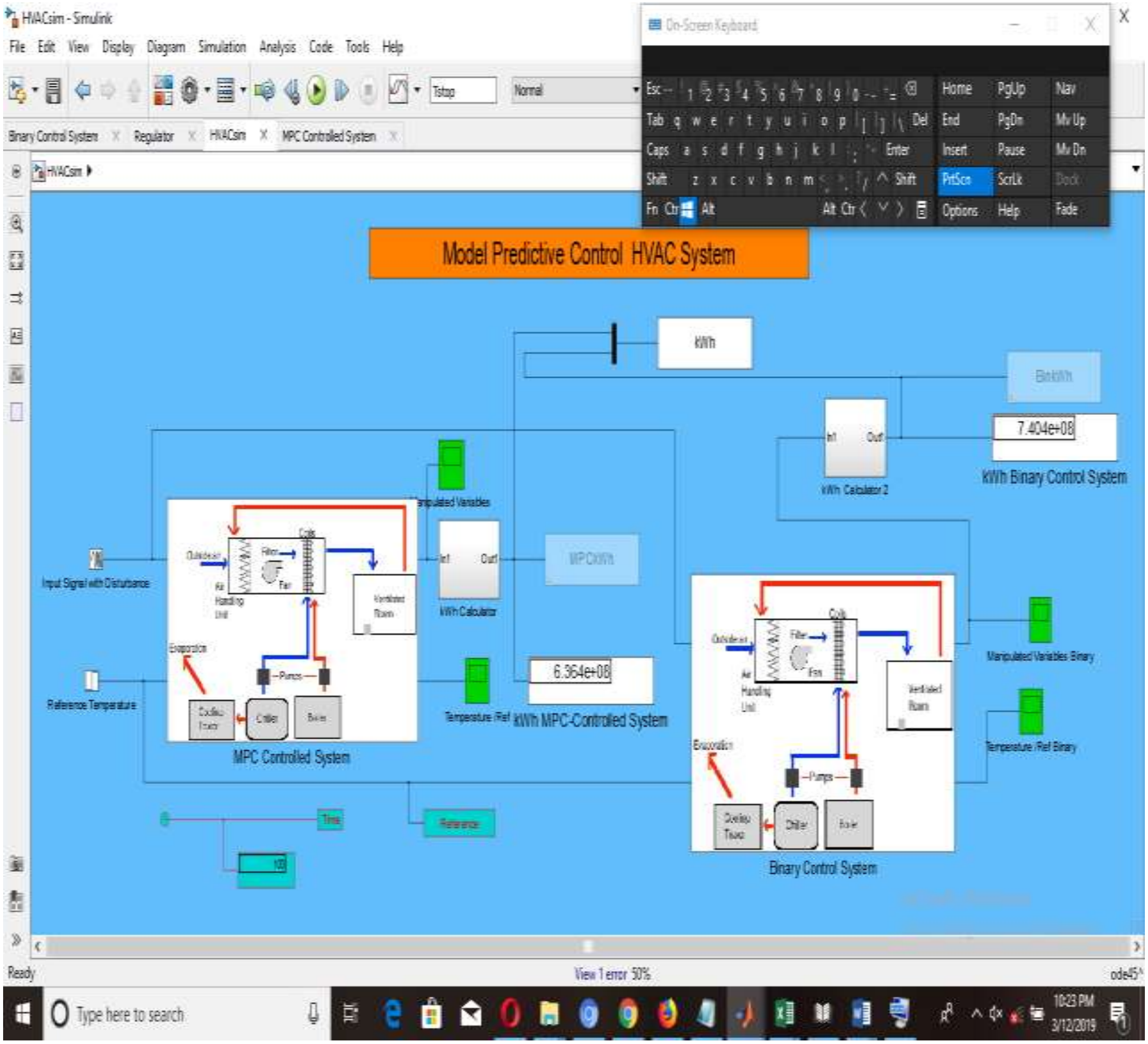


Fig 4.5: HVACsim
Source: Field Survey (2018)

Fig 4.5 presents the HVACSim (HVAC simulation) it is the interface that show the energy consumption by the HVAC system using the binary Control system and the MPC system. It is the interface shows the obvious difference/possible energy savings that can be made using the MPC controller. From the Model, it can be seen that when the simulation was done in morning with the same reference temperature range (16-22^{o}C), the Binary control system predicted an energy of (3.339 X 10^{6}) Kwh while the MPC predicted (2.181 X 10^{6}) Kwh. In a similar occasion using the same reference temperature but at night the result of the binary control system predicted (7.357×10^8) Kwh while the MPC predicted (6.364×10^8) Kwh. Several all other simulation can also be carried out even with varied reference temperature and repeatedly the MPC control system predicts a smaller energy consumption. The Table 4.14, shows the result of the simulation of six of the typical Hotel scenarios and the possible percentage energy savings made by the adoption of the MPC controller. From the result presented it can be deduce that there are significant percentage energy savings which though varies but can be as much as 34.6% energy savings. Details of the other percentage savings as tested is as shown in the Table.

Table 4.14 Result of the Use of the MPC Model to test some Hotel Scenarios and the Prospective Energy Saving

S/N	Binary Energy Prediction (Kwh)	Model Predictive Control (MPC) Prediction (Kwh)	Energy Saving By Using The MPC Controller (Kwh)	Percentage Energy Savings
1	3.339×10^6	2.181×10^6	1.15×10^6	34.6%
2	7.357×10^8	6.364×10^8	0.993×10^8	13.5%
3	2.404×10^9	2.308×10^9	9.6×10^7	4.2%
4	1.039×10^9	9.19×10^8	1.2×10^8	11.6%
5	1.059×10^9	9.313×10^8	1.2×10^8	12.1%
6	1.079×10^9	9.239×10^8	1.5×10^8	14.4%

Source: Field Survey, (2018)

In line with this, a Comparative Analysis of Energy Consumption is as shown in Fig 4.6 while a comparative analysis of the temperature responses using the two control systems is as shown in Fig 4.7

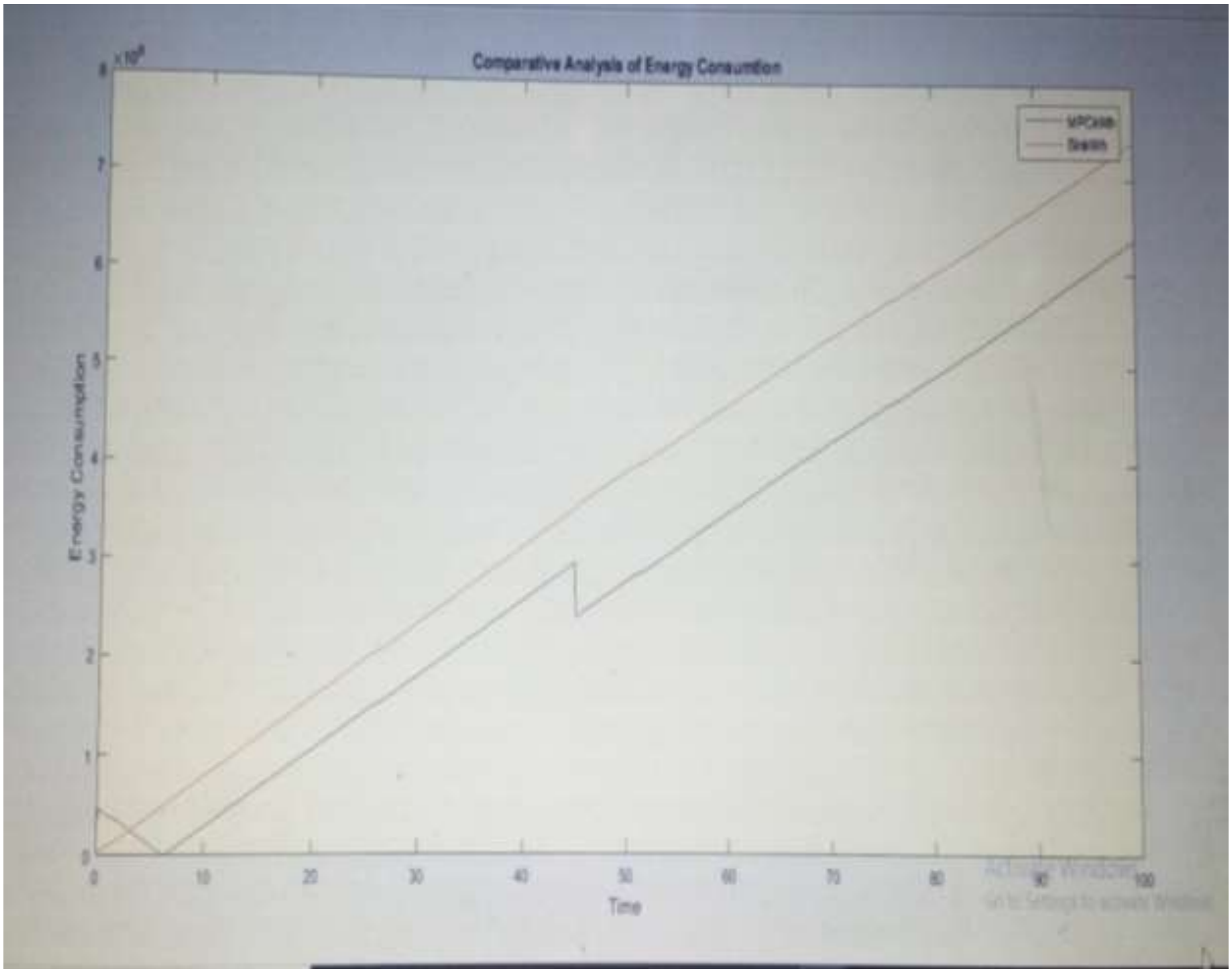


Fig 4.6: Comparative Analysis of Energy Consumption
Source: Field Survey

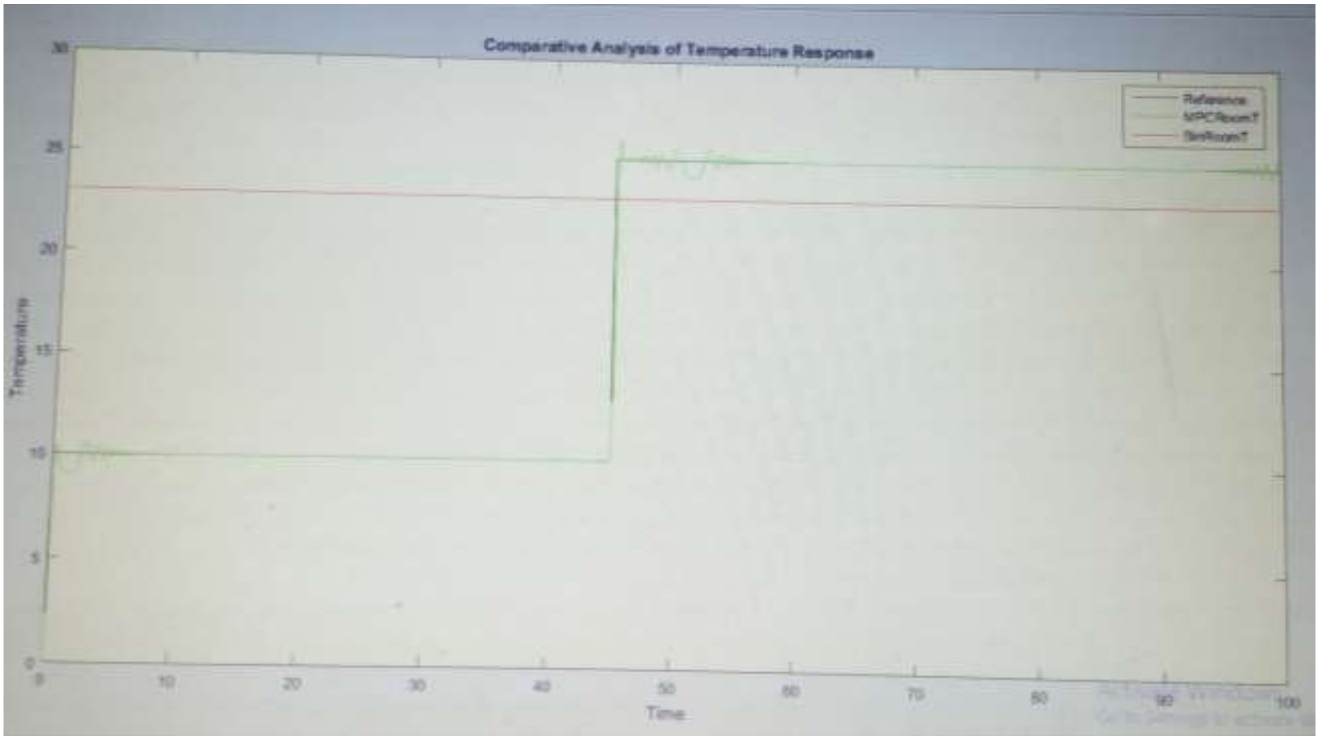


Fig 4.7: Comparative analysis of the Temperature Responses
Source: Field Survey

4.4 HYPOTHESES TESTING

Three hypotheses were formulated for this study. These hypotheses were tested using the Z-test and Principal component method of factor analysis as appropriate. Decision was taken at 5% level of significance.

4.4.1 Hypothesis One

Hypothesis one is intended to ascertain the level of maintenance of HVAC components system in Hotels in Owerri Nigeria. The null (Ho) and alternative (Ha) hypothesis is as stated below:

Ho: HVAC components system has not been of adequate maintenance in Hotels in Owerri Nigeria.

Ha: HVAC components system has been of adequate maintenance in in Hotels in Owerri Nigeria.

Level of Significance (α) = 0.05

Test Statistic: **t** = $\frac{\bar{x} - \mu_o}{\frac{s}{\sqrt{n}}}$ with n-1 degree of freedom

Table 4.15: Normality test result of the dataset

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Average Response	.200	8	.200*	.911	8	.360

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

The normality test result with Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) statistic values of 0.200 and 0.911 respectively and associated probability value of 0.200 and 0.360 respectively indicates that the series follows a normal distribution. The skewness (Sk = 0.152) and Kurtosis statistics (K = -1.753) shows that the series are skewed to the right and without excess kurtosis (**see Appendix VI**).

This confirms appropriateness of application of t-test in testing the hypothesis. The t-test result is as presented below:

One-Sample t-test: Test Value = 3.00

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Level of Maintenance	-1.749	7	.124	-.13125	-.3087	.0462

Source: Researcher's SPSS 25 output

The empirical result above with t-statistic value of -1.749 and associated probability value of 0.124 > 0.05 indicates that the HVAC components system has not been of adequate maintenance in the hotels. The researcher therefore upholds the null hypothesis.

4.4.2 Hypothesis Two

Hypothesis two sought to ascertain whether there are HVAC installation components that are better maintained in the hotels. The null (Ho) and alternative (Ha) hypothesis is as stated below:

Ho: There is no HVAC installation components that are better maintained in the Hotels.

Ha: There is HVAC installation components that are better maintained in the Hotels.

Table 4.16: The Pearson Correlation Test Result

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Correlation	X_1	1.000							
	X_2	.190	1.000						
	X_3	.578	.726	1.000					
	X_4	.590	.323	.823	1.000				
	X_5	.376	.203	.670	.957	1.000			
	X_6	.143	.262	.726	.833	.852	1.000		
	X_7	-.103	.186	.577	.594	.623	.936	1.000	
	X_8	.866	.423	.878	.790	.580	.553	.371	1.000

a. This matrix is not positive definite.

Source: Researcher's SPSS 25 output

Where;

X_1 = Chillers

X_2 = Air Distribution System

X_3 = Ventilation

X_4 = Water Pumps

X_5 = Air handling and fan coil units

X_6 = Air cooled packaged units and precision computer Air-condition Equipment

X_7 = Switch Board

X_8 = Piping System

The Pearson correlation test was used to measure (pairwise) linear association among the factors. From the correlation result, it was discovered that most of the pairwise associations are of high degrees ($r \geq 0.50$). This indicates presence of serial correlation and therefore confirms appropriateness of factor analysis techniques. Hence, they were subjected to factor analysis in order to simplify these relationships among the large bodies of variables and collapse them into significant and orthogonal components that better explains the system.

Table 4.17: Principal Component Result of the maintenance of components of HVAC

Variable Name	Variable label	Components		Communalities
		I	II	
Chillers	X_1	.112	.474	.883
Air Distribution System	X_2	.096	.167	.308
Ventilation	X_3	.185	.112	.914
Water Pumps	X_4	.188	-.009	.916
Air handling and fan coil units	X_5	.170	-.149	.802
Air cooled packaged units and precision computer Air-condition Equipment	X_6	.171	-.311	.995

Switch Board	X_7	.136	-.417	.907
Piping System	X_8	.170	.277	.933
Eigenvalue		*5.083*	*1.576*	
%age of variance		*63.54*	*19.70*	
Cum %age		*63.54*	*83.24*	

Source: Researcher's extract from SPSS 25.0 Output **(See Appendix)**

The principal component scores result indicates that two components out of the eight were extracted as major components maintained by the people. The communalities result shows that these components were highly loaded; an indication of no much left over after representation of the installation components. From the component I result, water pumps were extracted among ventilation, Air cooled packaged units and precision computer Air-condition Equipment, Air handling and fan coil units, and piping system. This component (water pumps) extracted has a latent root (eigenvalue) of 5.083 indicating high relative importance value in accounting for level of maintenance of HVAC installation components in Hotels in Owerri. It explains about 63.54% of the total variation in the system.

In component II, chillers were extracted among the piping system and air distribution system. It has eigenvalue of 1.576 and explains about 19.70% of the total variations in the system. These two components extracted jointly explained about 83.24% of the total variations in the system which shows that they are the major HVAC component system maintained by the Hotels in the area. The null hypothesis is therefore rejected.

4.4.3 Hypothesis Three

Hypothesis three sought to measure the effect of maintenance of HVAC installation system on its energy consumptions in the area. The null (Ho) and alternative (Ha) hypothesis is as stated below:

Ho: Maintenance of HVAC installations do not significantly affect its energy consumptions in the area.

Ha: Maintenance of HVAC installations significantly affects its energy consumptions in the area.

Level of Significance (α) = 0.05

Test Statistic: **t =** $\frac{\bar{x} - \mu_o}{\frac{s}{\sqrt{n}}}$ with n-1 degree of freedom

One-Sample Test: Test Value = 2.0

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Mean responses	9.107	3	.003	.72000	.4684	.9716

Source: Researcher's SPSS 25.0 Result

With the t-statistic value of 9.107 and associated probability value of 0.003 < 0.05, the researcher rejects the null hypothesis and conclude that maintenance of HVAC installations significantly affects its energy consumptions in the area.

4.4.4 Hypothesis Four

Hypothesis Four sought to find out the major strategy for saving energy using HVAC system in the hotels. The null (Ho) and alternative (Ha) hypothesis is as stated below:

Ho: There is no key strategy for saving energy using HVAC system

Ha: There is key strategy for saving energy using HVAC system

Table 4.18 Pearson Correlation Result

Variables		X_1	X_2	X_3	X_4	X_5	X_6	X_7
Correlation	X_1	1.000						
	X_2	.984	1.000					
	X_3	.967	.940	1.000				
	X_4	.485	.624	.463	1.000			
	X_5	.679	.769	.510	.743	1.000		
	X_6	.807	.867	.663	.702	.973	1.000	
	X_7	.992	.965	.991	.455	.588	.733	1.000

a. This matrix is not positive definite.

