ENERGY PERFORMANCE ANALYSIS OF ADNAN MENDERES INTERNATIONAL AIRPORT (ADM)

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ABSTRACT

ENERGY PERFORMANCE ANALYSIS OF ADNAN MENDERES INTERNATIONAL AIRPORT (ADM)

Space cooling and heating are needed throughout the year for commercial buildings and electricity use in these buildings accounts for about one-third of the total energy consumption in Turkey. In this study, Adnan Menderes International Airport (ADM) located in Izmir is simulated with EnergyPlus software which is a new generation building energy analysis tool. The simulation model is constructed first with Design Builder and than the measured data are used to compare the model. EnergyPlus simulations are used in this thesis to help understanding more about the ADM's dynamics and evaluate various strategies such as different orientation and heating, cooling, ventilation and air conditioning (HVAC) system. According to simulation and different HVAC system results; cooling electricity consumption increases 2.8 times in each month. According to simulation and east orientation results, heat gains decrease between 2% and 11% in winter, autumn and spring months and increase between 3% and 14% in summer months.

Measured data of ADM building showed that HVAC system had constituted almost 80% of the total energy consumption, according to the average data obtained in 2008. The difference between measured and simulation consumption values are greater more than 70%. According to simulation results, also there is 2.4 times more electricity consumption on 18 August when compared to 11 January. Finally, analysis showed that ADM building requires year-round cooling and very little heating.

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ÖZET

ADNAN MENDERES HAVAALANI DIŞ HATLAR TERMINALİ ENERJİ PERFORMANS ANALİZİ

Ticari binalarda bütün yıl boyunca ısıtma ve soğutmaya gereksinim vardır ve bu binalardaki elektrik tüketimi, Türkiye'nin toplam enerji tuketiminin üçte birini oluşturmaktadır. Bu çalışmada, İzmir'de bulunan Adnan Menderes Havaalanı Dışhatlar Terminali, yeni bir enerji analiz aracı olan EnergyPlus programı ile simule edilmiştir. Model öncelikle DesignBuilder programıyla çizilmiş ve tanımlanmıştır. Daha sonra ölçülmüş verilerle karşılaştırılmıştır. EnergyPlus ile yapılan bu simulasyon, ADM binasının enerji hareketlerinin anlaşılmasına yardımcı olmakda ve farklı ısıtma, soğutma ve havalandırma (HVAC) sistemi kullanilmasi veya binanin farkli yönde yerleştirilmesi gibi stratejilerin değerlendirilmesinde kullanılmaktadır. Simulasyon sonuçlarına göre; farklı bir HVAC sistem kullanıldığında, her ay için soğutma elektrik ihtiyacı 2.8 kat artar ve bina batı yönünde yerleştirildiğinde, ısı kazancı kış ve bahar aylarında % 2 ila % 11 azalırken, yaz aylarında % 3 ila % 14 artar.

ADM binasında toplam elektrik sarfiyatinin yaklaşık 80%'inin HVAC sistem için kullanıldığı 2008 yılına ait ölçüm değerlerinde gözükmektedir. Simulasyon sonuçları ile ölçüm değerleri arasında % 70 den fazla fark vardır. Ayrıca, simulasyon sonuçlarına göre; 18 Ağustos'daki günlük elektrik tüketimi, 11 Ocak'a göre 2.4 kat daha fazladır. Sonuç olarak, analiz yıl boyunca binada soğutma ihtiyacı olduğunu ve çok az ısıtma ihtiyacı olduğunu gösterir.

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CHAPTER 1

INTRODUCTION

The world energy demand increases rapidly with economic and population growth. The world population has doubled from 1970 to 2007, while energy consumption was increased more than four times per person in the same period (Soyhan 2009). According to International Energy Agency study, the world energy demand in 2020 would be 50%-80% higher than the 1990 levels (OECD, Paris, 1995).

Increasing of energy consumption has detrimental effects on environment such as global warming, ozone destroying gases, gaseous pollutants, and microbiological hazards. The most important problem is global warming resulted from conventional effluent gas pollutants such as SO_2, NO_x, CO_2, and CO.

The energy requirement of any country is a crucial input for the economic and social development. Hence energy consumption is determined depending on population growth and rapid urbinization. Turkey has involved in the group which consists of the fastest growing energy markets in the world for nearly two decades because of its young and growing population, per capita energy consumption, rapid urbanization, and economic growth. An average annual growth rate of Turkish economy has been reached to 4.1% over past 20 years. The process of economic development in the devoloping countries, in the case of Turkey, is the cause of rapid growth for energy consumption and imports. In Turkey, energy imports have increased rapidly because of small increase in national energy production and rapid increase in demand. In the next years, this increase in energy imports will be continued. Net energy import, which met 54% in 1990 and 67% in 2000 of the total primary energy supply, is expected to increase to 76% in 2020. Turkey as a developing country is getting more dependent on imported energy resources and is getting almost two thirds of its energy needs from imported energy resources. Consequently, providing sufficient and secure energy supplies become the top priority of Turkey's energy policy (Ozturk 2005).

Domestic and industrial buildings are responsible for approximately 40 percent of the world annual energy consumption. In 2004, building consumption in the European (EU) was 37% of final energy, bigger than industry (28%) and transport

(32%). In the UK, the proportion of energy use in building (39%) is slightly above the European figure (Lombard et al. 2008).

According to the International Energy Agency (EIA) estimation, energy use in the buildings will grow by 34% in the next 20 years, at an average rate of 1.5%. In 2030, estimated consumption attributed to dwellings and the non-domestic sectors will be 67% and 33% respectively (approximately). Figure 1.1 shows EIA's analyses and forecast future trends in building energy consumption (EIA 2006).

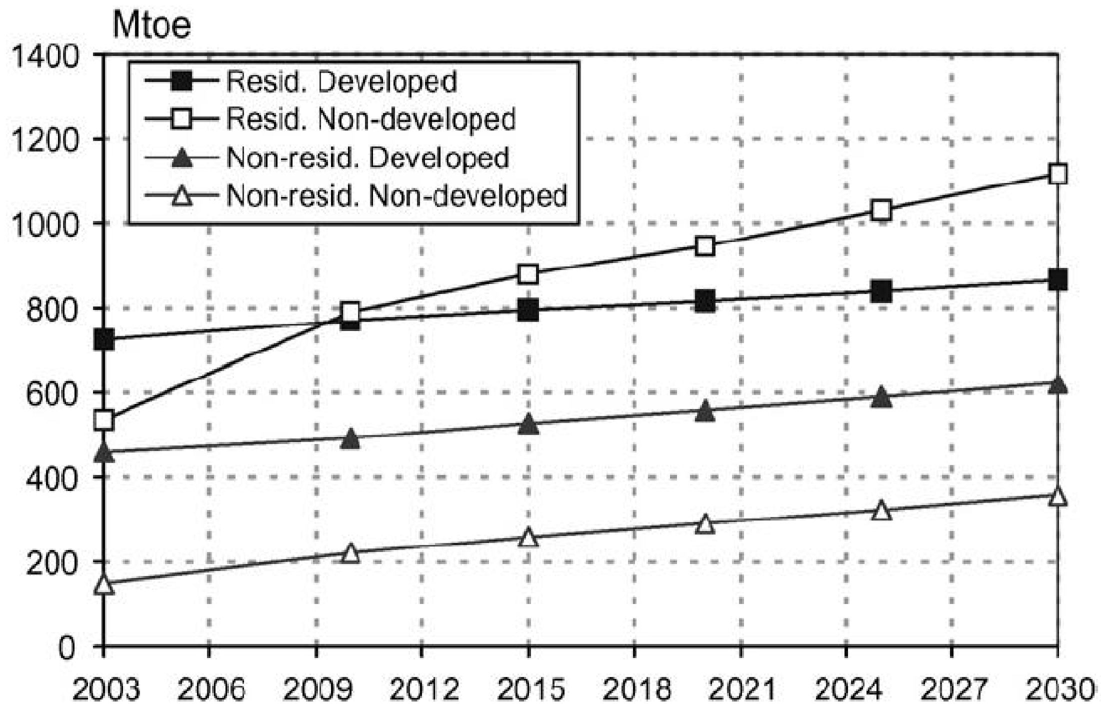


Figure 1.1. Buildings Energy Consumption Outlook.
(Source: EIA 2006)

As a result, energy efficiency and saving strategies in the buildings are a priority objective for energy policies. Kyoto Protocol is one of the most important international agreement linked to the United Nations Framework Convention on Climate Change. The other regulation is the European Energy Performance of Buildings Directive (EPBD) Directive Implementation Advisory Group (DIAG) that was established in 2002 and it aims to advise the UK Government on the energy performance of buildings and the implementation of the European Energy Building Performance Directive. European Union Directive on the Energy Performance of Buildings (2002/91/EC) define energy performance of a building :

> The amount of energy actually consumed or estimated to meet the different needs associated with a standardised use of the building, which may include, inter alia, heating, hot water heating, cooling, ventilation and lighting. This amount shall be reflected in one or more numeric indicators which have been calculated, taking into account insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighbouring structures, own-energy generation and other factors, including indoor climate, that influence the energy demand (EPBD 2002).