Source: Researcher's SPSS 25 output

Where;

X_1 = On/off toolbox

X_2 = Timers

X_3 = Automatic thermostat based control

X_4 = Variable Fan speed adjuster

X_5 = Air intake control

X_6 = Carbon dioxide sensors

X_7 = Variable motor speed adjuster

Since factor analysis is a technique applicable when there is a systematic interdependence among a set of observed or manifest variables and the this hypothesis is interested in finding out the major strategy which is fundamental to this commonality, the correlation test was performed to ensure that these outlisted strategies are interdependence/correlated before they can be subjected to factor analysis proper. The result as shown above indicates that the variables are highly correlated among themselves (with $r \geq 0.50$).

Table 4.18: Principal Component result of strategies for saving energy using HVAC system

Variable Name	Variable label	Components		Communalities
		I	II	
On/off toolbox	X_1	.298	-.099	.997
Timers	X_2	.209	.022	.997
Automatic thermostat based control	X_3	**.369**	-.206	.977
Variable Fan speed adjuster	X_4	-.238	**.498**	.796
Air intake control	X_5	-.178	.463	.937
Carbon dioxide sensors	X_6	-.058	.336	.937
Variable motor speed adjuster	X_7	.347	-.169	.999
Eigenvalue		*5.596*	*1.044*	
%age of variance		*79.94*	*14.91*	
Cum %age		*79.94*	*94.85*	

Source: Researcher's extract from SPSS 25.0 Output **(See Appendix)**

The principal component scores and communalities result indicates that two components strategies are relevant in the system (see scree plot and variance decomposition table). The result of communality estimates which shows how much of each variable is accounted for by the underlying factor taking together have high loadings indicating that there is no much left over after the factors representation. From the component I result, X_3(Automatic thermostat based control) was extracted among X_7(Variable motor speed adjuster) and X_1(On/off toolbox). The extracted automatic thermostat based control has eigenvalue of 5.596 and explains about 79.94% of the total variation in the system.

In component II, X_4(Variable Fan speed adjuster) was extracted among X_5(Air intake control) and X_6(Carbon dioxide sensors). This strategy has an eigenvalue of 1.044 and explains about 14.91% of the total variations in the system. The Automatic thermostat based control and Variable Fan speed adjuster extracted jointly accounts for a total of about 94.85% of the total variations in the system which indicates that the two strategies are the major strategies in which energy can be saved using the HVAC system in Hotels in Owerri Nigeria. The researcher therefore rejects the null hypothesis and accepts the alternative.

4.5 SUMMARY OF FINDINGS:

Based on the analysis carried out and the set research questions and hypotheses, the major findings of this study are:

The study revealed that the most of the Hotels in Owerri are owned by Private individuals. It was also discovered that though most of the hotels are originally built as hotels, there are significant number of Hotels that were originally built for other purposes like offices, halls and hostels which were adapted into Hotels. It was also discovered that majority of the hotels were less than 20years old of construction/alteration/retrofitting. The study also revealed that most of the hotels were with of 0-3 floors above ground floor, with an average number of rooms of within the range of 31-40 rooms. Also it was discovered that the virtually all the rooms in all the Hotels studied had a HVAC system installed in it and it's mostly Room Conditioning Unit Packaged HVAC equipment.

In addition, the study revealed that most of the Hotels operate throughout the year and by extension the facilities in the hotels. Still on the characteristic operation of the HVAC system in the building, the study reveal that in most of the hotels, occupants/customers are not restricted in their use of the HVAC though there are more certainty for the provision of electricity for the use of the HVAC systems at night in some Hotels. Also, the study shows that the Hotels have their maximum room occupancy at weekends and so also are the energy demand of the HVAC systems. The study also reveal that most of the Hotel leaves the responsibility of energy management in the hands of the building operators. Most of the Hotels do not have energy consumption budget even though they know from experience that HVAC consumes a lot of energy, however, for hotels that claim to have a budget they couldn't prove with certainty the fraction to the entire energy consumption of the Hotels.

The result also revealed that the Hotel Management rarely conduct a review of the energy consumption of the hotels however in the few hotels where it is done, it takes between 13-

18months. It was also revealed that maintenance of the HVAC systems is informed by the following facts in the order of severity; availability of fund, faulty operation of the system and in few occasion it is a normal maintenance routine. Result also revealed that the repair responds time for the maintenance of the HVAC systems when reported stays as much as four weeks and even more.

In continuation, the study revealed that the maintenance of the HVAC systems in most of the Hotels done in interval of 18months with only few Hotels (such as Immaculate, Bay view Hotel, Ideal Suit, Rock view and City global Hotel)who take less timing of about 7-12months. Also, it was revealed that maintenance contractors to the hotels are responsible for the maintenance of HVAC systems in the. With regards to the maintenance of the HVAC system, the study reveal that; the most maintained component of the HVAC system are the chillers. The result further revealed the common maintenance activities carried out on the various components of the HVAC systems ranked in their order of occurrence. The result revealed that for the Chillers ("Inspection and adjustment of all operating safety controls", "Lubrication of vane/ linkage/ bearing", "Visually inspection of the chillers and associated components, for an unusual sound or noise for evidence of unusual conditions" and "Check on the refrigerant level, leak test with electronic Leak detector. If abnormal, trace and rectify as necessary").

In continuation, the result also revealed the following: Checking all bolts and nuts for tightness and tighten as necessary"; Checking all pump bearings and lubricate with oil or grease as necessary" and "Inspection of all water pumps" as the ranking of the common maintenance check for the water pump as the component of the HVAC system in the Hotels. Still on the maintenance of the of the component of the HVAC systems, the result also revealed that the common check frequently done on the Air Handling Units are: "Inspection of all air handling and fan coil unit"; "Checking and cleaning of all the condensate pans, trays and drains"; and "Checking all air filters and clean or change filters as necessary" arranged in their order of severity.

Still on the maintenance of the various component of the HVAC system, the result also revealed that the most frequent maintenance checks carried out on the Air Cooled Packages

Units and precision Computer air conditioning equipment are: "Checking electrical terminals and contactors operation and connection for tightness" and "Checking fan and motor mounting brackets. Similarly, the most frequent maintenance checks carried on the Air Distributions System is: "Checking operation of all modulating and fixed dampers controlling air flow through unit. Lubricate all damper bearings and linkages as necessary".

In furtherance, the study revealed that "Tightening of the motor terminals"; "Check starter contacts" and "Checking the tension of all belt drives and adjust as necessary" are the basic and frequent maintenance often carried out in the Ventilation Component of the HVAC system. It was also discovered that maintenance checks such as: ranked "Cleaning and adjusting all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months" is most common maintenance checks carried out on the Switch Board of the HVAC system as a component. Lastly, on the maintenance of the various component of the HVAC system it was revealed that "Checking all piping system for leaks and repair" and "Checking for damage & deterioration of insulation or sheathings. Rectify as necessary" are the most frequent and reoccurring maintenance checks conducted on the Piping System of the HVAC in the various hotels assessed.

The study on the occupants' use of the HVAC system revealed that occupants are not restricted in their use of the system neither are occupants informed on operations of control of the HVAC nor given any contact to get in touch while in the hotel at the event of the HVAC system malfunctioning. The study further revealed that the Hotel management are not prompt in their response to the need for a maintenance of the HVAC system. This response was discovered to be delayed to the upwards of a week in most of the hotels studied. Furthermore, it was discovered that the there is no form of enlightenment of the occupants on the need and implication of energy conservation in the use of the HVAC system either through pictures or decorative frames. The study also revealed the possible average age of use of the HVAC systems in most of the hotels to be between 7-9years from date of installations. It was also discovered that the Nigerian Enugu Electricity Distribution Company (EDDC) is the major source of power for the HVAC system with supplementary sources like gas and petrol generating machine to complement the epileptic supply of power by the EDDC.

Concerning the energy saving and HVAC control Functionality, the study revealed that that the focus of most of the energy saving programme in the Hotels is mainly ‘energy efficiency’ with little attention given to Energy demand reduction by minimum operation of system’, HVAC system retrofit’ and energy ‘Demand scheduling’. The study further revealed that the most common HVAC operation control type and strategy used in most of the Hotels studied is ‘On/off toolbox’ while there are only a few hotels that use the ‘Automatic thermostat based control’. With regards to the common/observable faults in the HVAC control systems in the hotels, the study revealed that most common fault often observed in the HVAC control is ‘Control Sensor Faults’; ‘faulty Adjusters’; very low ‘Control setting’ and ‘Control settings higher than desired’ arranged in the order of severity. Still in line with the energy saving strategy of the HVAC systems, it was discovered that the use of Automatic thermostat was given priority as a promising energy saving strategy using the HVAC system. Other strategy such as the use of ‘Variable motor speed adjuster’ and ‘On/off toolbox’ were also suggested though not as much as the use of Automatic thermostat.

In addition, the study reveal an unsatisfactory and unacceptable general observation (valve tagging, pressure gauge installations and automatic air vent installations) of the HVAC installation. It also reveal a generally unsatisfactory Fan installation assessment except for duct indication of the fan which was adequately indicated in most of the hotel. Study also revealed that most of the hotels have very good Gate valve installations and Pipe identifications however almost all didn’t conform to other standard checks like: provision of supporting systems, control sequence and changeover unit installations of the chillers. The checks also revealed a bad temperature sensor connection to (Direct Digital Control) DDC and faulty Selector switch connection to DDC in most of the hotel HVAC control system

In continuation, the study also reveals a potential energy savings and chances of generating energy consumption data using an energy simulation built from the theory of the Model Predictive Control of the HVAC installations (when simulated in the morning with the same reference temperature range (16-22^{o}C), Binary control system predicted an energy of (3.339 X 10^6) Kwh while the MPC predicted (2.181 X 10^5) Kwh. In a similar occasion using the same reference temperature but at night the result of the binary control system predicted

(7.357×10^8) Kwh while the MPC predicted (6.364×10^8) Kwh.). The MPC HVAC also promises a 4.2- 34/6%% HVAC energy saving per square meter when test with the peculiarities of the various Hotels studied.

Finally, the study revealed that out of the three (3) hypotheses formulated, one (1) was accepted and two rejected. That is, the study observed that:

1. HVAC components system has not been of adequate maintenance in Hotels in Owerri Nigeria.
2. There is HVAC installation components that are better maintained in the Hotels;
3. There is key strategy for saving energy using HVAC system.
4. The maintenance of HVAC installations significantly affects its energy consumptions in the area.

CHAPTER FIVE

5.0: CONCLUSION AND RECOMMENDATIONS

5.1: CONCLUSION:

The growing trend in the HVAC installations in buildings which have now become almost essential in parallel to the spread in the demand for thermal comfort, considered a luxury not long ago have also resulted in increase in the energy consumption. This growing trend of HVAC Energy consumption will continue during the coming years due to the expansion of built area and associated energy needs, as long as resources and environmental exhaustion or economic recession allows it. To this end, this study was conceived to study how a sustainable energy Consumption of HVAC systems can be achieved through installations conformity with standards, adequate maintenance of the major components of the HVAC and the use of a Predictive Control to plan and regulate the energy consumptions of the HVAC systems in the Hotels. Based on the summary of the major findings of the study as shown in section 4.4 and the research objectives in section 1.3, the following conclusion were reached:

1. The most common type of HVAC system used in almost all the Hotels is the Unit Packaged HVAC equipment and as such the number of HVAC units in the Hotels were almost exactly the number of rooms in the Hotels excluding those in the receptions and offices. Also with the number of floors in the hotels being within to 0-3 floors above ground floor and with an average number of rooms of within the range of 31-40 rooms it show cases the average number of HVAC units in each Hotel. The average age of use of the HVAC systems in most of the hotels to be between 7-9years from date of installations. Also wing to the fact that occupants/customers are neither restricted in any way to the use of the HVAC systems, nor is there any provided guide, misused is often the report and consequently energy wastage. To this, the need for HVAC control system and the most common HVAC operation control type and strategy used in most of the Hotels studied is ‘On/off toolbox’

2. Maintenance of the HVAC systems is informed by the following facts in the order of severity; availability of fund, faulty operation of the system and in few occasion it is a normal maintenance routine. The maintenance of the HVAC systems when reported stays as much as four weeks and even more. The routine maintenance of the HVAC systems in most of the Hotels is done in interval of 18months with only few Hotels (such as Immaculate, Bay view Hotel, Ideal Suit, Rock view and City global Hotel) who take less timing of about 7-12months. the most common fault often observed in the HVAC control is 'Control Sensor Faults'; 'faulty Adjusters'; very low 'Control setting' and 'Control settings higher than desired' arranged in the order of how frequent it occurs.
3. The most maintained component of the HVAC system are the chillers. While an overview of the common maintenance check in each of the components are as follows:
    a) the Chillers ("Inspection and adjustment of all operating safety controls", "Lubrication of vane/ linkage/ bearing", "Visually inspection of the chillers and associated components, for an unusual sound or noise for evidence of unusual conditions" and "Check on the refrigerant level, leak test with electronic Leak detector. If abnormal, trace and rectify as necessary").
    b) the Water Pump (Checking all bolts and nuts for tightness and tighten as necessary"; Checking all pump bearings and lubricate with oil or grease as necessary" and "Inspection of all water pumps")
    c) Air Handling Units are ("Inspection of all air handling and fan coil unit"; "Checking and cleaning of all the condensate pans, trays and drains"; and "Checking all air filters and clean or change filters as necessary" arranged in their order of severity).
    d) the Air Cooled Packages Units and precision Computer air conditioning equipment are: ("Checking electrical terminals and contactors operation and connection for tightness" and "Checking fan and motor mounting brackets)
    e) the Ventilation Component ("Tightening of the motor terminals"; "Check starter contacts" and "Checking the tension of all belt drives and adjust as necessary")

f) the Switch Board (“Cleaning and adjusting all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months”)

g) The Piping System (“Checking all piping system for leaks and repair” and “Checking for damage & deterioration of insulation or sheathings. Rectify as necessary”)

4. Automatic thermostat is a promising energy saving strategy using the HVAC system. But with the introduction of a Model Predictive Controller, energy consumption can be predicted based on a reference temperature range and the controller has the potency of reducing the energy consumption of the HVAC system.. Other strategy such as the use of ‘Variable motor speed adjuster’ and ‘On/off toolbox’ can be use but not as effective as Automatic thermostat. The Model predictive control identified as a good energy simulation tool for HVAC energy prediction and potential energy savings that can be made

5. There is an unsatisfactory and unacceptable general observation of the HVAC system (this entails; valve tagging, pressure gauge installations and automatic air vent installations) contrary to the provision/requirement of ASHRAE Standard 62.1 and 62.2. There are also reoccurring bad temperature sensors connection to (Direct Digital Control) DDC and faulty Selector switch connection to DDC in most of the hotel HVAC control system.
6. HVAC components system has not been of adequate maintenance in Hotels in Owerri Nigeria.
7. There is HVAC installation components that are better maintained in the Hotels;
8. There is key strategy for saving energy using HVAC system.
9. The maintenance of HVAC installations significantly affects its energy consumptions in the area.

5.2: RECOMMENDATIONS

From the findings of the research, the following recommendations are made for an effective HVAC energy consumption in the Hotels in Owerri:

A. The installation of the HVAC systems should be based strictly on the requirement and specification of standards such as ASHRAE 62.1 and 62.2 from the acquisition stage through the installation stage in the Hotels.
B. The HVAC systems in most of the Hotels that are aging out should be replaced with recent energy saving HVAC units
C. Equal maintenance attention should be given to all the components of the HVAC system as the entire components are interdependent and needs to work together as an entity to avoid energy wastage
D. There should be a more frequent maintenance routine (less than the common 18months interval identified) and a prompt response to the call for maintenance at the event of any fault in the HVAC system.
E. and or the Automatic thermostat in the control of the HVAC system to achieve a definite control of the energy consumption of the HVAC systems in the Hotels in Owerri
F. As much as possible a definite attention must be given to the HVAC control component to ensure that there is no any form of fault such bad temperature sensors connection to (Direct Digital Control) DDC and faulty Selector switch connection to DDC at any point in time in hotels.
G. The study also recommends the use of Automatic thermostat as against the common On/off toolbox' in the control of the HVAC system to achieve a definite and lasting control of the energy consumption of the HVAC systems in the Hotels in Owerri
H. In addition to a functional control system, the study recommends the adoption of a Model Predictive Controller, as it have the potency to predict the HVAC energy consumption and reduce the energy consumption simultaneously. Also as it promises an energy savings of about 5.7-10% while still predicting the energy consumption for managerial purposes.
I. Finally, the study recommends the adoption of Model Predictive Control to simulate the HVAC energy consumption in the Hotel in Owerri to help them predict and plan the energy budget of the Hotels.

5.3: CONTRIBUTIONS TO KNOWLEDGE:

This research has opened a new dimension of study in this area since there has been no previous research done in sufficient details as regard the assessment of the HVAC system maintenance and energy consumption in the study area. Hence, the major contributions to knowledge from this study include the following:

i. The study generated both qualitative and quantitative assessment of the HVAC installations in the Hotels as a public building in Owerri Municipal Imo State buildings;
ii. The research provided an understanding of the maintenance culture of the various HVAC system component in the Hotels in owerri which previously do not exist;
iii. The study also developed qualitative and quantitative data on how the maintenance of the HVAC systems affects the HVAC energy consumptions.
iv. The research identified issues related to the Energy saving strategy for HVAC installations with and the challenges with the energy control of HVAC systems in the Hotels in owerri
v. The research also generated qualitative and quantitative conformity assessment of the HVAC installations in the Hotels in Owerri to the provision of the Standards for HVAC installations.
vi. The study developed a Model Predictive Control simulation software that can readily predict of HVAC energy and possible savings using the MPC, which before now there is no MPC simulation for HVAC peculiar to Nigeria or Owerri in Nigeria.

5.4 RECOMMENDATIONS FOR FURTHER STUDIES.

This research is one of the first research on the field of the Energy consumption of HVAC systems in Nigeria and Owerri in particular and as such a lot of areas or aspects are still open to further researches. Therefore, this research recommends that further should be:

a) Extended to other types of public buildings like school, Hospitals and even residential building where the use of HVAC systems are becoming rampant and no longer considered as luxury but a necessity for thermal comfort

b) More researches, should be extended in the use of MPC algorithm to accommodate the other HVAC systems especially the centralized systems
c) Further research should be embarked on to cover other aspect of The Heating and Ventilation Systems especially the area of the heaters boilers in the buildings in the move for sustainable energy consumption.

REFERENCES

Abrahamse, W., L. Steg, C. Vlek, and T. Rothengatter (2005), A review of intervention studies aimed at household energy conservation, Journal of Environmental Psychology 25, 273-291.

Adeyemi A. and Ibe A (2014). Pattern of Firewoood Exploitation and Utilization in Peri-Urban And Rural Areas of Owerri Zone in Southern Nigeria. *Nigerian Journal of Agricultural and Environment*. 10(3): 113-119

Afram, A.; Janabi-Sharifi, F. Theory and applications of HVAC control systems—A review of model predictive control (MPC). *Build. Environ.* 2014, *72*, 343–355.

Afram, A.; Janabi-sharifi, F.; Fung, A.S.; Raahemifar, K. Artificial neural network (ANN) based model predictive control (MPC) and optimization of HVAC systems: A state of the art review and case study of a residential HVAC system. *Energy Build.* 2017, *141*, 96–113.

Alcala, R.; Benitez, J.M.; Casillas, J.; Cordon, O.; Perez, R. Fuzzy control of HVAC systems optimized by genetic algorithms. *Appl. Intell.* 2003, *18*, 155–177.

Al-Homoud, (2005). M.S. Performance characteristics and practical applications of common building thermal insulation materials. *Build. Envrion.*, *40*, 353–366.

Aliyu, A., Ramli, A., Saleh, M. (2013). Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. Energy, 61(8), 354-367. doi:10.1016/j.energy.2013.09.011

Álvarez, J.D.; Redondo, J.L.; Camponogara, E.; Normey-Rico, J.; Berenguel, M.; Ortigosa, P.M. Optimizing building comfort temperature regulation via model predictive control. *Energy Build.* 2013, *57*, 361–372.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *2013 ASHRAE Handbook—Fundamentals (SI Edition)*; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2013.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *2015 ASHRAE Handbook—HVAC Applications*; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2015.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *Standard 55—Thermal Environmental Conditions for Human Occupancy*; ASHRAE: Atlanta, GA, USA, 2016.

Andersen, K.K.; Madsen, H.; Hansen, L.H. Modelling the heat dynamics of a building using stochastic differential equations. *Energy Build.* 2000, *31*, 13–24.

Arabali, A.; Ghofrani, M.; Etezadi-Amoli, M.; Fadali, M.S.; Baghzouz, Y. Genetic-algorithm-based optimization approach for energy management. *IEEE Trans. Power Deliv.* 2013, *28*, 162–170.

ASHARE. (2011). *Advanced energy design guide for small to medium office buildings : achieving 50% energy savings toward a net zero energy building*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE. (2008). *Advanced energy design guide for K-12 school buildings : achieving 30% energy savings toward a net zero energy building.* ASHRAE, Atlanta, Ga.

Asif, M.; Muneer, T.; Kelly, R (2007). Life cycle assessment: A case study of a dwelling home in Scotland. *Build. Environ*. *42*, 1391–1394.

Asif, M.; Muneer, T.; Kelly, R. (2007) Life cycle assessment: A case study of a dwelling home in Scotland. *Build. Environ*., *42,* 1391–139

Aste, N.; Manfren, M.; Marenzi, G. Building Automation and Control Systems and performance optimization: A framework for analysis. *Renew. Sustain. Energy Rev.* 2017, *75*, 313–330.

Atam, E.; Helsen, L. Ground-coupled heat pumps: Part 1—Literature review and research challenges in modeling and optimal control. *Renew. Sustain. Energy Rev.* 2016, *54*, 1653–1667.

Australian Greenhouse Office. (2010). Australian Public Building Sector Green-House Gas Emission. AGO, Canberra, Australia; 1990–2010.

Bacher, P.; Madsen, H. Identifying suitable models for the heat dynamics of buildings. *Energy Build.* 2011, *43*, 1511–1522.

Balaras CA, Grossman G, Henning H, Ferreira CAI, Podesser E, Wang L, et al.(2007). Solar air conditioning in Europe – an overview. Renew Sustain Energy Rev 2007;11:299–314

Barr, S. Gilg, A.W. and N. Ford (2005), The household energy gap: examining the divide between habitual- and purchase-related conservation behaviours. Energy Policy 33, 1425–1444.

Belz, F.-M, M. Bilharz (Eds.) (2005), Nachhaltigkeits-Marketing in Theorie und Praxis,Wiesbaden 2005.

Belz, F.-M., M. Bilharz (2005), Nachhaltiger Konsum: Zentrale Herausforderung für moderne Verbraucherpolitik, Consumer Science TU München, Diskussionsbeitrag No. 1, München 2005.

Bemporad, A. A multiparametric quadratic programming algorithm with polyhedral computations based on nonnegative least squares. *IEEE Trans. Autom. Control* 2015, *60*, 2892–2903.

Bemporad, A.; Morari, M. Robust model predictive control: A survey. *Lect. Notes Control Inf. Sci.* 2007, *245*, 207–226.

Bernardini, D.; Bemporad, A. Stabilizing model predictive control of stochastic constrained linear systems. *IEEE Trans. Autom. Control* 2012, *57*, 1468–1480.

Bloem, J. *System Identification Applied to Building Performance Data*; Joint Research Centre European Commission: Geel, Belgium, 1994.

Boardman, B., Killip, G., Darby, S., Sinden, G., Jardine, C.N., Hinnells, M. and Palmer, J. (2005) 40% House Report, Environmental Change Institute (ECI), Oxford.

Borrelli, F. Fast stochastic predictive control for building temperature regulation. In Proceedings of the 2012 American Control Conference (ACC), Montreal, QC, Canada, 27–29 June 2012.

Brandon, G., Lewis, A., 1999, Reducing household energy consumption: a qualitative and quantitative field study. Journal of Environmental Psychology 19 (1), 75–85.

Brechling, V., Smith, S. (1994), Household energy efficiency in the UK. Fiscal Studies 15, 44-56.

Building Smart Alliance. (2010). “National BIM Standard | Whole Building Design Guide.” <http://www.wbdg.org/bim/nbims.php> (Mar. 27, 2011).

Buys J. H. (2002() Integration of economic and performance analysis for HVAC systems. PhD thesis, Potchefstroom University for Christian Higher Education, Potchefstroom, South Africa, pp-120

Camacho, E.F.; Bordons, C.A. *Model Predictive Control*, 2nd ed.; Springer: London, UK, 2007.

Capozzoli, A.; Cerquitelli, T.; Piscitelli, M. Enhancing energy efficiency in buildings through innovative data analytics technologies. In *Next Generation Platforms for Intelligent Data Collection*; Dobre, C., Xhafa, F., Eds.; Elsevier: Cambridge, MA, USA, 2016; pp. 353–389.

Carlisle, N.; Elling, J.; Penney, T. *A Renewable Energy Community: Key Elements*; National Renewable Energy Laboratory Technical Report, NREL/TP-540-42774; US Department of Energy: Washington, DC, USA, 2008; Available online: http://www.chemkeys.com/ blog/wpcontent/uploads/2008/09/renewable-energy-key-elements.pdf (accessed on 7 July 2018).

Carlsson-Kanyama, A., A.-L. Linden (2007), Energy efficiency in residences-challenges for women and men in the North. Energy Policy 35, 2163–2172.

Carlsson-Kanyama, A., A.-L. Linden and B. Ericsson (2005), Residential energy behaviour: does generation matter? International Journal of Consumer Studies 29, 239–252.

Castilla, M.; Álvarez, J.D.; Normey-Rico, J.E.; Rodríguez, F. Thermal comfort control using a non-linear MPC strategy: A real case of study in a bioclimatic building. *J. Process Control* 2014, *24*, 703–713.

CBECS. (2008). *Electricity Consumtion (Btu) by End Use for All Buildings*

Chen, X.; Wang, Q.; Srebric, J. Model predictive control for indoor thermal comfort and energy optimization using occupant feedback. *Energy Build.* 2015, *102*, 357–369.

Chenari, B.; Dias Carrilho, J.; Gameiro Da Silva, M. Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review. *Renew. Sustain. Energy Rev.* 2016, *59*, 1426–1447.

CIBSE, 2000. Guide to Ownership, Operation and Maintenance of Building Services, Chartered Institution of Building Services Engineers (CIBSE), London.

CIBSE, 2002. Guide to Building Services for Historic Buildings: Sustainable Services for Traditional Buildings, Chartered Institution of Building Services Engineers (CIBSE), London.

Claasen D. T (2003) New procedures of reduce cost in HVAC systems. PhD thesis, Potchefstroom Christian University of Higher Education, Potchefstroom

Computer Integrated Construction Research Program. (2010). *BIM Project Execution Plann ing Guide Version 2.0*. The Pennsylvania State University, University Park, PA, USA.

Corbin, C.D.; Henze, G.P.; May-Ostendorp, P. A model predictive control optimization environment for real-time Public building application. *J. Build. Perform. Simul.* 2013, *6*, 159–174.

CSIR (2001): Agenda 21 for Sustainable Construction in Developing Countries. Programme for Sustainable Human Settlement .

Curtis, F., P. Simpson-Housley, and S. Drever (1984). Household energy conservation. Energy Policy 12, 452–456.

Desideri U, Proietti S, Sdringola P. (2009). Solar-powered cooling system: technical and economic analysis on industrial refrigeration and air-conditioning applications. Appl Energy 2009;86:1376–86.

Dillman, D., E. Rosa and J. Dillman (1983) Lifestyle and home energy conservation in the United States: the poor accept lifestyle cutbacks while the wealthy invest in conserva- tion, Journal of Economic Psychology 3, 299–315.

Dimoudi, A.; Tompa, C (2008). Energy and environmental indicators related to construction of office buildings. *Resour. Conserv. Recycl*., *53*, 86–95.

Dirrective 2002/91/CE of the European Parliament and the Council of 16December 2002 on the energy performance of buildings, 2002

Dounis, A.I.; Caraiscos, C. Advanced control systems engineering for energy and comfort management in a building environment—A review. *Renew. Sustain. Energy Rev.* 2009, *13*, 1246–1261.

Eberle, U., Brohmann, B. and K. Graulich (2004), Sustainable Consumption needs Visions, Position Paper by the Institute of applied Ecology, Öko-Institut Freiburg/Darmstadt.

El Razaz, Z (2010). Design for dismantling strategies. *J. Build. Apprais.*, *6*, 49–61.

Empacher, C. (2001), Zielgruppenspezifische Potenziale und Barrieren für nachhaltigen Konsum. Ergebnisse einer sozial-ökologischen Konsumentenuntersuchung Vortrag gehalten bei der Tagung "Nachhaltiger Konsum? Auf dem Wege zur gesellschaftlichen Verankerung", 29./30.11.2001 (http://www.isoe.de/ftp/CEHohenheim.pdf).

Energy Conversation Building Code (ECBC).(2007). Bureau of Energy Efficiency, Ministry of Power, Government of India; 2007.

Energy Information Administration (EIA). *2012 Public Buildings Energy Consumption Survey Data*; EIA: Washington, DC, USA, 2012.

Energy Information Administration Residential Energy Consumption Survey (RECS) U. S. Departement of Energy, 200.

Energy Information Administration, International Energy Outlook 2006, U. S Department of Energy, June 2006

Esther, B.P.; Kumar, K.S. A survey on residential Demand Side Management architecture, approaches, optimization models and methods. *Renew. Sustain. Energy Rev.* 2016, *59*, 342–351.

Ferguson M. R. (1993), Energy-saving housing improvements in Canada (1979 - 82): a ested logit analysis, Environment and Planning A 25, 609 – 625.

Ferreira, P.M.; Ruano, A.E.; Silva, S.; Conceição, E.Z.E. Neural networks based predictive control for thermal comfort and energy savings in public buildings. *Energy Build.* 2012, *55*, 238–251.

Fichter, K. (2005), Interpreneurship. Nachhaltigkeitsinnovationen in interaktiven Perspektiven eines vernetzenden Unternehmertums, Marburg.

Fiorentini, M.; Cooper, P.; Ma, Z. Development and optimization of an innovative HVAC system with integrated PVT and PCM thermal storage for a net-zero energy retrofitted house. *Energy Build.* 2015, *94*, 21–32.

Fiorentini, M.; Cooper, P.; Ma, Z.; Robinson, D.A. Hybrid model predictive control of a residential HVAC system with PVT energy generation and PCM thermal storage. *Energy Procedia* 2015, *83*, 21–30.

Fiorentini, M.; Wall, J.; Ma, Z.; Braslavsky, J.H.; Cooper, P. Hybrid model predictive control of a residential HVAC system with on-site thermal energy generation and storage. *Appl. Energy* 2017, *187*, 465–479.

Firląg, S.; Yazdanian, M.; Curcija, C.; Kohler, C.; Vidanovic, S.; Hart, R.; Czarnecki, S. Control algorithms for dynamic windows for residential buildings. *Energy Build.* 2015, *109*, 157–173.

Florita, A.; Henze, G. Comparison of Short-Term Weather Forecasting Models for Model Predictive Control. *HVAC&R Res.* 2009, *15*, 835–853.

Fong KF, Chow TT, Lee CK, Lin Z, Chan LS. (2010). Comparative study of different solar cooling systems for buildings in subtropical city. Sol Energy 2010;84:227–44.

Gagendran, T (2000). *An Integrated Approach to Assess Facilities Performance*. Unpublished Masters thesis. National University of Singapore.

Gianluca S, Massimo F, Alfonso C, Daniele B, Alberto B (2018). Model Predictive Control (MPC) for Enhancing Building and HVAC System Energy Efficiency: Problem Formulation, Applications and Opportunitie. Energies 2018, 11, 63.

Gilleard .J.D (2003): *Challenges and Opportunities:* Facilities Management in Shanghai. MCB University press, Hong Kong

Gondhalekar, R.; Oldewurtel, F.; Jones, C.N. Least-restrictive robust periodic model predictive control applied to room temperature regulation. *Automatica*2013, *49*, 2760–2766.

Graham, P (2003). *Building Ecology—First Principles for a Sustainable Built Environment*; lackwell, publishing: Oxford, UK.

Gyalistras, D.; Gwerder, M. *Use of Weather and Occupancy Forecasts for Optimal Building Climate Control (OptiControl): Two Years Progress Report*; ETH Zurich: Zurich, Switzerland, 2009.

Hagras, H.; Packharn, I.; Vanderstockt, Y.; McNulty, N.; Vadher, A.; Doctor, F. An intelligent agent based approach for energy management in Public buildings. In Proceedings of the 2008 IEEE International Conference on Fuzzy Systems (IEEE World Congress on Computational Intelligence), Hong Kong, China, 1–6 June 2008; pp. 156–162.

Halliday, S (2008). *Sustainable Construction*; Butterworth Heinemann: London, UK.

Halvgaard, R.; Bacher, P.; Perers, B.; Andersen, E.; Furbo, S.; Jørgensen, J.B.; Poulsen, N.K.; Madsen, H. Model predictive control for a smart solar tank based on weather and consumption forecasts. *Energy Procedia* 2012, *30*, 270–278.

Halvgaard, R.; Poulsen, N.K.; Madsen, H.; Jørgensen, J.B. Economic Model Predictive Control for building climate control in a Smart Grid. In Proceedings of the 2012 IEEE PES Innovative Smart Grid Technologies (ISGT), Washington, DC, USA, 16–20 January 2012; pp. 1–6.

Hansen, U., T. Hennig (1995), Der Co-Produzenten-Ansatz im Konsumgütermarketing, in: U. Hansen (Eds.) Verbraucher- und umweltorientiertes Marketing, Schäffer-Poschel, Stuttgart.

Hansen, U., U. Schrader (1997), A Modern Model of Consumption for a Sustainable Socie-ty, Journal of Consumer Policy 20, 443-468.

Hensen, J.; Lamberts, R. *Building Performance Simulation for Design and Operation*, 1st ed.; Routledge: London, UK, 2012.

Hilliard, T.; Kavgic, M.; Swan, L. Model predictive control for Public buildings: Trends and opportunities. *Adv. Build. Energy Res.* 2016, *10*, 172–190.

Hilliard, T.; Swan, L.; Kavgic, M.; Qin, Z.; Lingras, P. Development of a whole building model predictive control strategy for a LEED silver community college. *Energy Build.* 2016, *111*, 224–232.

Hirst, E., Goeltz, R. (1982), Residential energy conservation actions: analysis of disaggregated data. Energy Systems and Policy 6, 135–150.

Holness G. V. R. (2008) Improving Energy Efficiency in existing buildings. ASHRAE Journal Vol. 50, Iss 1, January 200, pp 10-26

Huang, G. Model predictive control of VAV zone thermal systems concerning bi-linearity and gain nonlinearity. *Control Eng. Pract.* 2011, *19*, 700–710.

Huang, W.; Lam, H.N. Using genetic algorithms to optimize controller parameters for HVAC systems. *Energy Build.* 1997, *26*, 277–282.

Huberman, N.; Pearlmutter, D (2008). A life cycle energy analysis of building materials in the Negev desert. *Energy Build.*, *40*, 837–848.

IDM technical Team. (2007). *"Quick Guide: Business Process Modelling Notation (BPM N)."*
Kagioglou, M., Cooper, R., Aouad, G., and Protocol, P. (1998). A generic guide to the design and construction process protocol. Process Protocol.

IEA. 2004. Energy Balances for OECD Countries and Energy Balances for non-OECD Countries; Energy Statistics for OECD Countries and Energy Statistics for non-OECD Countries (2004 editions) Paris.

IEO, International Energy Outlook (IEO), Energy Information Administration. <http://www.eia.doe.gov/oiaf/ieo>.

Ilha, M.S.O.; Oliveira, L.H.; Gonçalves, O.M. Environmental assessment of residential buildings with an emphasis on water conservation. *Build. Serv. Eng. Res. Technol.* 2009, *30*, 15–26.

International Energy Agency (IEA). *Technology Roadmap: Energy-Effcient Buildings: Heating and Cooling Equipment*; IEA: Washington, DC, USA, 2012.

International Organization for Standardization (ISO). *ISO 7730:2005—Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*; ISO/TC159/SC5; ISO: Geneva, Switzerland, 2005.

IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, witzerland, 104 pp.

Jaffe, A.B. and R.N. Stavins (1994), Energy-efficiency investments and public policy. The Energy Journal 15, 43-65.

Jager, W. (2000), Modelling Consumer Behaviour, Universal Press, Groningen.

Jumilla S. (2004) An Environmental Impact of an Office building throughout its life cycle. Espo, Helsinki University of Technology, Construction Economics and Management (Doctoral Dissertating) Quoted from United National Environmental programme (2007) Building and Climate Change: Status, Challenge and Opportunities.

Kaenzig, J., R.Wüstenhagen (2006), Understanding strategic choices for sustainable consumption: the case of residential energy supply, Proceedings: Sustainable Consumption and Production: Opportunities and Threats, Wuppertal.

Kahneman, D., A. Tversky (Eds.) (2002), Choices, values, and frames, Cambridge University Press, New York.

Kavgic, M.; Hilliard, T.; Swan, L. Opportunities for implementation of MPC in Public buildings. *Energy Procedia* 2015, *78*, 2148–2153.

Kelman, A.; Borrelli, F. Bilinear Model Predictive Control of a HVAC System Using Sequential Quadratic Programming. *IFAC Proc. Vol.* 2011, *44*, 9869–9874.

Khakimova, A.; Kusatayeva, A.; Shamshimova, A.; Sharipova, D.; Bemporad, A.; Familiant, Y.; Shintemirov, A.; Ten, V.; Rubagotti, M. Optimal energy management of a small-size building via hybrid model predictive control. *Energy Build.* 2017, *140*, 1–8.

Killian, M.; Kozek, M. Ten questions concerning model predictive control for energy efficient buildings. *Build. Environ.* 2016, *105*, 403–412. [Google Scholar] [CrossRef]

Larsen, G.K.H.; Van Foreest, N.D.; Scherpen, J.M.A. Power supply—Demand balance in a Smart Grid: An information sharing model for a market mechanism. *Appl. Math. Model.* 2014, *38*, 3350–3360.

Lazos, D.; Sproul, A.B.; Kay, M. Optimisation of energy management in Public buildings with weather forecasting inputs: A review. *Renew. Sustain. Energy Rev.* 2014, *39*, 587–603.

Lehmann, B.; Gyalistras, D.; Gwerder, M.; Wirth, K.; Carl, S. Intermediate complexity model for Model Predictive Control of Integrated Room Automation. *Energy Build.* 2013, *58*, 250–262.

Lenzen, M.; Treloar, G.J (2002). Embodied energy in buildings: Wood *versus* concrete-reply to Borjesson and Gustavsson. *Energy Policy*, *30*, 249–244.

Li, X.; Wen, J. Review of building energy modeling for control and operation. *Renew. Sustain. Energy Rev.* 2014, *37*, 517–537.

Li, Z.; Han, Y.; Xu, P. Methods for benchmarking building energy consumption against its past or intended performance: An overview. *Appl. Energy* 2014, *124*, 325–334.