Turkey participates in both Climate Change and Kyoto Protocol. In July 2008, Turkey signed Kyoto Protocol and committed to reduce greenhouse gas emissions by 10% compared to 1998 (Kyoto Protocol 1997). Turkish thermal insulation standard (TS 825) has been in effect since 1999, althought it was published firstly in 1970. TS 825 was revised according to Turkey's conditions in 2008.

Turkey is revising its legislations on building energy performance as foreseen in 2002/92/EC, European Union Directive on the Energy Performance of Buildings, through the European Union accession process. TS 825 (2008), "Thermal insulation requirements for buildings" which came into force at 2000, is revised in 2008. In 2007 "Energy Efficiency Law" and "Energy Performance of Building Regulation" in 2008 provide accelaration for studies on a methodology for energy performance evaluation of the buildings. "Energy Performance of Buildings Regulation" for a calculation procedure including heating, cooling, domestic hot water production and lighting energy consumptions and CO_2 emissions have been just completed in December 2009. There will be a need to improve limitation of energy consumption values because of these standarts and the studies related to energy performance development.

Energy efficiency potential of Turkey is defined as up to 30% in buildings, 20% in industry and 15% in transportation sectors by WEC (World Energy Council), predicting 4 billion TL energy saving. Industry, building and service sectors are accepted as primary sectors in energy efficiency studies because of their highest proportion on total consumption and high potential energy saving. Imported expenditure of oil and natural gas in our country will show a 1.4 billion USD-decrease under condition of 35% saving in heating and cooling of buildings and a 15% saving in transportation is obtained. For commercial buildings, space cooling and heating are needed throughout the year, and electricity use in the commercial buildings, accounts for about one-third of the total energy consumption in Turkey. For this reason, reducing energy usage for space cooling and heating in buildings is inevitable for energy conservation and environmental protection in Turkey (WECTNC 2005-2006).

Major energy sinks in buildings are lighting, heating, cooling, ventilation and hot water supply. Heating, cooling, ventilation and air conditioning system (HVAC) consumption in developed countries accounts for half the energy use in buildings and one fifth of the total national energy use. As can be seen in Figure 1.2, building type is critical in how energy end uses are distributed (EIA 2006).

The goal of this study is to simulate Adnan Menderes International Airport (ADM) building with EnergyPlus and DesignBuilder softwares. Built of our interest after the operator of the building has mentioned their concerns about the energy efficiency of our school and has requested an analysis. In addition, the reason why I study on this building is because of my previos experience in having worked at the construction of ADM building.

Measured data of ADM building showed that HVAC system had constituted almost 80% of the total energy consumption, according to the average data obtained in 2008. Because of this massive energy consumption, ADM building is selected the case study of this thesis.

There are two basic way to reducing building energy consumption: using renewable energy and increasing of building energy performance. In order to provide high level of energy performance to design building that are more economical in its use of energy for HVAC system, lighting, and hot water supply.

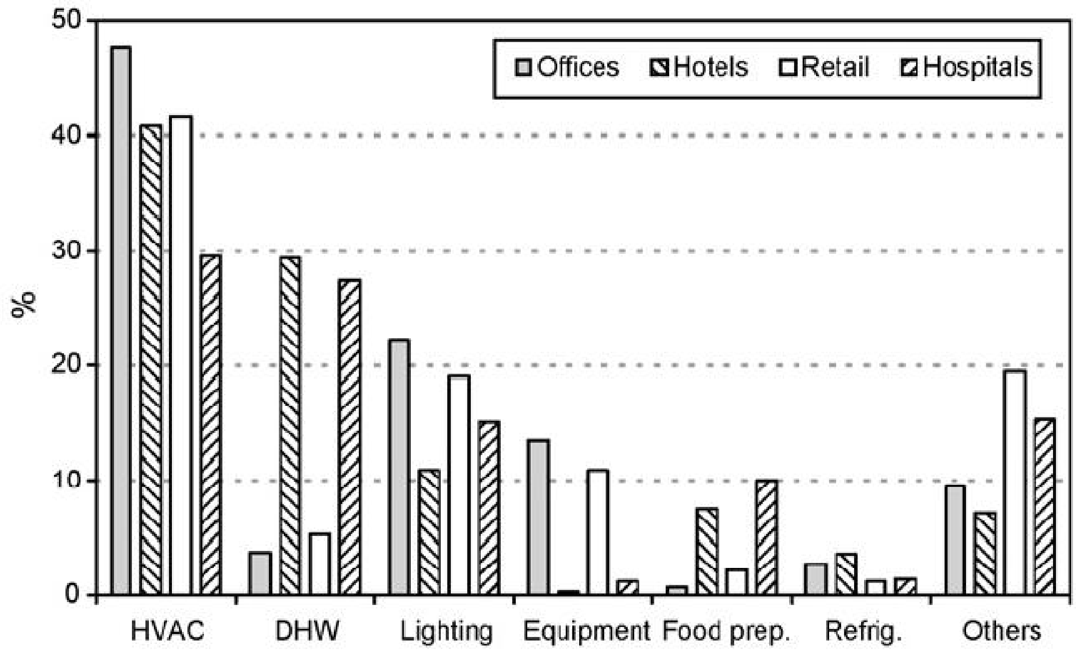


Figure 1.2. Consumption by End Use for Different Building Types.
(Source: EIA 2006)

Many physical aspects of heat transfer such as heat conduction, convective flow, radiation, mass flows through buildings walls must be properly addressed to simulate a building. Simulation becomes the most cost effective way to improve the energy efficiency of buildings because of complexity and highly coupled nature of these phenomena. To get a better understanding of the energy conserving design principles and operational strategies, there is an essential need to study of the factors affecting the energy performance of buildings and the energy characteristics of the building systems. Computer programs give great opportunity to get detailed building energy simulation. So, it provides an extensive and systematic examination of these factors through the use of a computer modeling technique (Clarke 2001).

Computer-based simulation is accepted by many studies as a tool for evaluating building energy. There are many different types of computer-based simulation tools that are available for performing whole building simulation. An on-line directory sponsored by the US Department of Energy lists 386 building-energy software tools developed worldwide that have thousands of users (US Department of Energy 2009).

DESIGN BUILDER and ENERGYPLUS commercial softwares are used in this thesis for the modeling and simulation of the energy performance of ADM building in Izmir besides evaluating the thermal data taken on site. It is a great difficulty in analyzing and evaluating the whole building energy consumption. The aim with this thesis is to, by an energy simulation program EnergyPlus, investigate how the energy demands in ADM building are changing with different circumstances.

ADM building is the subject of this research studies. The total area of ADM building including concources and terminal is over 110.000 m². This building has a central air-conditioning an building management system (BMS). BMS is used to control HVAC equipment in order to optimise indoor confort conditions and reduce energy consumption.

This thesis introduces the method of ADM building simulation and presents one case study in that the methods is used in analyzing the energy consumption of the building Furthermore this study can help designers compare various design option and lead them to energy efficient designs in manner of cost-effectiveness.

Second chapter of this thesis, description of ADM building including introduction to the building and it's HVAC system. Chapter 3 is inroducing the using software with ADM building energy performance calculation, modelling, assumptions and results of measurements. Results of the simulation, Direct Expansion HVAC, and different orientation scenarios are given in chapter four. In the last chapter, important findings are presented as conclusions.

Building Energy Performance Studies in the World

The most important issue is how to evaluate and estimate the energy demand of a building, especially the building which have air conditioning systems. There are lots of variations in a building as follows; the climate conditions, occupant population's fluctuations, occupation schedule and the internal loads. Because of these variations, energy consumption calculations are difficult to evaluate. Following paragraphs contain some studies about building energy performance to get better understanding the complexities of the subject.

The study of Yik et al. (2001) was a good example for simulation of commercial buildings and hotels. Their studies provided a simple model to predict the energy consumption for 23 commercial buildings and 16 hotels. Three programs were used for simulating the buildings: one for cooling load simulation, one for detailed building heat transfer simulation and one for air conditioning system simulation. The authors used the energy and cooling load profiles provided by the detailed simulation programs to feed a simpler model based on the normalized cooling load profiles related to the gross floor area of the buildings studied in their research. The results show a very good correlation (average deviations of 2% between detailed simulation programs and proposed model). It should be pointed out that this methodology is based on the evaluation of energy and cooling load profiles calculated by detailed simulation programs and calibrated by actual energy consumption profiles.

The study of Gugliermetti et al. (2004) was important because of indicating the important role of climate data aspects on forecasting the energy consumption in office buildings. They showed the use of a typical month day instead of annual weather tape can induce an over or under estimation of the building energy profiles.

In the study of Qinglin and Zhuolun (2007), Sanya Airport was simulated and it was an example for design of aviation building. Mechanical fans in different plans was used to simulate the potential of natural ventilation and air modulation of Sanya in summer by the computational fluid dynamics (CDF) software PHOENICS. Consequently, it is concluded that the wide usage of air modulation by mechanical fans in tropical zones can lead to lower energy consumption under the same indoor thermal comfort

Computers with software packages have presented great opportunities to calculate the building energy performance. Over the past 50 years, hundreds of building energy programs have been developed, enhanced and now they are in use. Softwares are differ from their calculation method and following subtitles include example of the studies made by these programs.