Lindelof, D.; Afshari, H.; Alisafaee, M.; Biswas, J.; Caban, M.; Mocellin, X.; Viaene, J. Field tests of an adaptive, model-predictive heating controller for residential buildings. *Energy Build.* 2015, *99*, 292–302.

Long, J. (1993), An econometric analysis of residential expenditures on energy conservation and renewable energy sources. Energy Economics 15, 232-238.

López, A.; Sánchez, L.; Doctor, F.; Hagras, H.; Callaghan, V. An evolutionary algorithm for the off-line data driven generation of fuzzy controllers for intelligent buildings. In Proceedings of the 2004 IEEE International Conference on Systems, Man and Cybernetics, The Hague, The Netherlands, 10–13 October 2004; Volume 1, pp. 42–47.

Luis P., Ortiz. J, Pout .C (2008) . 'A Review on Building Energy Consumption Information ; Energy and building , 40(2008) 394-398

Ma Q, Wang RZ, Dai YJ, Zhai XQ. (2006). Performance analysis on a hybrid air conditioning system of a green building. Energy Build 2006;38:447–53.

Mady, A.E.; Provan, G.M.; Ryan, C.; Brown, K.N. Stochastic Model Predictive Controller for the Integration of Building Usage and Temperature Regulation. In Proceedings of the Twenty-Fifth AAAI Conference on Artificial Intelligence, San Francisco, CA, USA, 7–11 August 2011; pp. 1371–1376.

Magoulès, F.; Zhao, H. *Data Mining and Machine Learning in Building Energy Analysis: Towards High Performance Computing*, 1st ed.; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2016. [Google Scholar]

Martiskainen, M. (2007), Affecting consumer behaviour on energy demand, Final report to EdF Energy, Brighton, East Sussex.

Mathews, E. H. and Botha, C (2003) Improved thermal building management with the aid f integrated dynamics HVAC simulation, Building and Environment, Vol 38, No 12, pp 1423-1429

Matthews, E.; Amann, C.; Fischer-Kowalski, M.; Huttler, W.; Kleijn, R.; Moriguchi, Y.; Ottke, C.; Rodenburg, E.; Rogich, D.; Schandl, H.; Schutz, H.; van der Voet, E.; Weisz, H. (2009)*The Weight of Nations: Material Outflows from Industrial Economies*; World Resources Institute: Washington, DC, USA, 2000; Available online: http://pdf.wri.org/weight_of_nations.p (accessed on 24 May 2009.

Mayer, B.; Killian, M.; Kozek, M. Management of hybrid energy supply systems in buildings using mixed-integer model predictive control. *Energy Convers. Manag.* 2015, *98*, 470–483.

Mbamali (2005): Stone Quarrying in Nigeria. An Overview of Necessary Initiatives Towards a Sustainable Built Environment. Conference Series. Department of Building, A.B.U., Zaria. September

Michael Laar and Friedrich Wilhelm Grimme, 2002. Sustainable Buildings in the Tropics. Institute of Technology in the Tropics ITT, University of Applied Sciences Cologne: Presented at RIO 02 – World Climate & Energy Event, January 6-11, 2002.

Middleton, Nick, 2013, The Global Casino - An Introduction to Environmental Issues, Fifth Edition, New York, NY: Routledge.

Minna Sunikka-Blank & Ray Galvin (2012) Introducing the prebound effect: the gap between performance and actual energy consumption, Building Research & Information 40:3, 260-273, DOI: 10.1080/09613218.2012.690952

Mirakhorli, A.; Dong, B. Occupancy behavior based model predictive control for building indoor climate—A critical review. *Energy Build.* 2016, *129*, 499–513

Moroşan, P.-D.; Bourdais, R.; Dumur, D.; Buisson, J. Building temperature regulation using a distributed model predictive control. *Energy Build.* 2010, *42*, 1445–1452.

Naidu, D.S.; Rieger, C. Advanced control strategies for heating, ventilation, air-conditioning, and refrigeration systems—An overview: Part I: Hard control. *HVAC&R Res.* 2011, *17*, 2–21.

Nassif, N. Modeling and optimization of HVAC systems using artificial neural network and genetic algorithm. *Build. Simul.* 2013, *7*, 237–245.

National Action Plan for Energy Efficiency. (2008). *Sector Collaborative on Energy Efficie ncy Accomplishments and Next Steps*.

Njoku . B.A (2009). Environmental Pollution In Owerri Municipal-Chemistry Education To The Rescue. Journal Of Research In National Development Volume 7

NPC 2006. List of Nigerian State by Ladmass and Population Density. National Population Commmision Census Result, MACOS Uran Management Consultants

Ntsoane, M. T. (2005) implementing energy efficiency: London: Sage Publications, first Edition, pp 110-226

O'Leary Z. (2004) the essential guide t doing research, London: Sage Publication, first Edition pp 11-226

OECD (2002), Decision-Making and Environmental Policy Design for Consumer Durabl,. ENV/EPOC/WPNEP(2002)7/FINAL. OECD, Paris.

OECD (2002), Towards Sustainable Consumption: An Economic Conceptual Framework, OECD, Paris.

Okafor, E, E., Hassan, A.R and Hassan, A.D. (2008): Environmental Issues ans Corporate Social Responsibility: the Experience. J. Hum. Ecol. 23(2): 101-107

Oldewurtel, F.; Parisio, A.; Jones, C.N.; Morari, M.; Gyalistras, D.; Gwerder, M.; Stauch, V.; Lehmann, B.; Wirth, K. Energy efficient building climate control using Stochastic Model Predictive Control and weather predictions. In Proceedings of the American Control Conference (ACC), Baltimore, MD, USA, 30 June–2 July 2010.

Parisio, A.; Fabietti, L.; Molinari, M.; Varagnolo, D.; Johansson, K.H. Control of HVAC systems via scenario-based explicit MPC. In Proceedings of the 2014 IEEE 53rd Annual Conference on Decision and Control (CDC), Los Angeles, CA, USA, 15–17 December 2014.

Pérez-Lombard L, Ortiz J and Pout C (2008). A review on buildings energy consumption information. Energy and Buildings 40 (394–398)

Perez-lombard L, Ortiz J, Pout C. (2008). A review on buildings energy consumption information. Energy Build;40:394–8.

Petersdorff, C., Boermans, T., and Harnisch, J. (2006). “Mitigation of CO2 Emissions from the EU-15 Building Stock. Beyond the EU Directive on the Energy Performance of Buildings (9 pp).” *Environmental Science and Pollution Research*, 13(5), 350–358

Platt, G.; Li, J.; Li, R.; Poulton, G.; James, G.; Wall, J. Adaptive HVAC zone modeling for sustainable buildings. *Energy Build.* 2010, *42*, 412–421.

Prívara, S.; Cigler, J.; Váňa, Z.; Oldewurtel, F.; Sagerschnig, C.; Žáčeková, E. Building modeling as a crucial part for building predictive control. *Energy Build.* 2013, *56*, 8–22.

Privara, S.; Vana, Z.; Zacekova, E.; Cigler, J. Building modeling: Selection of the most appropriate model for predictive control. *Energy Build.* 2012, *55*, 341–350.

Rawlings, J.B.; Mayne, D.Q. *Model Predictive Control: Theory and Design*, 5th ed.; Nob Hill Pub: Madison, WI, USA, 2012.

Reinink, MW (2007) Twards an effective energy labelling prgramme for commercial buildings: A Comparative evaluation of the green building for Africa Prgramme in relation to Internatinal experience, M .Arch. Thesis, University of the Witwatersrand

Reusswig,F., K. Gerlinger and O. Edenhofer (2004), Lebensstile und globaler Energieverbrauch - Analysen und Strategieansätze zu einer nachhaltigen Energiestruktur. Potsdam, PIK Report 90.

Sardinanou, E. (2007), Estimating energy conservation patterns of Greek households. Energy Policy 35, 3778-3791.

Sasnauskaite, V.; Uzsilaityte, L.; Rogoza, A (2007). A sustainable analysis of a detached house heating system throughout its life cycle. A case study. *Strateg. Prop. Manag.*, *11*, 143–155.

Saxon State Agency for Environment and Geology (2007), Awareness of energy efficiency in private households. Representive survey.

Scherhorn, G. (1994), Die Unersättlichkeit der Bedürfnisse und der kalte Stern der Knappheit, in: B. Biervert, M. Held (Eds.) Das Naturverständnis der Ökonomik, Campus, Frankfurt am Main.

Schimschar, S.; Blok, K.; Boermans, T.; Hermelink, A (2011). Germany’s path towards nearly zero-energy buildings—Enabling the greenhouse gas mitigation potential in the building stock. *Energy Policy, 39*, 3346–3360.

Scott, S., (1997), Household energy efficiency in Ireland: a replication study of owner of energy saving items. Energy Economics 19, 187–208.

Shaikh, P.H.; Nor, N.B.M.; Nallagownden, P.; Elamvazuthi, I.; Ibrahim, T. A review on optimized control systems for building energy and comfort management of smart sustainable buildings. *Renew. Sustain. Energy Rev.* 2014, *34*, 409–429.

Shove, E. (2003), Converging conventions of comfort, cleanliness and convenience, Journal of Consumer Policy 26, 395-418.

Siroky, J.; Cigler, J.; Ferkl, L. Hybrid MPC approach to reconfiguration of building heating system. In Proceedings of the 2013 Control Conference (ECC), Zurich, Switzerland, 17–19 July 2013.

Siroky, J.; Oldewurtel, F.; Cigler, J.; Privara, S. Experimental analysis of model predictive control for an energy efficient building heating system. *Appl. Energy*2011, *88*, 3079–3087.

Stern, P.C. (2000), Toward a Coherent Theory of Environmentally Significant Behavior,Journal of Social Issues 56, 407-424

Sturzenegger, D. *Bilinear Modeling of an Air Handling Unit for Model Predicitive Control Technical Report Models of the Components Nonlinear AHU Model*; Eidgenössische Technische Hochschule (ETH), Institut für Automatik: Zürich, Switzerland, 2015.

Sturzenegger, D. *Model Predictive Building Climate Control—Steps Towards Practice*; ETH Zurich: Zurich, Switzerland, 2012.

Sturzenegger, D.; Gyalistras, D.; Morari, M.; Smith, R.S. Model Predictive Climate Control of a Swiss Office Building: Implementation, Results, and Cost-Benefit Analysis. *IEEE Trans. Control Syst. Technol.* 2016, *24*, 1–12.

Sturzenegger, D.; Gyalistras, D.; Morari, M.; Smith, R.S. Semi-automated modular modeling of buildings for model predictive control. In Proceedings of the BuildSys '12 Fourth ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings, Toronto, ON, Canada, 6 November 2012; pp. 99–106.

Sunikka, M. (2006) Policies for Improving Energy Efficiency of the European Housing Stock, IOS Press, Amsterdam.

Sunikka-Blank, M. and Galvin, R. (Forthcoming 2012) The economic viability of thermal retrofit policies: implications for the UK Green Deal based on the experience from German mandatory thermal renovation standards. Energy Policy (forthcoming).

Sunikka-Blank, M., Chen, J., Britnell, J. and Dantsiou, D. (2012) Improving energy efficiency of social housing areas: a case study of a retrofit achieving an 'A' energy performance rating in the UK. European Planning Studies, 20(1), 133–147.

Swedish National Energy Administration (2001). Energy in Sweden [online]. Swedish National Energy Administration. Available from: http:// www.stem.se. [2002-06-05]

Thormark, C (2006). The effect of material choice on the total energy need and recycling potential of a building. *Build. Envrion.*, *41*, 1019–1026.

Tran, T.; Ling, K.-V.; Maciejowski, J.M. Economic Model Predictive Control—A Review. In Proceedings of the 31st International Symposiumon Automationand Roboticsin Constructionand Mining (ISARC), Sydney, Australia, 9–11 July 2014; pp. 1–8.

United Nations Environmental Programme (2007) building and Climate Change: Status, Challenge and Opportunities. Available at [http://www.unep.fr/pc/sbc/docu pp1-87](http://www.unep.fr/pc/sbc/docu) Accessed on the 15 June, 2018

Van Vliet, B. (2002), Greening the Grid. The Ecological Modernisation of Network-bound Systems. PhD-Thesis Wageningen University

Van Vliet, B., H. Chappels and E. Shove (2005), Infrastructures of Consumption. Environmental Innovation in the Utility Industries, Earthscan, London.

Verhelst, C.; Logist, F.; Van Impe, J.; Helsen, L. Study of the optimal control problem formulation for modulating air-to-water heat pumps connected to a residential floor heating system. *Energy Build.* 2012, *45*, 43–53.

Vvakloroaya V (2014) A review of different Strategies for HVAC energy saving , Energy conversion and Management, Western Sydney University

Wallace, M.; McBride, R.; Aumi, S.; Mhaskar, P.; House, J.; Salsbury, T. Energy efficient model predictive building temperature control. *Chem. Eng. Sci.* 2012, *69*, 45–58.

Walsh, M. (1989), Energy tax credits and housing improvement. Energy Economics 11,275–284.

Wang, S.; Ma, Z. Supervisory and Optimal Control of Building HVAC Systems: A Review. *HVAC&R Res.* 2007, *14*, 3–32.

WCED World Commission on Environment and Development (1987), Our Common Future, Oxford University Press, Oxford.

Weber, C., A. Perrels (2000), Modelling lifestyle effects on energy demand and related emissions. Energy Policy 28, 549-566.

Wendes H. (1994) HVAC Retrofit: Energy saving made easy. Lilbum, Gorgia: the Fairmont Press, pp 205-207

Wilhite, H. (2007), Will efficient technologies save the world? A call for new thinking on the ways that enduse technologies affect energy using practises, ECEEE 2007 SummerStudy, La Colle sur Loup.

Wilhite, H. R. Ling (1995), Measured energy savings from a more informative energy bill. Energy and Buildings 22, 145–155.

Wilson, A.; Uncapher, J.L.; McManigal, L.; Lovins, H.L.; Cureton, M.; Browning, W.D (1998). *Green Development: Integrating Ecology and Real Estate*; John Wiley and Sons, Inc.: New York, NY, USA.

Yao Y, Chen J, (2010). Global optimization of a central air-conditioning system using decomposition–coordination method. Energy Build;42:570–83.

Young, D. (2008), When do energy-efficient appliances generate energy savings? Some evidence from Canada. Energy Policy 36, 34-46

Yu, Z.; Huang, G.; Haghighat, F.; Li, H.; Zhang, G. Control strategies for integration of thermal energy storage into buildings: State-of-the-art review. *Energy Build.* 2015, *106*, 203–215.

Yudong, M.; Borrelli, F.; Hencey, B.; Packard, A.; Bortoff, S. Model Predictive Control of thermal energy storage in building cooling systems. In Proceedings of the CDC/CCC 48th IEEE Conference on Decision and Control, 2009 Held Jointly with the 2009 28th Chinese Control Conference, Shanghai, China, 15–18 December 2009; pp. 392–397.

Zakula, T.; Armstrong, P.R.; Norford, L. Modeling environment for model predictive control of buildings. *Energy Build.* 2014, *85*, 549–559. Lee, W.L.; Chen, H. Benchmarking Hong Kong and China energy codes for residential buildings. *Energy Build.* 2008, *40*, 1628–1636.

APPENDIX I –QUESTIONNAIRE

DEPARTMENT OF BUILDING
FACULTY OF ENVIRONMENTAL SCIENCE
NNAMDI AZIKIWE UNIVERSITY AWKA

Dear respondent,

QUESTIONNAIRE ADMINISTERED FOR DEVELOPING A MODEL FOR SUSTAINABLE ENERGY CONSUMPTION OF HVAC INSTALLATIONS IN HOTELS IN OWERRI, IMO STATE, NIGERIA

This questionnaire is intended to be used in Developing a Model for Sustainable Energy Consumption of HVAC Installations of Hotels in Owerri Nigeria. It will be used for academic purposes only. You are requested to kindly study and complete the questionnaire as carefully as possible.

Thank you.

bishopeio@yahoo.com

Section A: Personal Data

1) Sex?
   a) Male ( )
   b) Female ( )
2) Status?
3) What age range do you fall into
   a) Below 20yrs ( )
   b) 21-30yrs ( )
   c) 31-40yrs ( )
   d) 41 and above ( )
4) Which class of respondent are you?
   a) Staff of the Hotel ( )
   b) Contractor/Consultant to the Hotel ( )

5) If (a) in question 5 above, what class of staff are you?
   a) Front Desk Clerk ( )
   b) Supervisor of guest Services ( )
   c) House Keeping Supervisor ( )
   d) Kitchen Manager ( )
   e) Executive Chef ( )
   f) Maintenance officer ( )

Section B: Data Sheet Building Audit

6) Who owns the building?
   a) Government (Central or local) ( )
   b) Commercial private ( )
   c) Public Trust (University, Public societies, government trusts) ( )
   d) Private individual ( )

7) Any idea when the building was constructed or last refurbished with regards to HVAC system
   a) 0-10years ( )
   b) 11-20years ( )
   c) Over 20years ( )
8) Was the building used for a different purpose other than a Hotel before now?
   a) Yes ( )
   b) No ( )
   c) Don't Know ( )
9) If YES to question 8 above; what was the building originally used or designated for

a) Entertainment or assembly hall ( )
b) Offices or banking hall ( )
c) Library ( )
d) Storage and warehouse ( )

Section C: Building Physical Characteristics

10) What is the total number of storeys (above ground floors)
a) 0- 3 ( )
b) 4- 5 ( )
c) 6 and Above ( )

11) Area of a Standard guest room ………………..m^2

12) Have there ever been any energy audit conducted for the Hotel?
a) Yes ( )
b) No ( )

13) Does the Hotel Have any Building Management System?
a) Yes ( )
b) No ( )

14) What is the number of guest rooms in the Hotel?
a) 0-10 ( )
b) 11-20 ( )
c) 21-30 ( )
d) 31- 40 ( )
e) 51 and Above ( )

Section D: Building Operating Characteristics

15) Does the hotel operate throughout the whole year?
a) Yes ( )
b) No ( )

16) Does an Occupant have the privilege to operate the HVAC at all times through the day?
a) Yes ( )
b) No ( )

17) If *No* how many hours is an occupant privileged to operate the HVAC in a Day
a) 0-3hrs ( )
b) 4-6hrs ( )
c) All through the night 9.pm-6.am ( )

18) Are operational logs including repair, maintenance summary available?
a) Yes ( )
b) No ( )

19) Are HVAC manual available?

a) Yes ( )
b) No ( )

20) Are all the rooms occupied every day of the week?
a) Yes ( )
b) No ( )

21) Are the electricity bill for the building available?
a) Yes ( )
b) No ( )
If yes, a copy must be made or details noted

22) Does the building have a specific staff assigned to management of energy or plant operation?
a) Yes ( )
b) No ( )

23) What type of HVAC system is in use in the building?
a) Centralized system ( )
b) Room Conditioning Unit Packaged HVAC equipment ( )

24) If (a) in (26) above what categories below further accommodation the type of HVAC in the Building
a) Single zone system ( )
b) Multiple zone system ( )
c) Constant volume system ( )
d) Variable Volume system ( )
e) Single duct with reheat system ( )
f) Single Duct system ( )
g) Dual Duct system ( )
h) Induction system ( )

25) If (b) in (26) above what categories below
a) Radiators/ Convectors
b) Roof Top Units
c) Self-Contained Air Conditioners and thro wall heat pumps
d) Remotely cooled contained Air Conditioners and heat pumps
e) Heat Pump Loop System
f) Direct Fired Heating Units

Section E: Energy Management of the Hotels

26) Who is responsible for energy management in the building
a) Building operators ( )
b) Maintenance Contractors ( )
c) Nobody ( )

27) Is there an Energy consumption budget?
a) Yes ( )
b) No ( )
c) Not sure ( )

28) What fraction of (27) is constituted by HVAC System Consumption?
   a) Less than ¼
   b) ¼ to ½ ( )
   c) ½ to ¾ ( )
   d) Over ¾ ( )
29) Does the building management review or carry out analysis of energy consumption?
   a) Yes ( )
   b) No ( )
   c) Not sure ( )
30) If Yes above (29) at what time intervals are the energy consumption review carried out
   a) 0 to 6months ( )
   b) 7 to 12months ( )
   c) 13 to 1months ( )
   d) Over 18 months ( )
31) Are you familiar with the operation procedure of the HVAC system installed in this building?
   a) Yes ( )
   b) No ( )

32) Have you come across any placard explaining operation or any other issue concerning the HVAC system in this Hotel
   a) Yes ( )
   b) No ( )
33) How is the maintenance of this building organized?
   a) Whenever there is faculty operation ( )
   b) On regular basis ( )
   c) Whenever funds allow ( )
34) What is the waiting period taken to repair reported faults in the building?
   a) Less than 3days ( )
   b) 3days to one week ( )
   c) 1 week to 2 weeks ( )
   d) 2 weeks to 3 weeks ( )
   e) 4 weeks ( )
   f) Over 4 weeks ( )

Section F: HVAC Maintenance

35) Is there planned maintenance for HVAC systems in the building?
   a) Yes ( )
   b) No ( )
36) What are the schedule for the planned maintenance?
   a) 0-6mnths ( )
   b) 7-12 months ( )
   c) 13-18 months ( )

d) Over 18 months ( )

37) Who is in charge of HVAC system service maintenance in the building?
   a) Building operator ( )
   b) Maintenance contractor ( )
   c) Nobody ( )

38) If (b) in (37) is there is a maintenance or service contract?
   a) Yes ( )
   b) No ( )
   c) Not Sure ( )

39) If YES briefly tick from the choices below the elements covered by the maintenance or services contract?
   a) cddddfvzczServices or maintenance duration ( )
   b) Filter Replacement or clean up ( )
   c) Duct clean up ( )
   d) Replacement of faulty units/parts ( )
   e) Refrigerant recharge/change ( )
   f) Purging of system ( )
   g) Review of HVAC system performance and operational/ energy efficiency

40) Rank the Frequency of the maintenance and monthly check-up of the HVAC installation b the maintenance/services/facilities managers in the buildings
   Where: ND= Never Done; RD= Rarely Done; NI= No Idea; OD= Often Done; AD= Always Done

S/N	Maintenance of the HVAC Components	ND	RD	NI	OD	AD
A	Chillers					
1	Check refrigerant level, leak test with electronic Leak detector. If abnormal, trace and rectify as necessary, Inform department in writing on the rectification					
2	Inspect level and condition of oil. If abnormal, trace fault and rectify as necessary. Inform department in writing on the rectification					
3	Check the liquid line sight glasses for proper flow					
4	Check all operating pressure and temperature					
5	Inspect and adjust, if required, all operating safety controls					
6	Check capacity control, adjust if necessary.					
7	Lubricate vane/ linkage/ bearings.					
8	Visually inspect machine and associated components, and listen for unusual sound or noise for evidence of unusual conditions.					
9	Check lock bolts and chiller spring mount.					

10	Review daily operating log maintained by department‘s operating personnel Review daily operating log maintained by department‘s operating personnel					
B	**WATER PUMPS**					
1	Inspect all water pumps					
2	Check all seals, glands and pipelines for leaks and rectify as necessary.					
3	Re-pack and adjust pump glands as necessary					
4	Check all pump bearings and lubricate with oil or grease as necessary.					
5	Check the alignment and condition of all rubber couplings between pumps and drive motors and rectify as necessary.					
6	Check all bolts and nuts for tightness and tighten as necessary.					
C	**AIR HANDLING UNITS AND FAN COIL UNITS**					
1	Inspect all air handling and fan coil units					
2	Check all air filters and clean or change filters as necessary.					
3	Check all water coils, seals and pipelines for leaks and rectify as necessary					
4	Check and re-calibrate modulating valves and controls. Adjust and rectify as necessary to ensure compliance to the original specifications					
5	Purge air from all water coils.					
6	Check all fan bearings and lubricate with grease as necessary.					
7	Check the tension of all belt drives and adjust as necessary.					
8	Check and clean all the condensate pans, trays and drains.					
9	Check, clean and service smoke detectors. Carry out a system test to ensure that the smoke detector will trip the AHU‘s.					
D	**AIR COOLED PACKAGED UNITS AND PRECISION COMPUTER AIR-CONDITION EQUIPMENT**					
1	Check condenser fan motor load ampere					
2	Check fan and motor mounting brackets					
3	Check shafts and bearings. Lubricate with grease as necessary.					

4	Check the tension of all belt drives and adjust as necessary.					
5	Check for refrigerant leaks with electronic leak detector.					
6	Check electrical terminals and contactors operation and connection for tightness.					
7	Check compressor motor current					
8	Check refrigerant line driers and moisture indicators					
E	**AIR DISTRIBUTION SYSTEM**					
1	Check operation of all modulating and fixed dampers controlling air flow through unit. Lubricate all damper bearings and linkages as necessary.					
2	Check noise level of discharged air from diffusers					
F	**VENTILATION**					
1	Check adjust as necessary the air flow of all fans are in compliance with the original specifications.					
2	Check the tension of all belt drives and adjust as necessary					
3	Check and lubricate all fan bearings					
4	Tighten motor terminals.					
5	Check starter contacts					
G	**SWITCH BOARD**					
1	Clean and adjust all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months					
2	Check and prove operation of thermal over load and protection devices.					
3	Check and ensure tightness of all equipment fastenings and cable terminations within switch boards					
4	Vacuum clean all switch board cubicles					
H	**PIPING SYSTEM**					
1	Check all piping system for leaks and repair these where they have occurred					
2	Check for damage & deterioration of insulation or sheathings. Rectify as necessary					

Section G: Energy Saving and HVAC Control Functionality

41) Is there an energy saving program in operation or under review?
    a) Yes ( )
    b) No ( )
    c) Not Sure ( )
42) If YES in (41) what are the focuses of the energy saving program with regards to HVAC system?
    a) Demand reduction by minimum operation of system ( )
    b) Introduction of an energy management system ( )
    c) Demand scheduling ( )
    d) HVAC system retrofit ( )
    e) Energy efficient maintenance program ( )
    f) Duct cleaning ( )
43) Tick the control type/strategies used for HVAC system operation in the building
    a) On/off toolbox ( )
    b) Automatic thermostat based control ( )
    c) Automatic thermostat based control ( )
    d) Variable Fan speed adjuster ( )
    e) Air intake control ( )
    f) Carbon dioxide sensors ( )
    g) Variable motor speed adjuster ( )
    h) Timers ( )

44) Are the control in good working condition
    a) Yes ( )
    b) No ( )
45) If YES (44) what are the observable faults
    a) Control setting are very low ( )
    b) Control knobs are broken ( )
    c) Control settings are higher than desired ( )
    d) Control sensor faulty ( )
    e) Adjusters are faulty ( )

Section H: Effect of the maintenance of HVAC system on its energy consumption

46) Do you think that the maintenance of the HVAC system influence its energy consumption?
    a) Yes ( )
    b) No ( )
    c) Not Sure ( )
47) If YES in (46) do you think that the adequate maintenance of the HVAC system will help to reduce energy wastage and optimal use of energy?

a) Yes ( )
b) No ( )
c) Not Sure ( )

48) To what extent do you think that energy is consistently wasted due to nature of the maintenance of the HVAC systems in the Hotels?
a) A very High extent ( )
b) High Extent ( )
c) Inconsequential ( )
d) Low Extent ( )
e) Very low extent ( )

49) Do you think that you think that there is urgent need of improving the maintenance of the HVAC for a sustainable energy consumption
a) Yes ( )
b) No ( )

Section I: Occupants Use of HVAC

50) Are the occupants conversant with or informed on operations of controls?
a) Yes ( )
b) No ( )

51) Are there contact(s) given for persons to get in touch with in case the HVAC system is faulty?
a) Yes ( )
b) No ( )

52) How long does it take the management to act on the report of faulty items?
a) < 3days ( )
b) 4days to 1week ( )
c) 1 - 4 weeks ( )
d) < 4 weeks ( )

53) Are there sign of vandalism of the control knobs and switches?
a) Yes ( )
b) No ( )

54) Are the occupants informed about the importance of energy conservation and specific implication of HVAC system?
a) Yes ( )
b) No ( )

55) Is there a Building Management Systems?
a) Yes ( )
b) No ( )

56) Is there an operative/staff assigned to monitor the operation of the Building Management System
a) Yes ( )
b) No ( )

57) Rank the following strategies as to the extent you agree that they can be used to save energy when using HVAC system in the building

Where: SD= Strongly Disagree; D= Disagree; U= Undeceive; A= Agreed; SA= Strongly Agreed

S/N	Control Measures	SD	D	U	A	SA
1	On/off toolbox					
2	Timers					
3	Automatic thermostat based control					
4	Variable Fan speed adjuster					
5	Air intake control					
6	Carbon dioxide sensors					
7	Variable motor speed adjuster					

Section J: Component, Equipment and Measures Values

58) What is the age of the HVAC system?
   a) 0 – 3year ( )
   b) 4- 6year ( )
   c) 7-9year ( )
   d) 10years and above ( )

59) What is the power rating of the equipment and associated component?
   ……………………………………………………………………………………………
   ………………………………………………………………………………………

60) What are the Model type of the equipment and component?
   ……………………………………………………………………………………………
   ………………………………………………………………………………………

61) What are the year of manufacture of the HVAC system?
   ……………………………………………………………………………………………
   ……………………………………………………………………………………

62) What is the stated air change rate of the HVAC system?
   ……………………………………………………………………………………………
   ………………………………………………………………………………………

63) When is the HVAC system Operated
   a) All the time (24hrs) ( )
   b) As Long as the Building is Occupied ( )
   c) Only at Night ( )
   d) Only when condition warrant use ( )
   e) When the sensor switches on ( )
   f) When thermostat trips on ( )
   g) When occupants feel like ( )

64) How often is the duct cleaned?
   a) Every 0-6mnths ( )
   b) Every 6-12 months ( )
   c) Every 12-18 months ( )
   d) Every 10-24 months ( )
   e) Irregularly/ unplanned ( )
   f) Never ( )

65) Is there any visible leakage in the duct work?
   a) Yes ( )
   b) No ( )

66) Are there other source of power to the hotels aside the EDDC supply?
   a) Yes ( )
   b) No ( )

67) If YES to 62 above list he other sources of power to the Hotels

……………………………………………………………………………………………………
…………………………………………………………………………………………………

68) Does the other sources listed above leads to the pollution of the hotel environment
   a) Yes ( )
   b) No ( )

69) Kindly suggest measure that you feel can help reduce energy consumption of the Hotels?

……………………………………………………………………………………………………
…………………………………………………………………………

APPENDIX II- CHECKLIST

DEPARTMENT OF BUILDING
FACULTY OF ENVIRONMENTAL SCIENCE
NNAMDI AZIKIWE UNIVERSITY AWKA

A CHECKLIST ADOPTED FOR DEVELOPING A MODEL FOR SUSTAINABLE ENERGY CONSUMPTION OF HVAC INSTALLATIONS IN HOTELS IN OWERRI, IMO STATE NIGERIA

INSPECTORS: ……………………………………………………………		
LOCATION/ DEPARTMENT: …………………………………. **DATE: ……………………..**		
(√) Satisfactory/Present/ ok/adequate (X) Unsatisfactory, requires attention/absent/ insufficient		
S/N	**GENERAL WORK ENVIRONMENT**	
1	Unit installed on concrete pad with 2" thick coark	[ ]
2	Unit is installed on anti-vibration mounts	[ ]
3	Alignment and Levelling	[ ]
4	Condensate drain pipe directed to nearest floor drain	[ ]
5	Condensate drain pipe shall have a P-Trap	[ ]
6	Chilled water pipes installation	[ ]
7	Chilled water pipes insulation	[ ]
8	FDI installation on main ChW return pipe	[ ]
9	Pipes identifications	[ ]
10	Valves tagging	[ ]

11	Pressure gauges installation	[ ]
12	Thermometer installation	[ ]
13	Automatic air vent installation	[ ]
14	2-way valve installation	[ ]
15	Strainer installation	[ ]
16	General cleaning	
	FANS	
17	Smoke detector installation	[ ]
18	Differential pressure on AHU's filter	[ ]
19	Differential pressure on AHU's fan	[ ]
20	Ducts installations	[ ]
21	Ducts insulation	[ ]
22	Ducts identification	[ ]
23	Canvas installation at main supply and return ducts	[ ]
24	Fresh air duct installation	[ ]
25	Volume damper installation at FA duct with filter	[ ]
26	Clading or wrapping for Ch. W pipes	[ ]
	CHILLERS	
27	Spring Isolator Mountings Installation	[ ]
28	Installation Of Motorized Valve	[ ]
29	Gate Valves Installation	[ ]
30	Flexible Connections Installations	[ ]
31	Drv Installation	[ ]
32	Thermometer & PG Installations	[ ]
33	Leveling	[ ]
34	Chw Pipes Connections	[ ]

35	Pipes Insulation And Cladding	[ ]
36	Pipes Identification	[ ]
37	Supporting System	[ ]
38	Automatic Air Vent Installation	[ ]
39	Chw Drain Pipe For Each Chiller	[ ]
40	Electrical Connections	[ ]
41	Connection To (Building Management System) BMS	[ ]
42	Control Sequence	[ ]
43	Changeover Unit Installation	[ ]
44	General Cleaning	[ ]
45	Sound Attenuator For Condenser Fans	[ ]
46	Primary Pump Installation	[ ]
47	PG Installation At Suction & Discharge Sides	[ ]
48	Wires Installed Inside Liquid Tight Conduits	[ ]
49	Interlocking With Chiller	[ ]
50	Flexible Connections Installations	[ ]
51	Air Separator Installation With Drain	[ ]
52	Expansion Tanks Installation With Drain	[ ]
53	Chemical Dosing Set Installation	[ ]
54	Make Up Water Pumps Installation & Tank	[ ]
55	Softener For Make Up Water Installation	[ ]
	CONTROL	
56	Control panel installation	[ ]
57	Indication lamps	[ ]
58	Phase failure unit protection	[ ]

59	Overload protection	[ ]
60	Wires are tightly connected	[ ]
61	Flow switch connection to (Direct Digital Control) DDC	[ ]
62	Temperature sensor connection to DDC	[ ]
63	Pressure sensor connection to DDC	[ ]
64	Automatic valve connection to DDC panel	[ ]
65	Chillers command and signal statues	[ ]
66	Selector switch connection to DDC	[ ]
67	Outside air temperature sensor installation	[ ]
68	Outside air humidity sensor	[ ]
69	Sequence of operation programming	[ ]
70	2-way valve connection to DDC panel	[ ]
71	Smoke detector connection to DDC panel	[ ]
72	Filter differential switch connection to DDC panel	[ ]
73	Fan differential switch connection to DDC panel	[ ]
74	Thermostat installation and connection to DDC	[ ]
75	Humidistat installation and connection to DDC	[ ]
76	Outside air temperature sensor installation	[ ]
77	Outside air humidity sensor	[ ]
78	Heater and reheat stages connection to DDC panel	[ ]
79	Sequence of operation programming	[ ]
80	Interlocking with fire alarm system	[ ]

APPENDIX III-SPSS RESULT FOR HYPOTHESIS ONE

```
EXAMINE VARIABLES=Maintenance
  /PLOT BOXPLOT NPPLOT
  /COMPARE GROUPS
  /STATISTICS DESCRIPTIVES
  /CINTERVAL 95
  /MISSING LISTWISE
  /NOTOTAL.
```

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Level of Maintenance	8	100.0%	0	0.0%	8	100.0%

Descriptives

			Statistic	Std. Error
Level of Maintenance	Mean		2.8688	.07506
	95% Confidence Interval for Mean	Lower Bound	2.6913	
		Upper Bound	3.0462	
	5% Trimmed Mean		2.8653	
	Median		2.8750	
	Variance		.045	
	Std. Deviation		.21230	
	Minimum		2.62	
	Maximum		3.18	
	Range		.56	
	Interquartile Range		.39	
	Skewness		.152	.752
	Kurtosis		-1.753	1.481

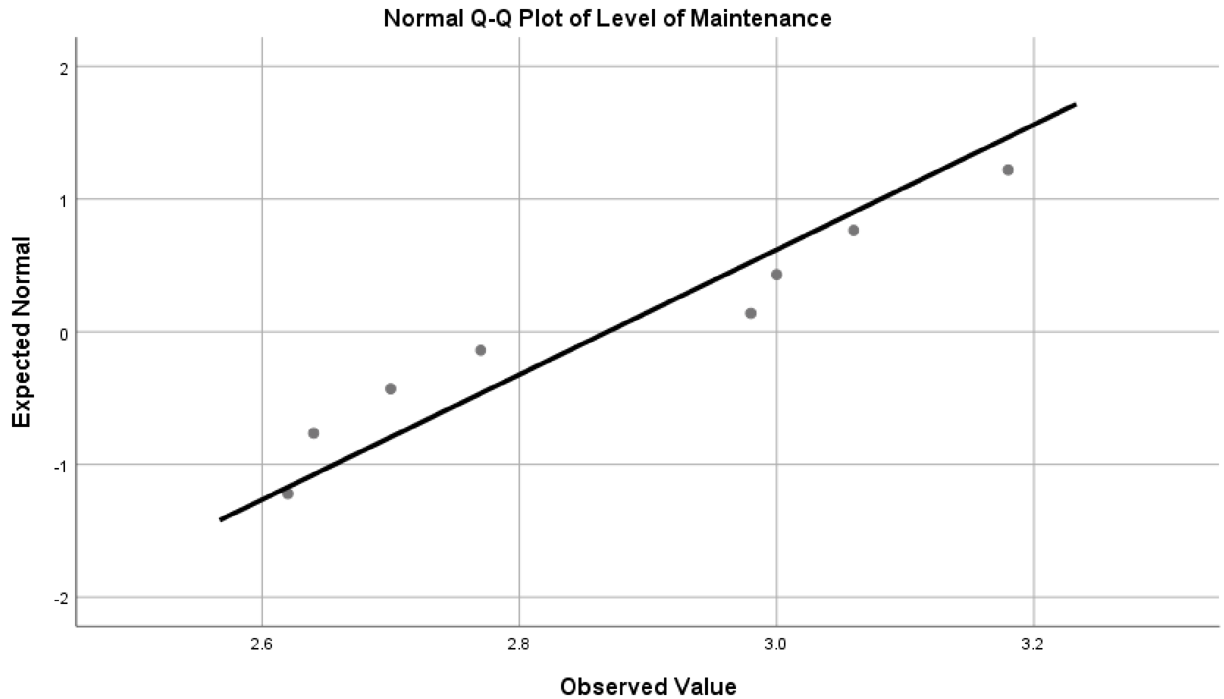
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.