Another commercial software called eQuest is another simulation software tool and Zhu (2006) was used it in order to create a virtual environment in the operation of the HVAC system and the lighting of the facility. In this study, they explored the capabilities and limitations of a simulation tool called eQuest to perform energy evaluation of an office building. According to the author this tool can provide important insights for the designer about the impact of different strategies for reducing energy consumption. The main negative point of eQuest is that this kind of tool requires detailed information on the building constructive aspects, as well as its occupancy, lighting and equipment operation schedules.

In building energy performance studies especially in acedemic studies' TRNSYS was used widely. TRNSYS was developed at the Solar Energy Laboratory at the University of Wisconsin in the mid-1970s for analysis of active solar heating and cooling systems. In literature Balaras`s studies have been expected as the most comprehensive studies for airport buildings simulations.

The study of 29 Helenic airports done by Balaras et al. (2003) evaluates current energy consumption and the potential for energy conservation. Three majors Helenic airports located at different climatic zones were selected for detailed studies. Detailed analysis was obtained from measurements by using thermal simulations. Potential energy savings were between 15 to 35% for these three airports, while improving and maintaining indoor environmental quality.

A large public building located in Shanghai have been simulated by Pan et al. (2009). EnergyPlus, DOE-2.1 and TRYSYS were compared based on their capabilities and advantages as a whole building energy analysis tool. It was understood from this study that large public buildings should take into account of the complicated system composition and operation strategies in order to achieve an accurate evaluation of building performance. This study is an evidence to bring out the capability of EnergyPlus.

The last example of airport building is performed by Griffith et al. (2003) in Teterboro airport. They employed EnergyPlus in order to analyze the effect of envolope system and schedules. Meanwhile, a new building in the Teterboro Airport for energy efficient was predesigned, developed an modelled by Griffith et al. with DOE-2.1. EnergyPlus was used to make whole building annual energy simulation.

CHAPTER 2

DESCRIPTION OF ADM BUILDING

2.1. General Information

ADM International Airport was constructed on a total area of 110.000 m2, to serve for 5.000.000 people/year. The airport has 70.000 m2 apron area, 10 passenger boarding bridges and 3.000 vehicle capacity parking area. ADM coordinate is 38° 17’ north, 27° 8’ east as shown in Figure 2.1.

Figure 2.1. ADM Building Birds Eye View from Google-Earth.

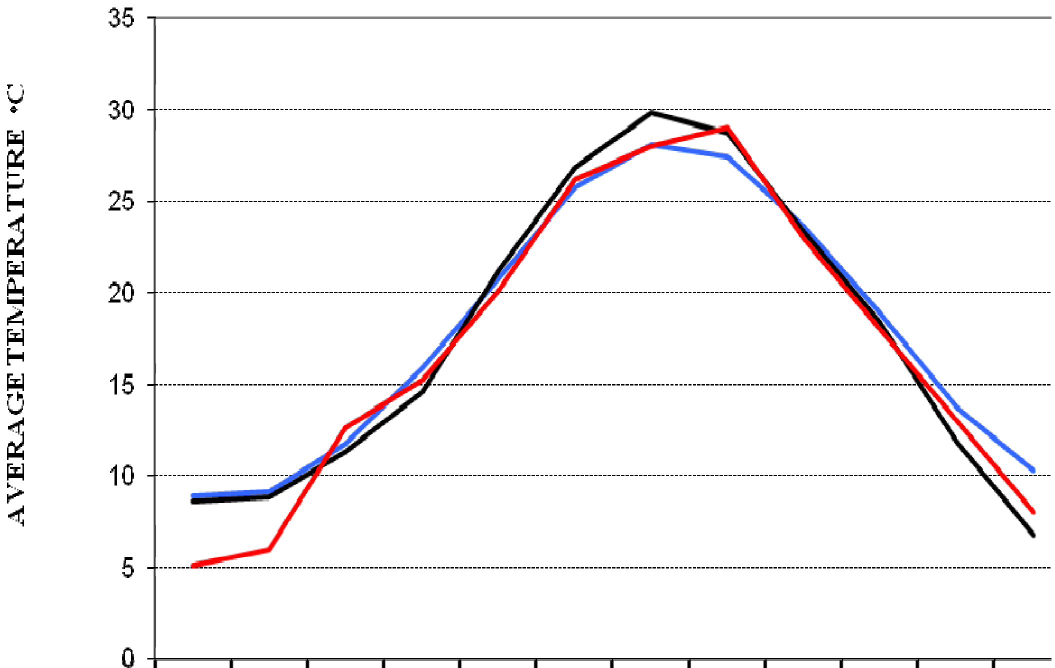
ADM includes a car park covering 64,000 m² with a capacity for 2,200 automobiles. There are the terminal boasts of 60 check-in counters, 32 passport control booths, nine passenger boarding bridges and six baggage claim carousels. A slick network of 36 elevators, 25 escalators and 26 travelators whisk passengers to their ultimate destination. ADM building operates on 24h basis throughout the year, with variable schedules and occupancy during certain periods.

ADM building consist of one central terminal building and two concourses building connected by long passageways to departure lounges for airplane loading. These areas are including large, open plan areas, often with high ceilings, ticketing counters, waiting areas, small office spaces, and various types of stores, concessions and convenience facilities. In Figure 2.2 shows Adnan Menderes Domestic and International Airport. This thesis's subject is only International Airport areas. Also this study does not cover car park area.

Figure 2.2. Adnan Menderes Domestic and International Airports.

2.2. Climatic Condition

In Izmir, there is a mild Mediterranean climate with average temperatures of 9 ^{0}C in winter and 29 ^{0}C in summer. Outdoor air temperature is the most significant parameters effecting heating-cooling loads of a building. Figure 2.3 shows of monthly Average Outdoor temperatures (1975-2006, 2006, and 2008).



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1975-2006	8,9	9,1	11,7	15,9	20,8	25,7	28,1	27,4	23,6	18,9	13,7	10,3
2007	8,6	8,8	11,3	14,6	21,2	26,8	29,8	28,7	23,3	18,4	11,8	6,8
2008	5.1	6	12.6	15.2	20.1	26.2	28	29	23	18	13	8

Figure 2.3. Comparison of Monthly Average Outdoor Temperatures (1975-2006, 2006, and 2008).

2.3. Envelope

ADM building is airtight building with no open windows and has large glazing areas more than 70% of the all building. There are five different type external glazing in ADM building. These are: FVG, SKY_VG, SVG_A, SSVG, and PFI. Type of glazing and their location are showed in Figure 2.4. Also glazing's specifications are given Appendix C.

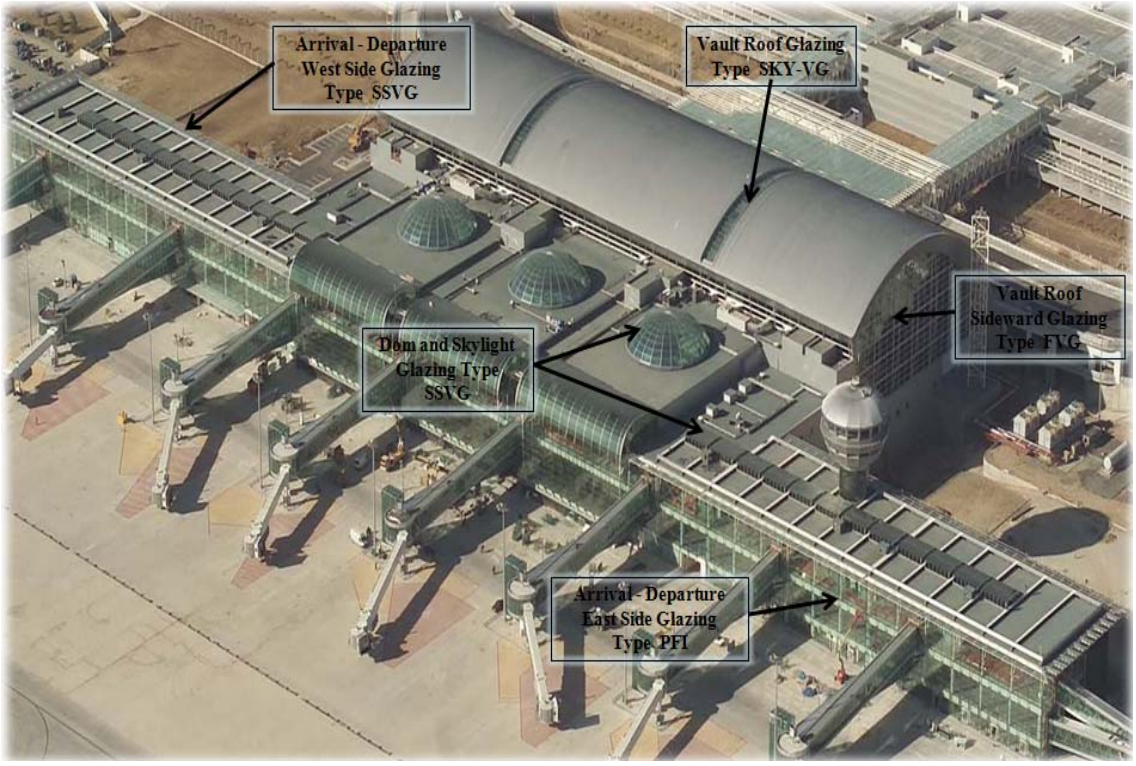


Figure 2.4. Glazing Types.

2.4. HVAC System

ADM building uses the central cooling system which has four water cooling chillers and towers, one air cooling chiller, one heating cooling packege chiller, fan-coils and local split unit air-conditioners in some offices as shown in Figure 2.5 & 2.6. There are also Computer Room Air Conditioning (CRAC) units in some computer rooms.

Figure 2.5. HVAC System Equipment(Cooling System).

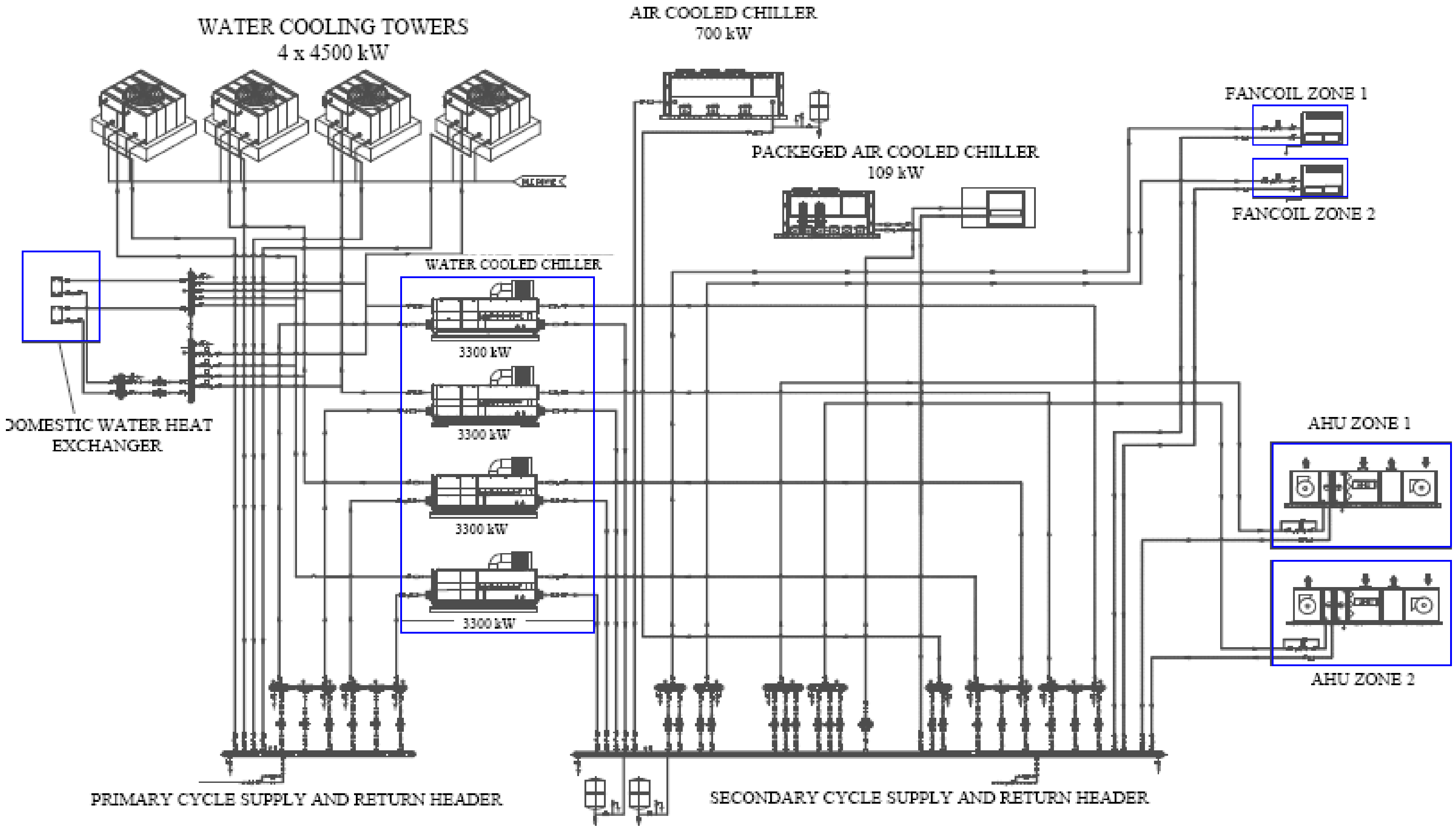


Figure 2.6. Cooling System Flow Diagram of ADM Building

ADM building uses the central heating system which has three steel boilers, solar panels and heat exchangers for domestic hot water system (DHW) and area shown in Figure 2.7 & 2.8. There are 71 AHUs (air handling units) in ADM building. These are used common heating and cooling.

Figure 2.7. HVAC System Equipment (Heating System).

Total rated cooling capacity is 3300x4 kW and heating capacity is 10450 kW in ADM building. Supply and return air ducts are located around the perimeter of the building. Hot water supplied from three boilers 2x3700&1x3050 kW (90 ºC/70 ºC). Total amount of supply air to the building is 1.145.000 m^3/h. There is a variable outdoor air intake per air handler.

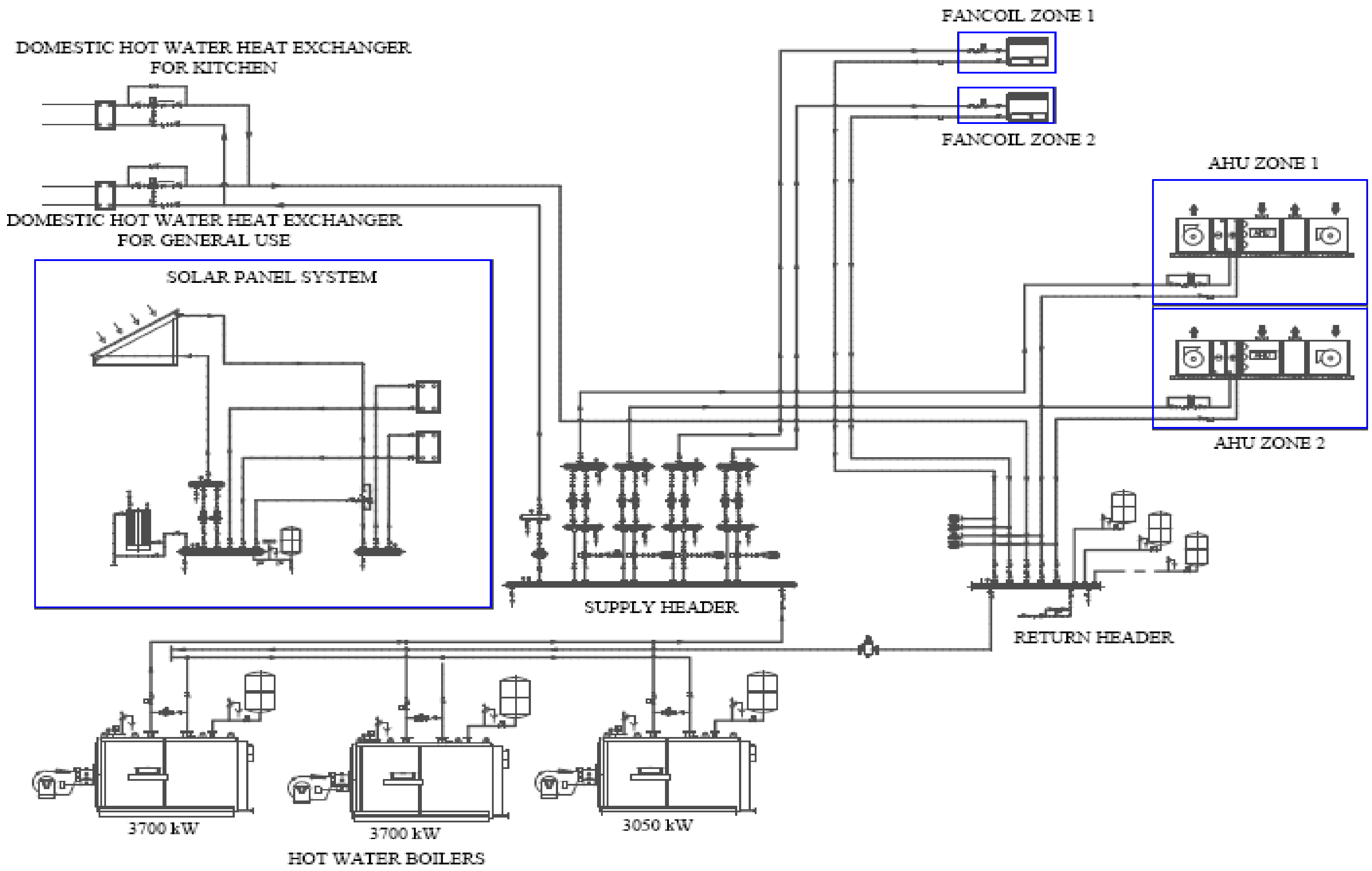


Figure 2.8. Heating System Flow Diagram of ADM Building

CHAPTER 3

METHODOLOGY

3.1. Measurements and Real Data

Electricity and fuel consumptions of the ADM Building is measured by technical personal of the building. Table 3.1 shows monthly electricity consumption data for the entire building between 2006 and 2008. Also, Figure 3.1 shows annuals energy consumption distribution for ADM building in 2008. According to this figure, ADM building had an air conditioning energy consumption almost 80%, during 2008 to meet passengers' higher comfort expectations and standards. The annual total energy consumption of ADM building (except car park area) is about 140 kWh/m^2, averaged 2-years period (2007-2008).