Level of Maintenance	.200	8	.200*	.911	8	.360

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction



SPSS RESULTS FOR HYPOTHESIS TWO

```
DATASET NAME DataSet3 WINDOW=FRONT.
DATASET ACTIVATE DataSet1.
FACTOR
  /VARIABLES Chillers Airdistribution Ventilation Waterpumps Airhandling
Aircooled Switchboard
    Pipingsystem
  /MISSING LISTWISE
  /ANALYSIS Chillers Airdistribution Ventilation Waterpumps Airhandling
Aircooled Switchboard
    Pipingsystem
  /PRINT INITIAL CORRELATION SIG KMO EXTRACTION FSCORE
  /PLOT ROTATION
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /ROTATION NOROTATE
  /METHOD=CORRELATION.
```

Factor Analysis

Communalities

	Initial	Extraction
Chillers	1.000	.883
Air Distribution System	1.000	.308
Ventilation	1.000	.914
Water Pumps	1.000	.916
Air handling and fan coil units	1.000	.802
Air cooled packaged units and precision computer Air-condition Equipment	1.000	.995
Switch Board	1.000	.907
Piping System	1.000	.933

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.083	63.543	63.543	5.083	63.543	63.543
2	1.576	19.698	83.241	1.576	19.698	83.241
3	.988	12.355	95.597			
4	.352	4.403	100.000			
5	6.999E-16	8.748E-15	100.000			
6	5.238E-16	6.547E-15	100.000			
7	-8.751E-17	-1.094E-15	100.000			
8	-2.618E-16	-3.272E-15	100.000			

Extraction Method: Principal Component Analysis.

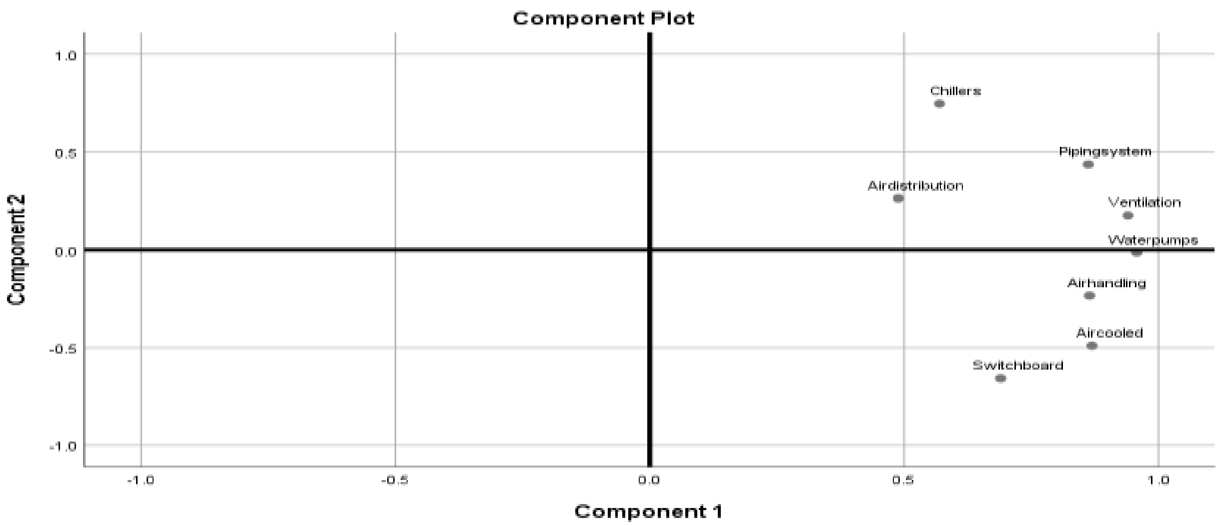
Component Matrix[a]

	Component	
	1	2
Chillers	.569	.747
Air Distribution System	.489	.263
Ventilation	.940	.176

Water Pumps	.957	-.014
Air handling and fan coil units	.864	-.235
Air cooled packaged units and precision computer Air-condition Equipment	.869	-.490
Switch Board	.690	-.657
Piping System	.862	.436

Extraction Method: Principal Component Analysis.

a. 2 components extracted.



Component Score Coefficient Matrix

	Component	
	1	2
Chillers	.112	.474
Air Distribution System	.096	.167
Ventilation	.185	.112
Water Pumps	.188	-.009
Air handling and fan coil units	.170	-.149
Air cooled packaged units and precision computer Air-condition Equipment	.171	-.311
Switch Board	.136	-.417
Piping System	.170	.277

Extraction Method: Principal Component Analysis.

Component Score Covariance Matrix

Component	1	2
1	1.000	.000
2	.000	1.000

Extraction Method: Principal Component Analysis.

SPSS RESULT FOR HYPOTHESIS THREE

```
FACTOR
  /VARIABLES Measure1 Measure2 Measure3 Measure4 Measure5 Measure6
Measure7
  /MISSING LISTWISE
  /ANALYSIS Measure1 Measure2 Measure3 Measure4 Measure5 Measure6 Measure7
  /PRINT INITIAL EXTRACTION ROTATION FSCORE
  /PLOT EIGEN
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /CRITERIA ITERATE(25)
  /ROTATION VARIMAX
  /METHOD=CORRELATION.
```

Factor Analysis

Communalities

	Initial	Extraction
On/off toolbox	1.000	.997
Timers	1.000	.997
Automatic thermostat based control	1.000	.977
Variable Fan speed adjuster	1.000	.796
Air intake control	1.000	.937
Carbon dioxide sensors	1.000	.937
Variable motor speed adjuster	1.000	.999

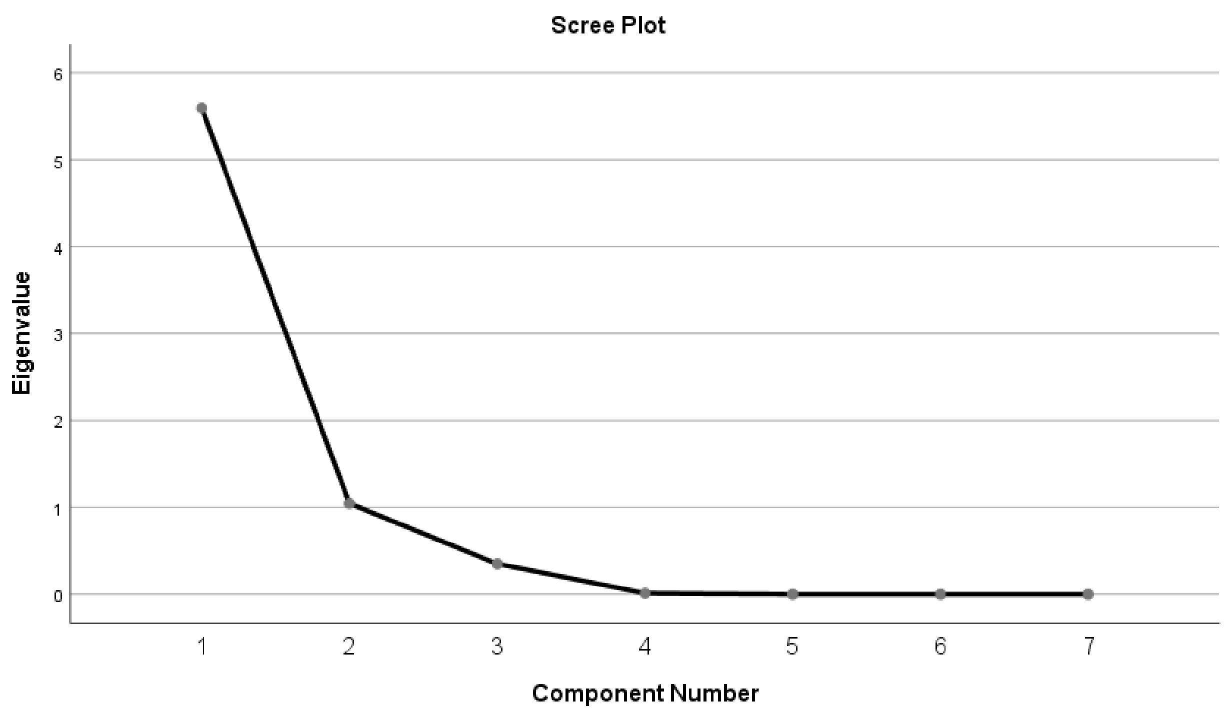
Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %

1	5.596	79.940	79.940	5.596	79.940	79.940	3.831	54.730	54.730
2	1.044	14.909	94.849	1.044	14.909	94.849	2.808	40.120	94.849
3	.350	4.998	99.847						
4	.011	.153	100.000						
5	5.185E-16	7.408E-15	100.000						
6	1.449E-16	2.070E-15	100.000						
7	-8.573E-16	-1.225E-14	100.000						

Extraction Method: Principal Component Analysis.



Component Matrix[a]

	Component 1	Component 2
On/off toolbox	.960	-.275
Timers	.992	-.117
Automatic thermostat based control	.900	-.408
Variable Fan speed adjuster	.693	.561

Air intake control	.833	.493
Carbon dioxide sensors	.916	.312
Variable motor speed adjuster	.931	-.364

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Rotated Component Matrix[a]

	Component	
	1	2
On/off toolbox	.922	.383
Timers	.849	.526
Automatic thermostat based control	.959	.241
Variable Fan speed adjuster	.193	.871
Air intake control	.345	.905
Carbon dioxide sensors	.523	.815
Variable motor speed adjuster	.955	.295

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Component Transformation Matrix

Component	1	2
1	.783	.623
2	-.623	.783

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Component Score Coefficient Matrix

	Component	
	1	2
On/off toolbox	.298	-.099
Timers	.209	.022
Automatic thermostat based control	.369	-.206
Variable Fan speed adjuster	-.238	.498
Air intake control	-.178	.463
Carbon dioxide sensors	-.058	.336
Variable motor speed adjuster	.347	-.169

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

APPENDIX- IV-- RESULT OF THE CHECKLIST SURVEY

KEY	(√) Satisfactory/Present/ ok/compliance (X) Unsatisfactory, /absent/ insufficient/violation

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN KENEGBU								
		Santiago Suite	**Benchmark Hotels Limited Owerri**	**Clairbon plaza Hotel te**	**Lodan International Htel Limited**	**Melvin Suites Hotel**	**Samara Guest House**	**Stayfine Hotel**	**Comet Hotel and conference Center**	**Fano Hotel**
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	√	√	√	√	√	√	√	√	√
3	Alignment and Levelling	√	√	√	√	X	X	X	X	X
4	Condensate drain pipe directed to nearest floor drain	√	√	√	√	X	X	X	X	X
5	Condensate drain pipe shall have a P-Trap	√	√	√	√	√	√	√	√	√
6	Chilled water pipes installation	X	√	X	X	√	√	√	√	√
7	Chilled water pipes insulation	X	X	X	X	√	√	√	√	√
8	FDI installation on main ChW return pipe	X	√	√	√	√	√	√	√	√
9	Pipes identifications	X	X	X	X	X	X	X	X	X
10	Valves tagging	X	X	X	X	X	X	X	X	X
11	Pressure gauges installation	X	X	X	X	X	X	X	X	X
12	Thermometer installation	X	X	X	X	X	X	X	X	X
13	Automatic air vent installation	X	X	X	X	X	X	X	X	X
14	2-way valve installation	X	X	X	X	X	X	X	X	X
15	Strainer installation	√	X	√	X	X	X	X	X	X
16	General cleaning	√	√	√	√	√	√	√	√	√
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
	Ducts identification	√	√	√	√	√	√	√	√	√
6	Canvas installation at main supply and return ducts	X	X	X	X	X	X	X	X	X
7	Fresh air duct installation	X	X	X	X	X	X	X	X	X

8	Volume damper installation at FA duct with filter	X	X	X	X	X	X	X	X	X
9	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	√	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	X
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	X	X	X	X	X	X	X	X
29	Softener For Make Up Water Installation	X	X	X	X	X	X	X	X	X
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√

7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programming	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	**Checks**	**REMARK ON THE VARIOUS HOTELS CHECKED AT IN NEW OWERRI**														
		Forever Hotel Suites	**Maranatha Suites Limited**	**Titanic view Hotel and suite**	**Greatwod Hotel Ltd**	**Transtell Suites and Services Apartment**	**Crown Plaza Htel Owerri**	**Newtn Hotels Ltd**	**Real Hotel and Catering Services**	**Immaculate Royal Internantional Hotel**	**Delegend Hotel and Suites**	**Cross View Hotel and Bar**	**G Towers Hotels and Tourism**	**Newcastel Hotel**	**Ideal suites**	**All Seasons Hotel**
A	**GENERAL OBSERVATIONS**															
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√	X	X	X	X	X	X
2	Unit is installed on anti-vibration mounts	√	√	√	√	√	√	√	√	X	X	X	X	X	X	X
3	Alignment and Levelling	X	X	X	X	X	X	X	X		X	X	X	X	X	X
4	Condensate drain pipe	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	directed to nearest floor drain															
5	Condensate drain pipe shall have a P-Trap		X	X		√	√	√	√	√	√	√	√	√	√	√
6	Chilled water pipes installation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7	Chilled water pipes insulation	X	X	X	X	X	X	X	X	X	√	√	√	X	X	X
8	FDI installation on main ChW return pipe	X	X	X	X	X	√	X	X	X	X	X	X	X	X	X
9	Pipes identifications	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	Valves tagging	X	X	√	√	X	X	X	X	X	X	X	X	X	X	X
11	Pressure gauges installation	√	X	√	√	X	X	X	X	X	X	X	X	X	X	X
12	Thermometer installation	X	X	√	√	X	X	√	√	X	X	X	X	X	X	X
13	Automatic air vent installation	X	X	X	X	X	X	√	√	X	X	X	X	X	X	X
14	2-way valve installation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	Strainer installation	X	X	X	X	X	X	X	X	X	√	√	X	X	X	X
16	General cleaning	X	X	√	√	√	X	X	X	X	√	√	X	X	X	X
B	**FANS**															
1	Smoke detector installation	X	√	√	X	√	√	X	√	√	√	√	√	√	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X	√	√	√	√	√	√
4	Ducts installations	X	X	X	X	X	X	X	X	X	√	√	√	√	√	√
5	Ducts insulation	X	X	X	X	X	X	X	X	X	√	√	√	√	√	√
6	Ducts identification	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7	Canvas installation at main supply and return ducts	X	√	√	√	√	√	X	X	X	X	X	X	X	X	X
8	Fresh air duct installation	X	√	√	√	√	√	X	X	X	X	X	X	X	X	X
9	Volume damper installation at FA	X	X	X	X	X	X	X	X	X	X	√	√	√	√	X

	duct with filter															
10	Clading or wrapping for Ch. W pipes	X	X	X	X	X	X	X	X	X	X	√	√	√	√	X
C	**CHILLERS**															
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√	√	X	√	X	√	X
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X	√	X	√	√	√	√
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√	√	X	√	√	√	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	√	X	X	√	√	√	√
5	Drv Installation	√	X	X	√	X	X	√	X	X	√	X	√	X	√	√
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
7	Leveling	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√	√	X	√	X	√	X
11	Supporting System	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√	√	X	√	X	√	X
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
16	Control Sequence	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
18	General Cleaning	√	X	X	√	X	X	√		X	√	X	√	X	√	X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X

21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	√	X	X	√	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√	X	X	√	X	√	X
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	√	X	X	√	X	√	X
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√	X	X	√	X	√	X
28	Make Up Water Pumps Installation & Tank	√	X	√	X	√	X	√	X	√	X	X	√	X	√	X
29	Softener For Make Up Water Installation	√	X	√	X	√	X	√	X	√	X	X	√	X	√	X
D	**CONTROL**															
1	Control panel installation	X	X	X	X	X	X	√	X	√	√	X	√	X	√	X
2	Indication lamps	X	X	X	X	X	X	√	X	√	√	X	√	X	√	X
3	Phase failure unit protection	X	X	X	X	X	X	√	X	√	√	X	√	X	√	X
4	Overload protection	X	X	X	X	X	X	√	X	√	√	X	√	X	√	X
5	Wires are tightly connected	X	√	√	X	√	√	√	X	√	√	X	√	X	√	X
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	√	X	√	√	X	√	X	√	X
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
8	Pressure sensor connection to DDC	X	X	X	√	X	√	X	X	X	√	X	√	X	√	X
9	Automatic valve connection to DDC panel	X	X	X	√	X	√	X	X	X	√	X	√	X	√	X
10	Chillers command	X	X	X	√	X	√	X	X	X	√	X	√	X	√	X

	and signal statues															
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√	X	X	√	X	√	X
14	Sequence of operation programming	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√	X	X	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√	√	X	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√	√	X	√	X	√	X
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√	√	√	X	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X	√	√	X	√	X	√
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN WORKS LAYOUT														
		De Range Hotel and suites	Mavis suite owerri	Crisp royal Hotel	Ochez Suite	Prestige Suites limited exclusive	Evatel hotels and suite	Mississippi leisure lodging and dance bar	Milton hotel and suites limited	Coco77 guess house	Prestige suites limited royal	Eddico International Hotel	Titanic view Hotel and suites	Masterpiece Hotel	Felivin Hotel Ltd	Shelvac Hotel
A	GENERAL OBSERVATIONS															
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√	√	X	√	X	√	X
2	Unit is installed on anti-vibration mounts	√	X	√	X	√	X	√	X	√	X	√	X	√	X	√
3	Alignment and Levelling	√	√	X	√	X	X	√	X	√	X	√	X	√	X	√
4	Condensate drain pipe directed to nearest floor drain	√	√	X	√	X	X	√	X	√	√	X	√	√	X	√
5	Condensate drain pipe shall have a P-Trap	√	√	X	√	X	√	X	√	√	√	X	√	√	X	√
6	Chilled water pipes installation	√	√	X	√	X	√	X	√	√	√	X	√	√	X	√
7	Chilled water pipes insulation	√	√	X	√	X	√	X	√	√	√	X	√	√	X	√
8	FDI installation on main ChW return pipe	√	√	X	√	X	√	X	√	√	√	X	√	√	X	√
9	Pipes identifications	√	X	√	X	√	√	X	√	√	√	X	√	√	X	√
10	Valves tagging	√	X	√	X	√	√	X	√	√	X	√	X	√	X	√
11	Pressure gauges installation	√	X	√	X	√	X	√	X	√	X	√	X	√	X	√
12	Thermometer installation	√	X	√	X	√	X	√	X	√	X	√	X	√	X	√
13	Automatic air vent installation	√	X	√	X	√	X	√	X	√	X	√	X	√	X	√
14	2-way valve installation	√	√	X	X	√	X	X	X	√	X	√	X	X	√	X

15	Strainer installation	√	√	X	X	√	√	X	X	√	√	X	X	X	√	X
16	General cleaning	√	√	X	X	√	√	X	X	√	X	√	X	X	√	X
B	**FANS**															
1	Smoke detector installation	X	√	√	X	√	√	X	√	√	√	X	√	X	√	X
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√	√	X	√	X	√	X
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
4	Ducts installations	X	√	X	X	X	X	X	X	X	√	X	√	X	√	X
5	Ducts insulation	X	√	X	X	X	X	X	X	X	√	X	√	X	√	X
6	Ducts identification	√	X	√	X	√	X	√	X	√	X	√	√	X	√	X
7	Canvas installation at main supply and return ducts	√	X	√	X	√	X	√	X	√	X	√	√	X	√	X
8	Fresh air duct installation	√	X	√	X	√	X	√	X	√	X	√	√	X	√	X
9	Volume damper installation at FA duct with filter	√	X			√	X	√	X		√	X	√	X	√	X
10	Clading or wrapping for Ch. W pipes	√	X	√	X	√	X	√	X	√	X	X	√	X	√	X
C	**CHILLERS**															
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√	√	X	√	X	√	X
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X	√	X	√	X	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√	√	X	√	X	√	X
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X	√	√	X	√	X	√
5	Drv Installation	√	X	X	√	X	X	√	X	X	√	√	X	√	X	√
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X	√	√	X	√	X	√
7	Leveling	√	X	X	√	X	X	√	X	√	X	√	X	√	√	X