Table 3.1. Energy Consumption of ADM Building.

ACTIVE & REACTIVE ENERGY CONSUMPTION				
	Beginning of invoice	**Finishing of invoice**	**Active (KWH)**	**Reactive (KWH)**
January	23/12/2006	29/01/2007	1.690.052	277.691
February	29/01/2007	26/02/2007	1.047.937	154.008
March	26/02/2007	29/03/2007	1.006.641	136.931
April	29/03/3007	27/04/2007	1.016.577	138.793
May	27/04/2007	29/05/2007	1.597.419	291.974
June	29/05/2007	28/06/2007	1.827.396	299.218
July	28/06/2007	27/07/2007	2.049.610	362.664
August	28/07/2007	28/08/2007	2.349.657	425.502
September	28/08/2007	27/09/2007	1.816.425	288.248
October	27/09/2007	26/10/2007	1.436.994	39.951
November	26/10/2007	28/11/2007	1.296.648	44.877
December	29/11/2007	27/12/2007	1.127.736	30.843
Totally			**18.263.092**	**2.490.698**
January	28.12.2007	29.01.2008	1.343.326	27.634
February	30.01.2008	27.02.2008	1.103.413	23.598
March	28.02.2008	28.03.2008	1.046.592	22.770

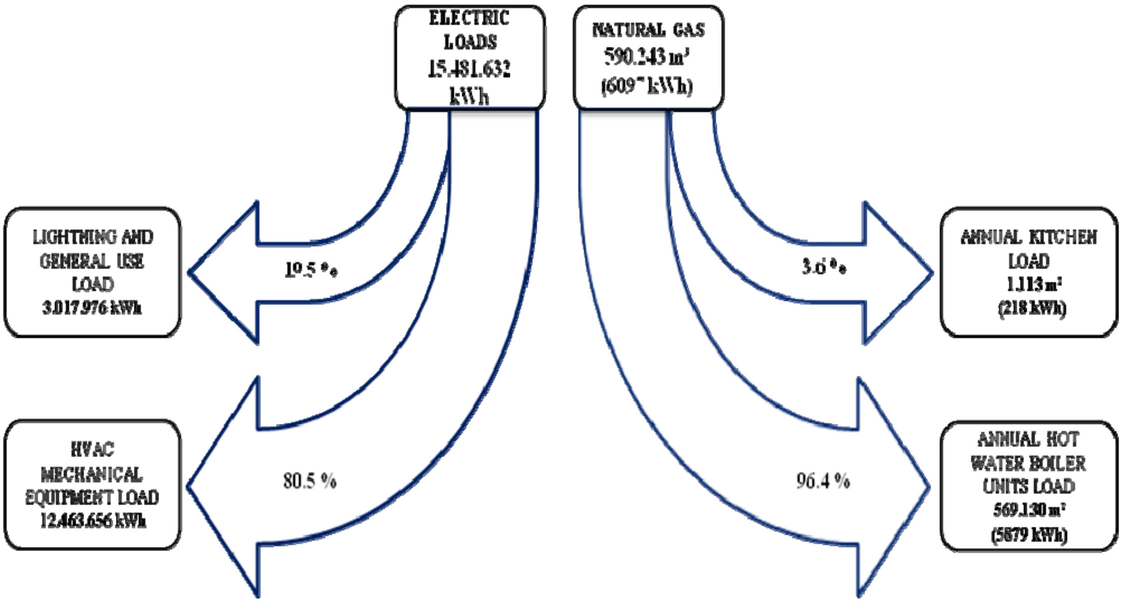


Figure 3.1. Annual Energy Consumption Distribution Chart for ADM building in 2008.

Energy related data was collected by BMS system. Measured data on the annual electric consumption distribution of all HVAC equipments in ADM buildings is illustrated in Figure 3.2. This pie graph consists of AHUs, fans, pumps, chillers, and CRACs. Interestingly, although chiller units constitute 7 percent of electric consumption of HVAC system, AHUs constitute more than half of the energy consumption of HVAC system in ADM building as shown in Figure 3.2.

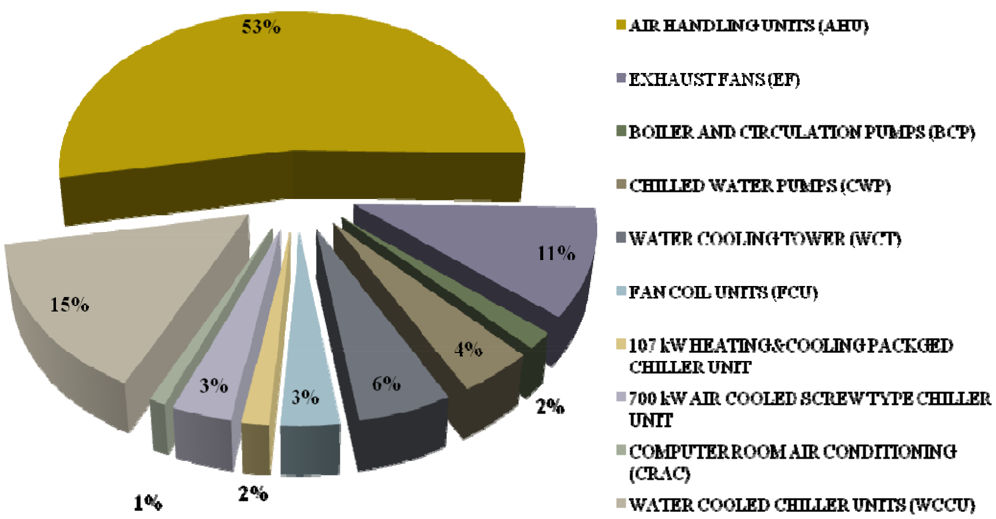


Figure 3.2. Annual HVAC Equipments Energy Consumption Portion in 2007.

The total number of AHU is 71 and Figure 3.3 indicates how much AHU's working capacity was obtained measured data from six months in 2008. These results were obtained assuming that the AHUs are working at full capacity in a 24 hour period.

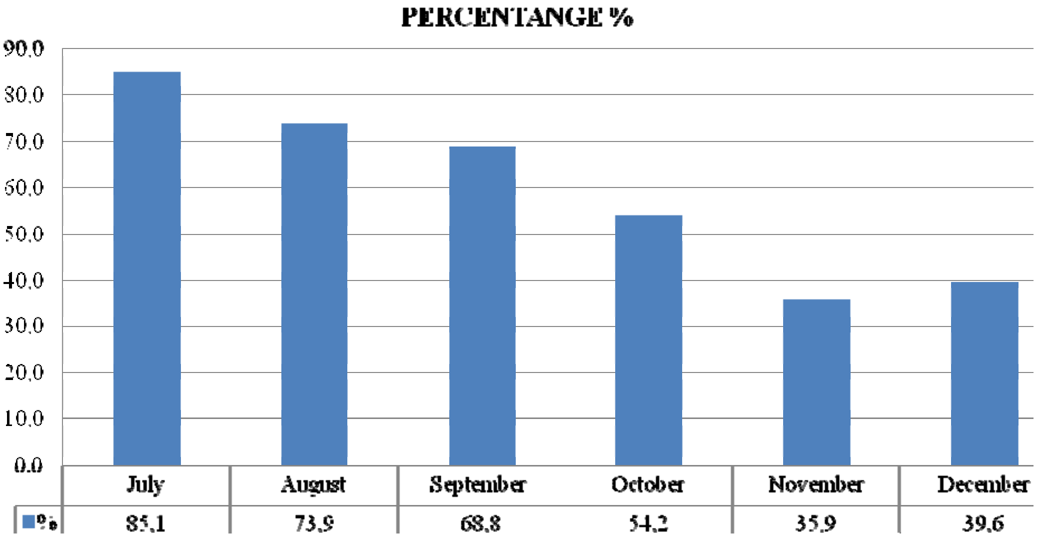


Figure 3.3. Energy Consumption Working Capacity of the AHUs in 2008.

The potantional for energy saving depends on the specific characteristics such as:

- reduce heating and cooling loads,
- appropriate indoor enviremental quality

Total energy consumption of the building decreases by year, because of the retrofit of the construction elements in ADM building. The electricity consumption of HVAC equipments is decreased 15% in 2008.

Based on measurements following comments were obtained. While heating and cooling system pumps were examined, it will be seen that the energy used in both pumps, which feed heating and cooling for fan coils constitute 10 percent of energy. Therefore, 90 percent of heating and cooling energy were used for AHUs. While the pumps that feed AHUs were 303 m^3/h and 1164 m^3/h for heating and cooling system respectively. On the other hand, the pumps that feed fan coils were 30 m^3/h and 117 m^3/h for heating and cooling system respectively.