8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X	√	√	X	√	√	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X	√	√	X	√	X	√
10	Pipes Identification	√	√	√	√	√	√	√	X	√	X	√	X	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	√	X	√	X	√	X	√
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√	√	√	X	√	√	X
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X	√	√	X	√	√	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X	√	√	X	√	√	X
15	Connection To (Building Management Syste) BMS	X	X	X	X	X	X	X	X	X	√	√	X	√	√	X
16	Control Sequence	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X	√	X	√	√	X	X
18	General Cleaning	√	X	X	√	X	X	√		X	√	X	√	√	X	X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	√	X	X	√	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	√	X	√	X	X	√	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	√	X	√	X	X	√	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	√	X	√	X	X	√	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√	X	√	X	X	√	X
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	√	X	X	√	X	√	X

27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√	√	X	√	X	√	X
28	Make Up Water Pumps Installation & Tank	√	X	√	√	X	X	√	X	√	√	X	X	√	X	√
29	Softener For Make Up Water Installation	√	√	X	X	√	X	√	√	X	X	√	√	X	X	√
D	**CONTROL**															
1	Control panel installation	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
2	Indication lamps	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
4	Overload protection	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√	√	X	√	X	√	X
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√	√	X	√	X	√	X
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X	√	√	X	√	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√	√	√	X	X	√	X

14	Sequence of operation programming	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X	√	X	√	X	√	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X	√	X	√	√	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√	X	X	√	X	√	X
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√	√	X	√	√	X	X
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X	√	√	X	X	√	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X	√	X	√	X	√	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	√	X	X	√	X	√	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√	X	X	√	X	√	X
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√	X	X	√	X	√	X
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X	√	√	X	√	√	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X	√	√	X	√	√	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN NEKEDE								
		Westbrook Ttel	**Fullmoon Htel Ltd**	**Imo concorde Hotel**	**City Global Hotels Owerri**	**Bayview Resort and Hote;**	**Winter Suite Hotel**	**Trans Amadi Holiday Resort**	**Mma Lodge**	**Villa Jemmys**
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	√	X	√	X	√	X	√	X	√
3	Alignment and Levelling	√	X	√	X	√	X	√	X	√
4	Condensate drain pipe directed to nearest floor drain	√	√	X	X	√	X	√	X	√
5	Condensate drain pipe shall have a P-Trap	√	√	X	X	√	X	√	X	√
6	Chilled water pipes installation	√	√	X	X	√	X	√	X	√
7	Chilled water pipes insulation	√	X	√	X	√	X	√	X	√
8	FDI installation on main ChW return pipe	√	X	√	√	X	X	√	X	√
9	Pipes identifications	√	X	√	√	X	√	X	X	√
10	Valves tagging	√	X	√	X	√	√	X	X	√
11	Pressure gauges installation	√	X	√	X	√	√	X	X	√
12	Thermometer installation	√	X	√	X	√	√	X	X	√
13	Automatic air vent installation	√	X	√	X	√	√	X	X	√
14	2-way valve installation	√	√	X	X	√	√	X	X	√
15	Strainer installation	√	√	X	X	√	X	√	X	√
16	General cleaning	√	X	√	X	√	X	√	X	√
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	√	X	X	X	X	X	X	X	X
4	Ducts installations	√	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identification	√	X	√	X	√	X	√	X	√
7	Canvas installation at main supply and return ducts	√	X	√	X	√	X	√	X	√
8	Fresh air duct installation	√	X	√	X	√	X	√	X	√
9	Volume damper installation at FA duct with filter	√	X	√	X	√	X	√	X	√
10	Clading or wrapping for Ch. W pipes	√	X	√	X	√	X	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X

20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	√	X	X	X	√	√	X
27	Chemical Dosing Set Installation	√	X	√	X	X	√	√	√	√
28	Make Up Water Pumps Installation & Tank	√	X	X	√	X	√	X	√	X
29	Softener For Make Up Water Installation	√	X	√	X	√	X	√	X	√
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programming	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN UGWU ORJI								
		HOUSE 57 OYRTAN	**VIVIAN HOTEL LTD**	**OLIVE HOTEL & SUITE NIG LIMITED**	**GEOMIL GUEST HOUSE**	**ROBINSON SUITE & HOTEL**	**BLOSSOM STAR HOTEL**	**OSPUC HOTEL**	**M7 SUITE LTD**	**COURTESY HOTEL OWERRI**
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	√	√	X	√	√	X	√	X	√
3	Alignment and Levelling	√	√	X	√	√	X	√	X	√
4	Condensate drain pipe directed to nearest floor drain	√	√	X	√	√	X	√	X	√
5	Condensate drain pipe shall have a P-Trap	√	X	√	X	√	X	√	X	√
6	Chilled water pipes installation									
7	Chilled water pipes insulation	√	X	√	√	X	√	√	X	√
8	FDI installation on main ChW return pipe	√	X	√	√	X	√	√	X	√
9	Pipes identifications	√	√	X	√	X	√	√	X	√
10	Valves tagging	√	√	X	√	X	√	√	X	√
11	Pressure gauges installation	√	√	X	√	X	√	√	√	X
12	Thermometer installation	√	√	X	√	X	√	√	√	X
13	Automatic air vent installation	√	√	X	√	X	√	√	√	X
14	2-way valve installation	√	X	√	√	X	√	√	X	√
15	Strainer installation	√	X	√	√	X	√	√	X	√
16	General cleaning									
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identification									
7	Canvas installation at	√	√	X	X	√	X	√	X	√

	main supply and return ducts									
8	Fresh air duct installation	√	√	X	X	√	X	√	X	√
9	Volume damper installation at FA duct with filter	√	X	√	√	X	√	√	X	√
10	Clading or wrapping for Ch. W pipes	√	X	√	√	X	√	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X

23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	X
27	Chemical Dosing Set Installation	√	√	X	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	√	√	X	X	√	X	√	X	√
29	Softener For Make Up Water Installation	√	√	X	X	√	X	√	X	√
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programming	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X

17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN ORJI								
		KEEDAN INTERNATIONAL HOTEL	MAGNITUDE HOTEL	INSTANBUL GUEST HOUSE	SILVER STONE HOTEL	NEW CASTLE HOTEL & BAR	KEL DAVE SUITE ANNEX	AIR PORTEL GUEST HOUSE	SEAVIEW HOTEL LTD	FINTON SUITE LTD
A	GENERAL OBSERVATIONS									
1	Unit installed on concrete pad with 2" thick coark	√	X	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	√	X	√	X	√	X	√	X	√
3	Alignment and Levelling	√	X	√	X	√	X	√	X	√
4	Condensate drain pipe directed to nearest floor drain	X	√	X	X	√	X	√	X	√
5	Condensate drain pipe shall have a P-Trap	X	√	X	X	√	X	√	√	X
6	Chilled water pipes installation	X	√	X	X	√	X	√	√	X
7	Chilled water pipes insulation	X	√	X	X	√	X	√	√	X
8	FDI installation on main ChW return pipe	X	√	X	X	√	X	√	√	X

9	Pipes identifications	X	X	√	X	√	X	√	X	√
10	Valves tagging	√	X	√	X	√	X	√	X	√
11	Pressure gauges installation	√	X	√	X	√	X	√	X	√
12	Thermometer installation	√	X	√	X	√	√	X	X	√
13	Automatic air vent installation	√	X	√	X	√	√	X	X	√
14	2-way valve installation	√	X	√	X	√	√	X	X	√
15	Strainer installation	√	X	√	X	√	√	X	X	√
16	General cleaning									
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identification	√	√	√	√	√	√	√	√	√
7	Canvas installation at main supply and return ducts	X	X	X	X	X	X	X	X	X
8	Fresh air duct installation	√	√	√	√	√	√	√	√	√
9	Volume damper installation at FA duct with filter	X	X	X	X	X	X	X	X	X
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	√	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X

23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	X
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	√	X	√	X	√	X	√	X
29	Softener For Make Up Water Installation	X	√	X	√	X	√	X	√	X
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programming	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN PREFAB AREA							
		DIAMOND KRUZE HOTEL	DANIEL COURT HOTEL & RESORT	JACOBS PLACE HOTEL	CATHY'S SUITE	VICINITY OF VISION	ISTANBUL GUEST HUSE	RIV ISLAND HOTEL LTD	THE HOME GUEST HOUSE
A									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√
2	Unit is installed on anti-vibration mounts	√	√	X	√	X	√	X	√
3	Alignment and Levelling	√	X	√	X	X	√	X	√
4	Condensate drain pipe directed to nearest floor drain	√	X	√	√	X	√	X	√
5	Condensate drain pipe shall have a P-Trap	√	X	√	√	X	√	X	√
6	Chilled water pipes installation	√	X	√	√	X	√	X	√
7	Chilled water pipes insulation	√	X	√	√	X	√	X	√
8	FDI installation on main ChW return pipe	√	X	√	√	X	√	√	X
9	Pipes identifications	√	X	√	√	X	√	√	X
10	Valves tagging	√	X	√	√	X	√	√	X
11	Pressure gauges installation	√	X	√	√	X	√	√	X
12	Thermometer installation	√	X	√	√	X	√	X	√
13	Automatic air vent installation	√	√	X	√	X	√	X	√
14	2-way valve installation	√	√	X	√	X	√	X	√
15	Strainer installation	√	√	X	√	√	X	X	√
16	General cleaning	√	√	X	√	√	X	X	√
B									
1	Smoke detector installation	X	√	√	X	√	√	X	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X
6	Ducts identification								
7	Canvas installation at main supply and return ducts	X	√	X	√	X	√	X	√
8	Fresh air duct installation	X	√	X	√	X	√	X	√
9	Volume damper installation at FA duct with filter	X	√	X	√	X	√	X	√
10	Clading or wrapping for Ch. W pipes	X	√	X	√	X	√	X	√
C									

1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√
3	Gate Valves Installation	√	√	√	√	√	√	√	X
4	Flexible Connections Installations	√	X	X	√	X	X	√	X
5	Drv Installation	√	X	X	√	X	X	√	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X
7	Leveling	√	X	X	√	X	X	√	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X
10	Pipes Identification	√	√	√	√	√	√	√	X
11	Supporting System	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√	
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	X	√	X	√	X	√	X
29	Softener For Make Up Water Installation	X	X	√	X	√	X	√	X
D									
1	Control panel installation	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X

4	Overload protection	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X
14	Sequence of operation programming	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X
24	Sequence of operation programming	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X

S/N	**CHECKS**	**REMARK ON THE VARIOUS HOTELS CHECKED AT IN EGBU**								
		MAYFAIR SUITE AND CONFERENCE	**LADIDA CONTINENTAL HOTEL**	**HEAVENLY HOTEL**	**LA-DIFFERENCE SUITES**	**GRANDEUR HOTEL**	**GRANDE ROYAL**	**GENANTH HOTELS**	**JASMINES PLACE**	**JAMES HOTEL**

						LIMITED PRIMEA	**HOTE L**			
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	X	X	X	X	X	X	X	X	X
3	Alignment and Levelling	X	X	X	X	X	X	X	X	X
4	Condensate drain pipe directed to nearest floor drain	X	X	X	X	X	X	X	X	X
5	Condensate drain pipe shall have a P-Trap	√	√	√	√	√	√	√	X	√
6	Chilled water pipes installation	√	√	√	√	√	√	√	X	√
7	Chilled water pipes insulation	X	X	X	X	X	X	X	X	X
8	FDI installation on main ChW return pipe	√	X	X	√	X	X	√	X	√
9	Pipes identificati ons	X	X	X	X	X	X	X	X	X
1 0	Valves tagging	√	√	√	√	√	√	√	X	√
1 1	Pressure gauges installation	√	√	√	√	√	√	√	X	√
1 2	Thermomet er installation	X	X	X	X	X	X	X	X	X
1 3	Automatic air vent installation	X	X	X	X	X	X	X	X	X
1 4	2-way valve installation	X	X	X	X	X	X	X	X	X
1 5	Strainer installation	X	X	X	X	X	X	X	X	X
1 6	General cleaning	√	√	√	√	√	√	√	X	√
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installation s	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identificati on	X	X	X	X	X	X	X	X	X
7	Canvas installation at main supply and return ducts	X	X	X	X	X	X	X	X	X

8	Fresh air duct installation	X	X	X	X	X	X	X	X	X
9	Volume damper installation at FA duct with filter	√	√	√	√	√	√	√	X	√
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X

22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	X	X	X	X	X	X	X	X	X
26	Expansion Tanks Installation With Drain	X	X	X	X	X	X	X	X	X
27	Chemical Dosing Set Installation	X	X	X	X	X	X	X	X	X
28	Make Up Water Pumps Installation & Tank	√	√	√	√	√	√	√	X	√
29	Softener For Make Up Water Installation	√	√	√	√	√	√	√	X	√
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programming	X	X	X	X	X	X	X	X	X

15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN EGBEADA								
		HOUSE 23	**SHADIV HOTEL LTD**	**KELVIC SUITES LTD PINEWOOD HOTEL LTD**	**MARAC`ANA HOTEL AND SUITE**	**BENZIN HOTEL**	**LINKS HOTEL GUEST HOUSE**	**CHRISTIAN SUITES**	**TRIUMPHAT GUEST HOUSE**	**DOLVIN GUEST HOUSE**
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	X	X	X	X	X	X	X	X	X
3	Alignment and Levelling	X	X	X	X	X	X	X	X	X
4	Condensate drain pipe directed to nearest floor drain	X	X	X	X	X	X	X	X	X

5	Condensate drain pipe shall have a P-Trap	√	√	√	√	√	√	√	X	√
6	Chilled water pipes installation	√	√	√	√	√	√	√	X	√
7	Chilled water pipes insulation	X	X	X	X	X	X	X	X	X
8	FDI installation on main ChW return pipe	√	X	X	√	X	X	√	X	√
9	Pipes identification s	X	X	X	X	X	X	X	X	X
10	Valves tagging	√	√	√	√	√	√	√	X	√
11	Pressure gauges installation	√	√	√	√	√	√	√	X	√
12	Thermomete r installation	X	X	X	X	X	X	X	X	X
13	Automatic air vent installation	X	X	X	X	X	X	X	X	X
14	2-way valve installation	X	X	X	X	X	X	X	X	X
15	Strainer installation	X	X	X	X	X	X	X	X	X
16	General cleaning	√	√	√	√	√	√	√	X	√
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identification	X	X	X	X	X	X	X	X	X
7	Canvas installation at main supply and return ducts	X	X	X	X	X	X	X	X	X
8	Fresh air duct installation	X	X	X	X	X	X	X	X	X
9	Volume damper installation at FA duct with filter	√	√	√	√	√	√	√	X	√
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermomete r & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X

8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	X
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	X	X	X	X	X	X	X	X
29	Softener For Make Up Water Installation	X	X	X	X	X	X	X	X	X
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct	X	√	√	X	√	√	X	X	√

	Digital Control) DDC									
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programmin g	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programmin g	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN AKWAKUMA LAYOUT								
		HORIZONTAL HOTEL	KINGS PARK HOTEL LTD	KELVIC SUITES LTD PINEWOOD HOTEL LTD	LAMONDE GUEST HOUSE	CHICHRIS GUEST HOUSE	DOWN TOWN GUEST HOUSE	ZUE INTERNATIONAL HOTEL	KINGS COURT HOTEL & SUITE	CICO77 GUEST HOUSE
A	**GENERAL OBSERVATIONS**									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	X	X	X	X	X	X	X	X	X
3	Alignment and Levelling	X	X	X	X	X	X	X	X	X
4	Condensate drain pipe directed to nearest floor drain	X	X	X	X	X	X	X	X	X
5	Condensate drain pipe shall have a P-Trap	√	√	√	√	√	√	√	X	√
6	Chilled water pipes installation	√	√	√	√	√	√	√	X	√
7	Chilled water pipes insulation	X	X	X	X	X	X	X	X	X
8	FDI installation on main ChW return pipe	√	X	X	√	X	X	√	X	√
9	Pipes identifications	X	X	X	X	X	X	X	X	X
10	Valves tagging	√	√	√	√	√	√	√	X	√
11	Pressure gauges installation	√	√	√	√	√	√	√	X	√
12	Thermometer installation	X	X	X	X	X	X	X	X	X
13	Automatic air vent installation	X	X	X	X	X	X	X	X	X
14	2-way valve installation	X	X	X	X	X	X	X	X	X
15	Strainer installation	X	X	X	X	X	X	X	X	X
16	General cleaning	√	√	√	√	√	√	√	X	√
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X

5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identificatio n	X	X	X	X	X	X	X	X	X
7	Canvas installation at main supply and return ducts	X	X	X	X	X	X	X	X	X
8	Fresh air duct installation	X	X	X	X	X	X	X	X	X
9	Volume damper installation at FA duct with filter	√	√	√	√	√	√	√	X	√
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermomete r & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identificatio n	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
16	Control Sequence	X	X	X	X	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
18	General Cleaning	√	X	X	√	X	X	√		X
19	Sound Attenuator For	√	X	X	√	X	X	√	X	X

	Condenser Fans									
20	Primary Pump Installation	X	X	X	X	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
23	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
24	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
25	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
26	Expansion Tanks Installation With Drain	√	X	X	√	X	X	√	√	X
27	Chemical Dosing Set Installation	√	√	√	√	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	X	X	X	X	X	X	X	X
29	Softener For Make Up Water Installation	X	X	X	X	X	X	X	X	X
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command	X	X	X	X	X	X	X	X	X

	and signal statues									
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
14	Sequence of operation programmin g	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programmin g	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN ORLU								
		DE PLAZA ORIENT CONTINENTAL	GOA HOTEL RESRT SERVICES ORLU	RAANAN TOTEL LTD	AUSTIN HOTEL LIMITED	PRESIDENTIAL HOTEL	PRINCE DE VILLA HOTEL	NOOREMAC HOTEL	DOMAS HOTEL	APATALA PALCE HOTEL
A	GENERAL OBSERVATIONS									
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√	√	X	√	√
2	Unit is installed on anti-vibration mounts	X	X	X	X	X	X	X	X	X
3	Alignment and Levelling	X	X	X	X	X	X	X	X	X
4	Condensate drain pipe directed to nearest floor drain	X	X	X	X	X	X	X	X	X
5	Condensate drain pipe shall have a P-Trap	√	√	√	√	√	√	√	X	√
6	Chilled water pipes installation	√	√	√	√	√	√	√	X	√
7	Chilled water pipes insulation	X	X	X	X	X	X	X	X	X
8	FDI installation on main ChW return pipe	√	X	X	√	X	X	√	X	√
9	Pipes identifications	X	X	X	X	X	X	X	X	X
10	Valves tagging	√	√	√	√	√	√	√	X	√
11	Pressure gauges installation	√	√	√	√	√	√	√	X	√
12	Thermometer installation	X	X	X	X	X	X	X	X	X
13	Automatic air vent installation	X	X	X	X	X	X	X	X	X
14	2-way valve installation	X	X	X	X	X	X	X	X	X
15	Strainer installation	X	X	X	X	X	X	X	X	X
16	General cleaning									
B	**FANS**									
1	Smoke detector installation	X	√	√	X	√	√	X	√	√
2	Differential pressure on AHU's filter	√	√	√	√	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X	X	X	X	X
4	Ducts installations	X	X	X	X	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X	X	X	X	X
6	Ducts identification	X	X	X	X	X	X	X	X	X
7	Canvas installation at	X	X	X	X	X	X	X	X	X

	main supply and return ducts									
8	Fresh air duct installation	X	X	X	X	X	X	X	X	X
9	Volume damper installation at FA duct with filter	√	√	√	√	√	√	√	X	√
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√	√	√	X	√
C	**CHILLERS**									
1	Spring Isolator Mountings Installation	√	√	X	√	√	√	√	X	√
2	Installation Of Motorized Valve	√	X	X	√	X	X	√	√	X
3	Gate Valves Installation	√	√	√	√	√	√	√	X	√
4	Flexible Connections Installations	√	X	X	√	X	X	√	X	X
5	Drv Installation	√	X	X	√	X	X	√	X	X
6	Thermometer & PG Installations	√	X	X	√	X	X	√	X	X
7	Leveling	√	X	X	√	X	X	√	X	X
8	Chw Pipes Connections	√	X	X	√	X	X	√	X	X
9	Pipes Insulation And Cladding	√	X	X	√	X	X	√	X	X
10	Pipes Identification	√	√	√	√	√	√	√	X	√
11	Supporting System	X	X	X	X	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√	√	√	X	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X	X	X	X	X
16	Connection To (Building Management System) BMS	X	X	X	X	X	X	X	X	X
17	Control Sequence	X	X	X	X	X	X	X	X	X
18	Changeover Unit Installation	X	X	X	X	X	X	X	X	X
19	General Cleaning	√	X	X	√	X	X	√		X
20	Sound Attenuator For Condenser Fans	√	X	X	√	X	X	√	X	X
21	Primary Pump Installation	X	X	X	X	X	X	X	X	X
22	PG Installation At Suction & Discharge Sides	X	X	X	X	X	X	X	√	X