3.2. Introduction to EnergyPlus and Design Builder

For more than 20 years, the US government supported development of two building energy simulation programs, DOE-2 and BLAST. BLAST is sponsored by the US Department of Defense (DOD) and DOE-2 is sponsored by the US Department of Energy (DOE). The main difference between the programs is load calculation method DOE-2 uses a room weighting factor approach while BLAST uses a heat balance approach. Both programs were widely used throughout the world before EnergyPlus (Crawley, et al. 2001).

EnergyPlus is the building energy simulation software for modelling building heating, cooling, lighting, ventilating, and other energy flows. It is based on the most popular features and capabilities of BLASTand DOE-2. It has many different simulation abilities. These are time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems (US Department of Energy 2009). On the other hand, EnergyPlus is a such a program that it could not work without a ’user friendly’ graphical interface. Furthermore, being open-source software is the other characteristic of EnergyPlus. Due to this limitation, EnergyPlus requires an interface like DesignBuilder. DesignBuilder is based on EnergyPlus software, implemented with a 3D interface and meteorological database. Friendly interface, meteorological database, and sophisticated model make DesignBuilder useful software to help EnergyPlus estimate energy requirement for internal and solar energy supply. The dynamic estimation of heating and cooling consumption during all seasons can be obtained by this software. The average value for indoor and surface temperature during all the year can be obtained by the help of DesignBuilder, as well.

DesignBuilder Software Ltd. (DBS) is an example of commercial software development and is started as a research company in 1999. This software was in use in 2005 for the first time. The foundation of DesignBuilder knowledge is lied into different categories: model importing CAD; template components; material database; natural ventilation model, etc. (Tronchin, et al. 2008).

EnergyPlus includes many simulation capabilities. These are; Heat balance load calculations, integrated loads, system and plant calculations in same time step, user-configurable HVAC system description, modular structure to make it easy for other developers to add new simulation modules, simple input and output data formats to facilitate graphical frontend development (Strand et al. 2001).

3.3. Energy Calculation Methods

ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines all methods and details about energy calculations. EnergyPlus calculations are based on ASHRAE definitions.

Approaches to Modeling

The Methods estimating energy use to model for building and HVAC system is discussed in ASHRAE. There are two approaches to modeling:

1. Forward(Classical) Approach
2. Data –Driven (Inverse) Approach

The objective is to predict the output variables of a specified model with known structure and known parameters. But, in Data-Driven (Inverse) Approach, input and output variables are known and measured, and the objective is to determine a mathematical description of the system and to estimate system parameters. The system (mean building) has already been built and actual performance data are available for model development and/or identification in Data-Driven Approach. However, forward approach is most often used because of ideal in the preliminary design.

EnergyPlus is based on forward simulation model. The first step of modeling is a physical description of the building system or component of interest. Building geometry, geographical location, physical characteristics (e.g., wall material and thickness), type of equipment and operating schedules, type of HVAC system, building operating schedules, plant equipment, etc., are the example of this description. All these details about ADM building are explained in this thesis. The peak and average energy use of such a building can then be predicted or simulated by the forward simulation model.

Methods for Energy Calculating

Calculating instantaneous space sensible load is a key step in any building energy simulation. The heat balance and weighting factor methods are used for these calculations. A third method, the thermal-network method, is not widely used. The instantaneous space sensible load is the rate of heat flow into the space air mass. This quantity, sometimes called the cooling load, differs from heat gain, which usually contains a radiative component that passes through the air and is absorbed by other bounding surfaces. Instantaneous space sensible load is entirely convective; even loads from internal equipment, lights, and occupants enter the air by convection from the surface of such objects or by convection from room surfaces that have absorbed the radiant component of energy emitted from these sources. The weighting-factor and heat balance methods use conduction transfer functions (or their equivalents) to calculate transmission heat gain or loss. The main difference is in the methods used to calculate the subsequent internal heat transfers to the room. Experience with both methods has indicated largely the same results, provided the weighting factors are determined for the specific building under analysis (ASHRAE 2005).

Heat balance method is more fundamental approaches than the weighting factor method and therefore it is chosen as the calculation method used in EnergyPlus software. The other major assumption in heat balance models is that room surfaces (walls, windows, ceilings, and floors) have (Crawley, et al. 2001).

- uniform surface temperatures;
- uniform long- and short-wave irradiation;
- diffuse radiating surfaces and
- one dimensional heat conduction.

As the assumptions mentioned above cause the heat balance model not to reflect physical reality, computational fluid dynamics (CFD) is the only current alternative.

> Heat balance approach applies a control volume at the outside face of every building surface, at the inside face of every building surface, and around the inside air of each thermal zone defined within the building. This can be seen graphically in Figures 3.4, 3.5, and 3.6 (Strand, et al. 2001).

In the outside and inside surface heat balance, the four and six thermal “forces” acting on the control volume at the outer surface of each wall as shown in Figure 3.4 and 3.5 must be balanced for energy to be conserved. Strand explains that mathematically speaking, we can formulate the following equation from this diagram:

$Q_{SWrad} + Q_{LWrad} + Q_{conv} + Q_{cond} = 0$

$Q_{solar} + Q_{SWlights} + Q_{LWradExch} + Q_{LWradIntGains} + Q_{conv} + Q_{cond} = 0$

Q_{SWrad} is the amount of solar radiation absorbed on the surface,

Q_{LWrad} is the amount of thermal radiation exchanged between the surface and its surroundings (including the ground, sky, air, other buildings, vegetation, etc.),

Q_{conv} is the amount of convection between the surface and the surrounding air,

Q_{cond} is the amount of energy conducted into the wall materials,

Q_{solar} is the amount of solar radiation absorbed on the inside face of the surface,

$Q_{SWlights}$ is the amount of short wavelength radiation from lights that is absorbed by the surface,

$Q_{LWradExch}$ is the amount of net long wavelength (thermal) radiation that is exchanged with other surface in the zone,

$Q_{LWradIntGains}$ is the amount of long wavelength (thermal) radiation from internal heat gains such as people, lights, and equipment that is absorbed by the surface,

Q_{conv} is the amount of convection between the surface and the air in the zone, and

Q_{cond} is the amount of energy conducted into the wall material

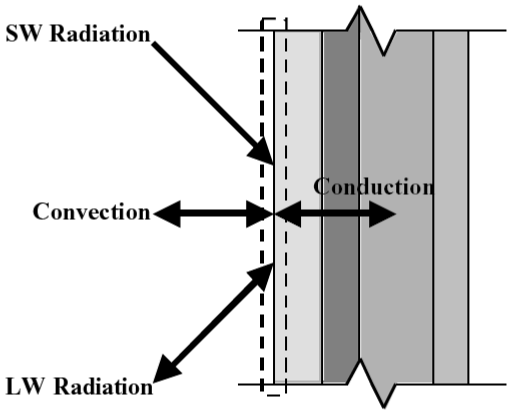


Figure 3.4 Outside Surface Heat Balance
(Source: Strand, et al. 2001).

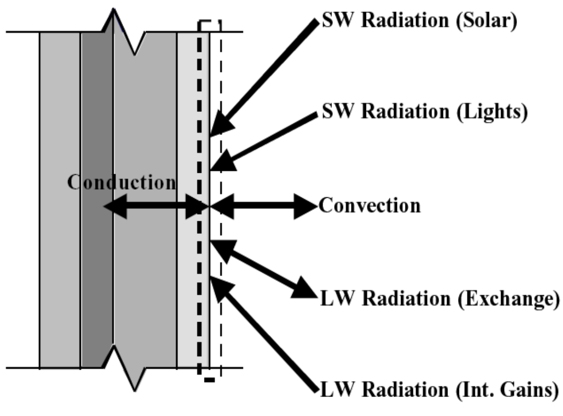


Figure 3.5. Inside Surface Heat Balance
(Source: Strand, et al. 2001).

The zone air heat balance has two possible formulations depending on whether or not the storage of energy in the air itself is taken into account. Strand states that as it can be seen in Figure 3.6, In the absence of accounting for energy storage in the zone air, a heat balance equation would be similar to the following:

$Q_{conv} + Q_{convIntGains} + Q_{infil} + Q_{sys} = 0$

Q_{conv} is the amount of convection between the all of the surfaces in the zone and the zone air,

$Q_{convIntGain}$ is the amount of heat convected from internal gains such as people, lights, and e quipment,

Q_{infil} is the amount of heat gained or lost due to infiltration, and

Q_{sys} is the amount of heat added to or subtracted from the space due to a space conditioning system

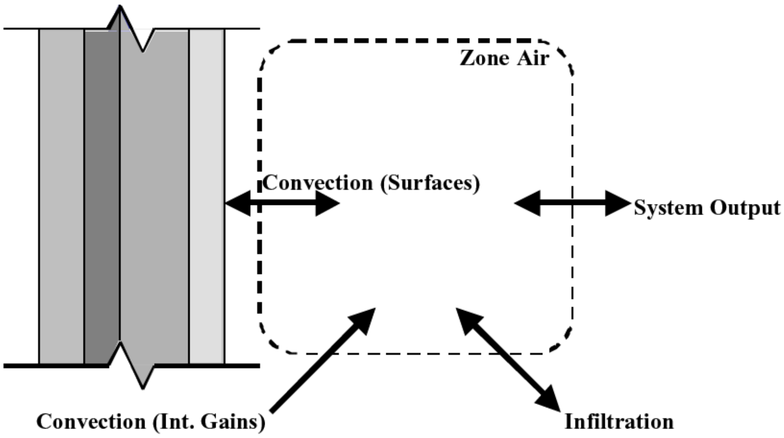


Figure 3.6. Zone Air Heat Balance
(Source : Strand, et al. 2001)

Strand indicates that

> For most cases, the quasi-steady equation shown above is adequate for solving the zone air heat balance.
> $C(dT/dt) = Q_{conv} + Q_{convIntGains} + Q_{infil} + Q_{sys}$
> where C is the product of the mass of the zone air and the specific heat of air

The control volumes at the inside and outside faces of each surface in particular zone and a control volume around the zone are the requirements of these equations to be set up (Strand, et al. 2001).

3.4. Modelling

Thermal simulation of a building requires the information with respect to the latter's dimensions, geometry, orientation and the thermal and optical properties of its materials. The basic physical, thermal and optical material property parameters are used to built Building element constructions in EnergyPlus are built from in building physics. Materials are specified by types, while constructions are defined by the composition of materials. Finally, surfaces are specified for the building with geometric coordinates as well as referenced constructions.
There are three material types that may be used to describe layers within opaque construction elements in EnergyPlus:

- Material: regular,
- Material: regular-R,
- Material: air.

The first type requires knowledge of many of the thermal, optical and physical properties of the material, but it allows EnergyPlus to take into account the thermal mass of the material and thus allows the evaluation of transient conduction effects. The second is similar in nature but only requires the thermal resistance (R-value) rather than the thickness, thermal conductivity, density, and specific heat. The last type is only used for an air gap between other layers in a construction. This type assumes that air is sufficiently lightweight and not moving, so as to require only an R-value (Papadopoulos, et al. 2008).

In Figure 3.7 shows the first model drawn as nearly real of all building construction. There are lots of details about building construction as shown in figure 4.7. But, in this instance, it was not possible to take results. However, when drawing was simplified such as drawing one skylight instead of 22 small skylights, computer can give results almost in one day. In figure 3.8 shows simplified drawing.

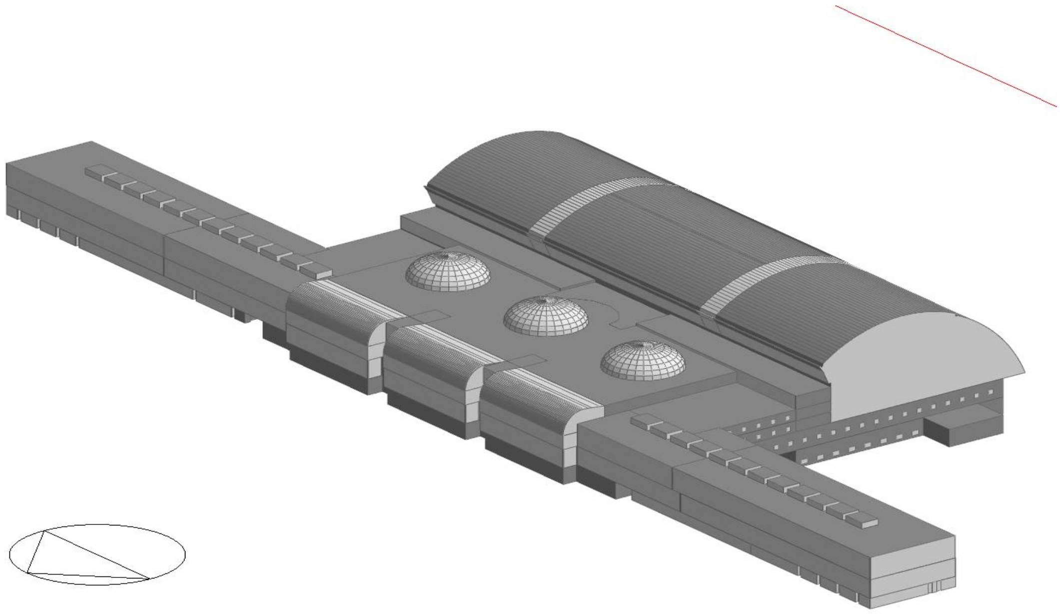


Figure 3.7. DesignBuilder 3-D View of First Model.

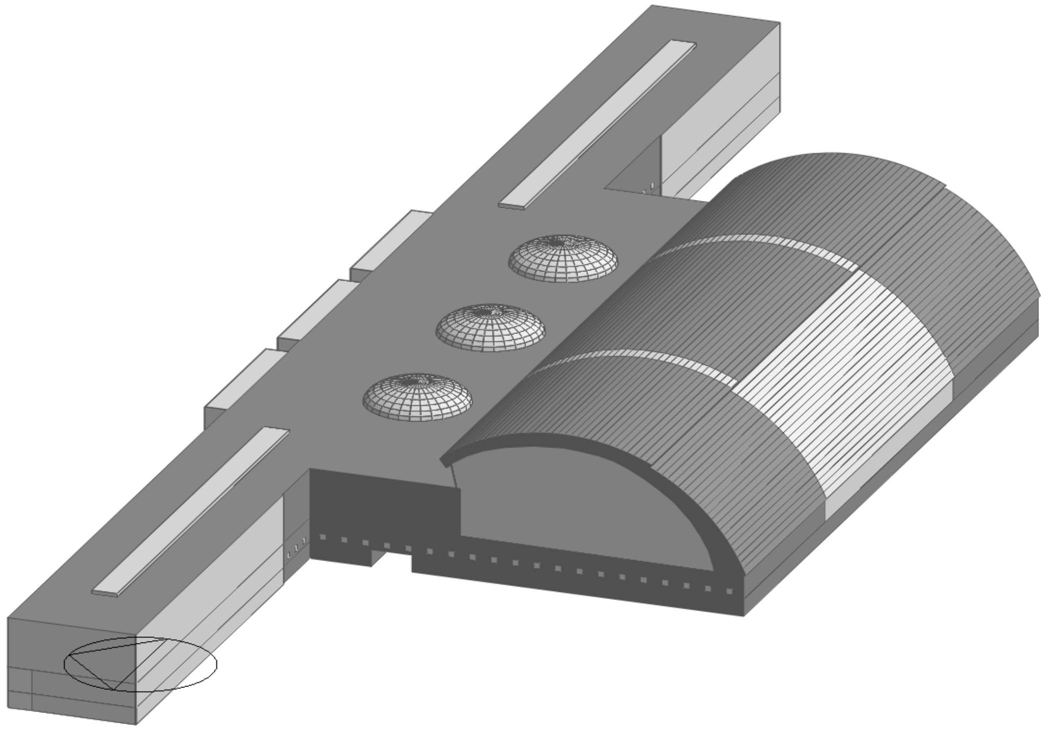


Figure 3.8. DesignBuilder 3-D View of Simplified Model.

Assumptions

The assumptions are made for the simulation referring either measurements or ASHRAE standards.

1. Building is put together by assembling blocks. Block creation and edit operations take place at the building level. ADM Building is divided into 4 blocks to simplify modeling of the building. Figure 3.9 shows blocks and modeling of the building by DesignBuilder.

2. Blocks are not subdivided into more than one zone by drawing partitions. There is not any partitioning takes place at the block level. The geometry information was collected from the scanned architecture drawings in AutoCAD.

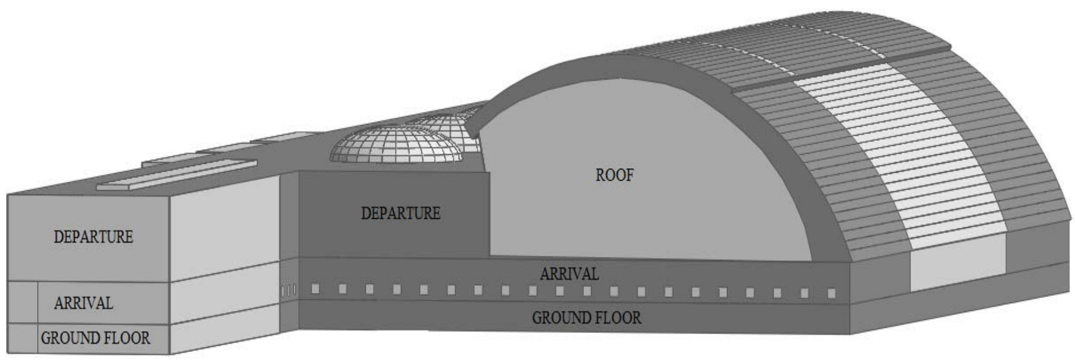


Figure 3.9. Blocks of Storey of ADM Building Modeled in DesignBuilder.

3. Data templates are the source of default data in DesignBuilder. They are used for loading data to the model en masse. It is loaded the Airport template at the building levels as shown in Table 3.2.

Table 3.2. Data Templates for Each Block in DesignBuilder.

BLOCKS' NAME	AREA	TEMPLATE AREA IN DESIGN BUILDER
Ground Floor	Ground Floor	Airport_MeetRm - An area specifically used for people to have meeting.
Arrival	First Floor	Airport_CirculationPub - All areas where passengers are walking/sitting.
Departure	Second Floor	Airport_Check - Area within an airport where travellers check in for their flight.
Roof	Under Vault	Airport_CirculationPub - All areas where passengers are walking/sitting.