23	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X	X	X	X	X
24	Interlocking With Chiller	X	X	X	X	X	X	X	X	X
25	Flexible Connections Installations	X	X	X	X	X	X	X	X	X
26	Air Separator Installation With Drain	√	√	√	√	√	√	√	√	√
27	Expansion Tanks Installation With Drain	X	X	X	X	X	X	X	X	X
28	Chemical Dosing Set Installation	X	X	X	X	X	X	X	X	X
29	Make Up Water Pumps Installation & Tank	X	X	X	X	X	X	X	X	X
30	Softener For Make Up Water Installation	√	√	√	√	√	√	√	X	√
D	**CONTROL**									
1	Control panel installation	X	X	X	X	X	X	X	X	X
2	Indication lamps	X	X	X	X	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X	X	X	X	X
4	Overload protection	X	X	X	X	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√	√	X	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√	√	X	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X	X	X	X	X
12	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√	√	√	X	√

14	Sequence of operation programming	X	X	X	X	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√	√	√	X	√
19	Thermostat installation and connection to DDC	X	X	X	X	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X	X	√	X	X
21	Outside air temperature sensor installation	X	X	X	X	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√	√	√	X	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√	√	√	X	√
24	Sequence of operation programming	X	X	X	X	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X	X	√	X	X

SOURCE; SURVEY, 2018

S/N	CHECKS	REMARK ON THE VARIOUS HOTELS CHECKED AT IN PORTHACCORT ROAD				
		Owerri Hotel Plaza	**Liberty Guest House**	**Royal billion Hotel**	**Roselife Hotel & Suite**	**Comet Hotel & Conference**
A	**GENERAL OBSERVATIONS**					
1	Unit installed on concrete pad with 2" thick coark	X	√	√	X	√
2	Unit is installed on anti-vibration mounts	X	X	X	X	X
3	Alignment and Levelling	√	√	√	√	√
4	Condensate drain pipe directed to nearest floor drain	X	X	X	X	X
5	Condensate drain pipe shall have a P-Trap	X	X	X	X	X
6	Chilled water pipes installation	X	X	X	X	X
7	Chilled water pipes insulation	√	√	√	√	√
8	FDI installation on main ChW return pipe	X	X	X	X	X
9	Pipes identifications	√	√	√	√	√
10	Valves tagging	X	X	X	X	X
11	Pressure gauges installation	X	X	X	X	X
12	Thermometer installation	X	X	X	X	X
13	Automatic air vent installation	√	√	√	√	√
14	2-way valve installation	X	X	X	X	X
15	Strainer installation	√	√	√	√	√
16	General cleaning	X	X	X	X	X
B						
1	Smoke detector installation	X	√	√	X	√
2	Differential pressure on AHU's filter	√	√	√	√	√
3	Differential pressure on AHU's fan	X	X	X	X	X
4	Ducts installations	X	X	X	X	X
5	Ducts insulation	X	X	X	X	X
6	Ducts identification	√	√	√	√	√
7	Canvas installation at main supply and return ducts	X	X	X	X	X
8	Fresh air duct installation	X	X	X	X	X
9	Volume damper installation at FA duct with filter	X	X	X	X	X
10	Clading or wrapping for Ch. W pipes	√	√	√	√	√
C						
1	Spring Isolator Mountings Installation	√	√	X	√	√
2	Installation Of Motorized Valve	√	X	X	√	X
3	Gate Valves Installation	√	√	√	√	√
4	Flexible Connections Installations	√	X	X	√	X

5	Drv Installation	√	X	X	√	X
6	Thermometer & PG Installations	√	X	X	√	X
7	Leveling	√	X	X	√	X
8	Chw Pipes Connections	√	X	X	√	X
9	Pipes Insulation And Cladding	√	X	X	√	X
10	Pipes Identification	√	√	√	√	√
11	Supporting System	X	X	X	X	X
12	Automatic Air Vent Installation	√	√	√	√	√
13	Chw Drain Pipe For Each Chiller	X	X	X	X	X
14	Electrical Connections	X	X	X	X	X
15	Connection To (Building Management System) BMS	X	X	X	X	X
16	Control Sequence	X	X	X	X	X
17	Changeover Unit Installation	X	X	X	X	X
18	General Cleaning	√	X	X	√	X
19	Sound Attenuator For Condenser Fans	√	X	X	√	X
20	Primary Pump Installation	X	X	X	X	X
21	PG Installation At Suction & Discharge Sides	X	X	X	X	X
22	Wires Installed Inside Liquid Tight Conduits	X	X	X	X	X
23	Interlocking With Chiller	√	√	√	√	√
24	Flexible Connections Installations	X	X	X	X	X
25	Air Separator Installation With Drain	X	X	X	X	X
26	Expansion Tanks Installation With Drain	X	X	X	X	X
27	Chemical Dosing Set Installation	√	√	√	√	√
28	Make Up Water Pumps Installation & Tank	X	X	X	X	X
29	Softener For Make Up Water Installation	√	√	√	√	√
D						
1	Control panel installation	X	X	X	X	X
2	Indication lamps	X	X	X	X	X
3	Phase failure unit protection	X	X	X	X	X
4	Overload protection	X	X	X	X	X
5	Wires are tightly connected	X	√	√	X	√
6	Flow switch connection to (Direct Digital Control) DDC	X	√	√	X	√
7	Temperature sensor connection to DDC	X	X	X	X	X
8	Pressure sensor connection to DDC	X	X	X	X	X
9	Automatic valve connection to DDC panel	X	X	X	X	X
10	Chillers command and signal statues	X	X	X	X	X
11	Selector switch connection to DDC	X	X	X	X	X

12	Outside air temperature sensor installation	X	X	X	X	X
13	Outside air humidity sensor	√	√	√	√	√
14	Sequence of operation programming	X	X	X	X	X
15	2-way valve connection to DDC panel	X	X	X	X	X
16	Smoke detector connection to DDC panel	X	X	X	X	X
17	Filter differential switch connection to DDC panel	√	√	√	√	√
18	Fan differential switch connection to DDC panel	√	√	√	√	√
19	Thermostat installation and connection to DDC	X	X	X	X	X
20	Humidistat installation and connection to DDC	√	X	X	√	X
21	Outside air temperature sensor installation	X	X	X	X	X
22	Outside air humidity sensor	√	√	√	√	√
23	Heater and reheat stages connection to DDC panel	√	√	√	√	√
24	Sequence of operation programming	X	X	X	X	X
25	Interlocking with fire alarm system	√	X	X	√	X

SOURCE; SURVEY, 2018

APPENDIX V- MODLE PREDICTIVE CONTROL SIMULATION CODE

```
%% Initialisation and Data
clear
clc
```

load HVACm

```
%% Plant Design
plant_input= [AirFlowRate Cooling Heating];
RefTemp=25*ones(336,1);
Ts=0.04;
M1=iddata(RefTemp,plant_input,Ts);
M1.OutputName = 'Room Temperature';
M1.InputName = {'AirFlowRate' 'Cooling' 'Heating'};
plant_tf=tfest(M1,2,0);
% [A B C D]=ssdata(plant_tf);
M2=iddata(U,Temps,Ts);
M2.InputName = {'Room Temperature' 'Ambient Temperature'};
M2.OutputName = {'AirFlowRate' 'Cooling' 'Heating'};
plant2_tf=tfest(M2,2,0);
% [a b c d]=ssdata(plant2_tf);
```

%% First Plant

```
%{

From input "AirFlowRate" to output "Room Temperature":
                        9.745
                 ---------------------
                 s^2 + 14.4 s + 0.1014

  From input "Cooling" to output "Room Temperature":
                        0.08674
                 ----------------------
                 s^2 + 4.739 s + 0.1102

  From input "Heating" to output "Room Temperature":
                        -1.658
                 -----------------------
                 s^2 + 133.1 s + 0.00994

Continuous-time identified transfer function.
%}
```

```
%   From input "AirFlowRate" to output "Room Temperature":
num1=9.745;
den1 = [1 14.4 0.1014];
```

```
%   From input "Cooling" to output "Room Temperature":
num2=0.08674;
den2 = [1 1.264 7.306];

%   From input "Heating" to output "Room Temperature":
num3=-1.658;
den3 = [1 133.1 0.1102];
sys1=tf(num1,den1);
[A1,B1,C1,D1] = tf2ss(num1,den1);
sys2=tf(num2,den2);
[A2,B2,C2,D2] = tf2ss(num2,den2);
sys3=tf(num3,den3);
[A3,B3,C3,D3] = tf2ss(num3,den3);
```

%% Second Plant

```
%{

From input "Room Temperature" to output...
                          -0.7722
            AirFlowRate:  ---------------------
                       s^2 + 3.995 s + 19.29

                          -0.07621
                Cooling:  ---------------------
                       s^2 + 4.807 s + 51.85

                           3.313
                Heating:  ---------------------
                       s^2 + 6.632 s + 20.55

 From input "Ambient Temperature" to output...
                          -0.01148
            AirFlowRate:  ----------------------
                       s^2 + 0.1875 s + 1.081

                           -2.266
                Cooling:  ---------------------
                       s^2 + 4.276 s + 21.92



                           -59.3
                Heating:  ---------------------
```

s^2 + 14.55 s + 57.34

Continuous-time identified transfer function.

```
  %}

% From input "Room Temperature" to output...
%     AirFlowRate

   AFR1num= -0.7722;
   AFR1den= [1  3.995  19.29];

%     Cooling
   CR1num = -0.07621;
   CR1den = [1  4.807  51.85];

%     Heating
   HR1num = 3.313;
   HR1den = [1  6.632  20.55];

%   From input "Ambient Temperature" to output...

 %     AirFlowRate
   AFR2num= -0.01148;
   AFR2den= [1  0.1875  1.081];

%     Cooling
   CR2num = -59.3;
   CR2den = [1  4.276  21.92];

%     Heating
   HR2num = 3.313;
   HR2den = [1 14.55 57.34];


[A21,B21,C21,D21] = tf2ss(AFR1num,AFR1den);
[A22,B22,C22,D22] = tf2ss(CR1num,CR1den);
[A23,B23,C23,D23] = tf2ss(HR1num,HR1den);
[A24,B24,C24,D24] = tf2ss(AFR2num,AFR2den);
[A25,B25,C25,D25] = tf2ss(CR2num,CR2den);
[A26,B26,C26,D26] = tf2ss(HR2num,HR2den);
```

%% MPC Design

```
%  MV=struct('Min',-inf,'Max',Inf,'RateMin',-inf,'RateMax',inf);
```

```
%  OV=struct('Min',-inf,'Max',1);
R=0;
kgainC=0;
kgainH=0;
AFRUnc=10;
Ts=0.04;
p=100;
m=25;
RT=0;
mpchvac=mpc(plant_tf,Ts,p,m);
% mpchvac=mpc(ss(A1,B1,C1,D1),Ts,p,m,[],MV,OV);
%% System Simulation
Tstop=100;
sim('HVACsim.mdl')
% Inst=1:length(MPCkWh);
% Inst=Inst';
MPCkWh=kWh(:,1);
BinkWh=kWh(:,2);
```

%% Results and Plots

```
figure (1)
plot(Time,Reference,'-k',Time,MPCRoomT,'-g',Time,BinRoomT,'-r')
title('Comparative Analysis of Temperature Response')
xlabel('Time')
ylabel('Temperature')
legend ('Reference','MPCRoomT' ,'BinRoomT')

figure (2)
plot(Time,MPCkWh,'-k',Time,BinkWh,'-r')
title('Comparative Analysis of Energy Consumtion')
xlabel('Time')
ylabel('Energy Consumption')
legend ('MPCkWh','BinkWh')
```

APPENDIX VI- VIEW OF SOME OF THE HOTELS AND THE HVAC INSTALLATIONS

PLATES 1 GREAT WOOD HOTEL

PLATE 2 MARANATHA HOTEL

PLATE 3 BENCONN HOTEL LTD

PLATE 4 WESTBROOK HOTEL




PLATE 5 GLOBAL HOTEL



PLATE 6 OCEAN PILLARS HOTELS


PLATE 7 JAIMEL HOTEL

Plate 8 SAGA SUITE

PLATE 9 BAY VIEW HOTEL

PLATE 10 LEGACY HOTELS AND SUITES OWERRI

PLATE 11 CITY GLOBAL HOTEL

TABLE OF Contents **PAGE NO**

CHAPTER ONE..1

1.0 INTRODUCTION..1

1.1 Background of Study...1

1.2 Statement of the Problem 4

1.3 Aim and Objectives 6

1.4 Research Questions 6

1.5 Research Hypotheses..7

1.6 Significance of Study 7

1.7 Scope and Delimitation of the Study..8

1.8 The Study Area..8

1.9 Structure of Dissertation (Outline) 14

CHAPTER TWO..16

2.0 THEORETICAL, CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW ...16

2.1 THERETICAL FRAMEWORK 16

A. Overview on Building and HVAC System Control Methods 17

B. Model predictive control (MPC) 18

C. History of Model Predictive Control...19

D. Stability of the Model Predictive Control 20

E. Previous Reviews That Consider MPC Only as One among Many Possible Control Methods 21

F. Previous Reviews That Are Entirely Focused on MPC 21

2.1.2 Framework and Structure of the Model Predictive Control................................22

A. MPC Typologies 26

B. ASHRAE Classification of Modeling of Building and the HVAC System 28

2.1.3 Modelling HVAC System in the Building 30

A. The Prediction Models of Disturbances 36

B. The Controlled Systems 38

C. Constraints in MPC Model of HVAC 41

D. Control Goals and Objective Functions 43

E. Elemental MPC Controller Formulation 46

2.1.4. HVAC System Types 48

A. Central HVAC Systems 48

B. Packaged HVAC systems 51

C. Individual Room Air Conditioning 53

2.2 Conceptual Framework 54

2.2.1 Strategies and Methods of Sustainable Implementation 56

2.2.2 Resource Conservation 56

2.2.3 Energy Conservation 59

2.2.4. Definitions of Sustainable Consumption 63

2.2.5. Socio-Economic and Psychological Approaches to customer behavior 65

2.2.6 General Factors Influencing Sustainable Energy Consumption 67

2.3 Review of Related Literature 72

2.3.1. Energy Consumption In Comercial Buildings 72

2.3.2 Global Perspective of Energy Conservation 75

2.3.3 Building Envelope 76

2.3.4 Design of Buildings for Energy Efficiency 77

2.3.5 Thermal Comfort Conditions and Energy Consumption 79

2.3.6 Thermal comfort defined 79

2.3.7 Historical Perspective of Thermal Comfort 81

2.3.8 Factors Affecting Thermal Comfort 83

2.3.9 ASHRAE Standard for Thermal Comfort 86

2.3.10 Thermal Comfort Relative to the Psychrometrics...87

2.3.11 Thermal Comfort, Psychometric Chart and Building Design.............................91

2.3.12 HVAC System...92

2.3.13 Description of General HVAC Systems 95

2.3.14. Chillers 99

2.3.15 Energy Efficiency Techniques for HVAC System 100

A. Operational Techniques for Energy Efficiency 101

B. Design Techniques for Energy Efficiency 104

2.4: Study Gap 105

CHAPTER THREE 108

3.0 RESEARCH METHODOLOGY 108

3.1 Research Design 108

3.2 Population, Sample and Sampling Technique...109

3.2.1: Population of the Study 109

3.2.2: Sample, Sample size and techniques 109

3.3 Data Collection Methods and Instruments 113

3.3.1 Design and Administration of Questionnaires...117

3.3.2 Checklist 118

3.3.3 Walk-through survey/Physical or Direct Observation. 118

3.3.4: HVAC Energy Consumption Simulation Using MPC 119

3.4 Method and Instrument of Data Analysis 119

3.4.1 Validity and Reliability of the Instrument 122

4.1.1 Respondents Profile 124

4.1.2 Data Sheet building Audit 125

Table 4.3 Data Sheet building Audit 125

4.1.3 Building Physical Characteristics 126

Table 4.4 Building Physical Characteristics 126

4.1.4 Building Operating Characteristics 127

Table 4.5 Building Operating Characteristics 127

4.1.5 Energy Management in the Hotels 130

Table 4.6 Energy Management of the Hotels 130

4.1.6 HVAC Maintenance 132

Table 4.7 HVAC Maintenance 132

4.1.7 Ranking of Maintenance of the HVAC Components 133

Where: ND= Never Done; RD= Rarely Done; NI= No Idea; OD= Often Done; AD= Always Done 136

4.1.8 Occupants Use of HVAC 139

Table 4.9 Occupants Use of HVAC 139

4.1.9 Component, Equipment and Measures Values 140

Table 4.10 Component, Equipment and Measures Values 140

4.1.10 Effect of the maintenance of HVAC system on its Energy Consumption 141

4.1.11 Energy Saving and HVAC Control Functionality 143

Table 4.12 Energy Saving and HVAC Control Functionality 143

4.1.12 Energy Saving Strategies for HVAC Systems..144

4.2 RESULT OF THE CHECKLIST ANALYSIS 145

4.3 SIMULATION OF ENERGY CONSUMPTION USING A MODEL PREDICTIVE CONTROL..146

Fig 4.5: HVACsim..151

Source: Field Survey (2018)...151

4.4 HYPOTHESES TESTING...154

4.4.1 Hypothesis One 154

4.4.2 Hypothesis Two 156

4.4.3 Hypothesis Three 158

4.4.4 Hypothesis Four 159

4.5 SUMMARY OF FINDINGS: 162

CHAPTER FIVE...167

5.0: CONCLUSION AND RECOMMENDATIONS..167

5.1: CONCLUSION:...167

5.2: RECOMMENDATIONS 169

5.3: CONTRIBUTIONS TO KNOWLEDGE:...171

5.4 RECOMMENDATIONS FOR FURTHER STUDIES. 171

REFERENCES..173

APPENDIX III: HOTELS WITHIN OWERRI MUNICIPAL 13

APPENDIX IV –QUESTIONNAIRE..187

APPENDIX V- CHECKLIST 199

APPENDIX VI-SPSS RESULT FOR HYPOTHESIS ONE 203

APPENDIX- VII-- RESULT OF THE CHECKLIST SURVEY..211

APPENDIX VIII- MODLE PREDICTIVE CONTROL SIMULATION CODE...............252

%% First Plant 252

APPENDIX IX- VIEW OF SOME OF THE HOTELS AND THE HVAC INSTALLATIONS 256