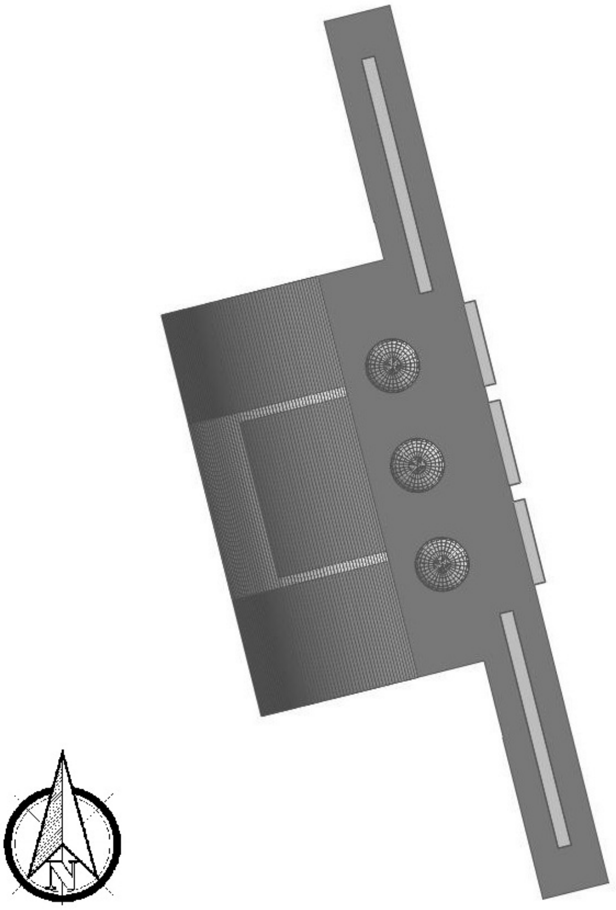


Figure 3.10. A View Plan of ADM Building Modeled in DesignBuilder.

4. Internal gain caused by office equipment is taken as 5 -15 W/m2 from the measurements which is also valid for ASHRAE 55 (2004). Heated and cooled zones in the building are treated as airport areas and according to ASHRAE 55 (2004), metabolic activity factor is 0.90, clo value is 1 for heating and 0.5 for cooling season, occupation density is calculated as 0.07 – 0.25 person/m2 based on data collected from airport template data in ASHRAE. Heating (18 - 22°C) and cooling (23 - 25°C) set point temperatures are the average temperatures of heated and cooled zones at the ADM building floors. Also, there are no any gains from computers, catering, and process. APPENDIX A shows all these details.

5. Lighting load is assumed 12.5 W/m^2 when activated with target illuminance of 200 - 500 lux for the ADM building floors as shown in APPENDIX A.

6. HVAC system parameters are not determined by EnergyPlus. EnergyPlus HVAC system library has no central heating and cooling system. That’s why it is created the new HVAC system which is named “AHU and FANCOIL”. APPENDIX B shows this HVAC system’s details.

7. Glazings’ specifications are provided with building contractor. APPENDIX C shows these glazings’ details. The outside glazing all use a double pane of 6 - 10 mm thick clear or green glass with 12 – 16 mm air and U-values of 1.64, 1.83, and 2.7 W/m2K. Window-to-wall area ratio of the building is approximately 70%.

8. Construction materials’ specifications are provided with the as-built drawings which are prepared by building contractor and the pictures were taken when the building constructed (Figure 3.11). APPENDIX D shows these construction materials’ details.

The external walls of the base case model are each composed of four layers: 3 mm light weight metallic clading on the outdoor side, 50 mm stone wool, 200 mm concrete block and 25 mm thick gypsum plaster board with paint on the indoor side as shown in figure 4.11. The overall U-value of the external wall is 0.38 Wm^2/K (according to Design Builder calculation). The other surface elements specifications were defined in the same way. In EnergyPlus, the heat transfer by radiation, convection and conduction is calculated at each time step.

Figure 3.11. External Wall of ADM Building.

9. Meteorological data used in the simulations are taken from the measured data. Normally, EnergyPlus uses Izmir downtown data. Dry bulb temperature for ADM building was recorded in 2007 and used in EnergyPlus for monthly calculations. That's why measured data and EnergyPlus meteorogical data are different as shown in Figure 3.12.

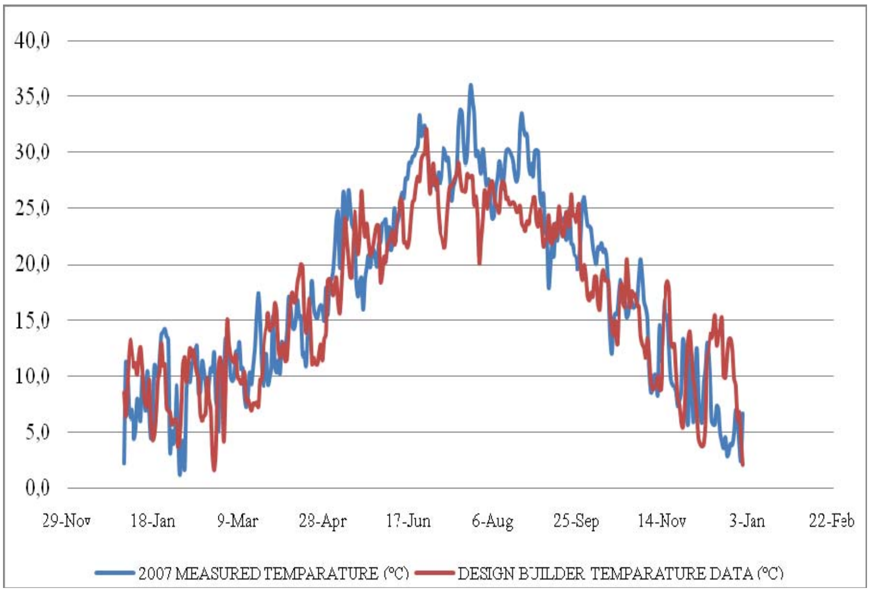


Figure 3.12. Comparison of Outside Temperatures.

3.5. EnergyPlus Data Options

EnergyPlus is an hourly/daily/monthly/annual energy simulation engine which employs a simultaneous load/system/plant simulation methodology (Pan, et al. 2009).

Comfort data is including inside air, the radiant and comfort temperatures, relative humidity, and Fanger PMV (Fanger Predicted Mean Vote). Internal operative temperature mean of the internal air and radiant temperature.

Simulations are performed with EnergyPlus to obtain Fanger PMV value to have an idea about the total comfort every floors of ADM building for all year. PMV value is a statistical index regarding comfort level of the selected space and ASHRAE 55 (2004) classify comfort as given in Table 3.3.

Table 3.3. Comfort Level According to PMV Values
(Source: ASHRAE 55 2004).

PMV	Comfort	PMV
-3	< Cold <	-2
-2	< Cool <	-1
-1	< Slightly cold <	-1
0	Neutral	0
0	< Slightly warm <	1
1	< Warm <	2
2	< Hot <	3

According to Fanger PMV index, -1 <PMV<+1 comfort range covers 53.2% of the population (Fanger 1970). In this study, -1 <PMV<+1 range is used to compare comfort conditions of different scenarios. Fanger PMV indexes for whole building is calculated by years with the changes in occupation, heating set point temperature and operation profile.

DesignBuilder gives also internal gains, heat gains and fuel consumption. Internal gains include equipment, lighting, occupancy, solar and HVAC heating/cooling delivery. Heat gains and loss (negative values) to the space from the surface element (walls, floors, ceilings etc.) and ventilation are named Fabric and Ventilation in

DesignBuilder. Fuel breakdown means fuel consumption broken down by system category. Fuel consumption broken down also can be seen as fuel.

3.6. EnergyPlus Status

EnergyPlus, a state of-the-art building energy analysis program was first released in 2001. Since its first distribution, several versions were released with new features and increased accuracy of simulation results. This study is performed with version 4.0. The first working version of EnergyPlus, an alpha version, was completed in December 1998 for internal testing by the team. This was followed by various beta versions of EnergyPlus to outside users and developers made available throughout 1999 (Strand, et al. 2001).

CHAPTER 4

RESULTS AND DISCUSSION

The energy consumption of the ADM building is modeled and simulated by DesignBuilder and EnergyPlus software. Performance improvement measures are proposed and the results are discussed. In this section presents simulation of ADM building. Furthermore, the effect of different HVAC system and different orientation of ADM building are examined on monthly energy requirements. Additionally, the output results of the program are compared with the values obtained from the measurements done by BMS and the total energy consumption of the building.

4.1. Simulation of Original Building Orientation

The results of simulations with EnergyPlus described above are reported in the following figures. These figures show monthly and hourly simulation results.

Simulation of Monthly Results

Comfort data results are reported in Figures 4.1 and 4.2. Operative temperatures of each floor are reported in Figure 4.1. The maximum operative temperatures have in the first floor (Arrival) for all months (Figure 4.1). Also, in Figure 4.1, roof used as a check-in area has the best comfort temperatures.

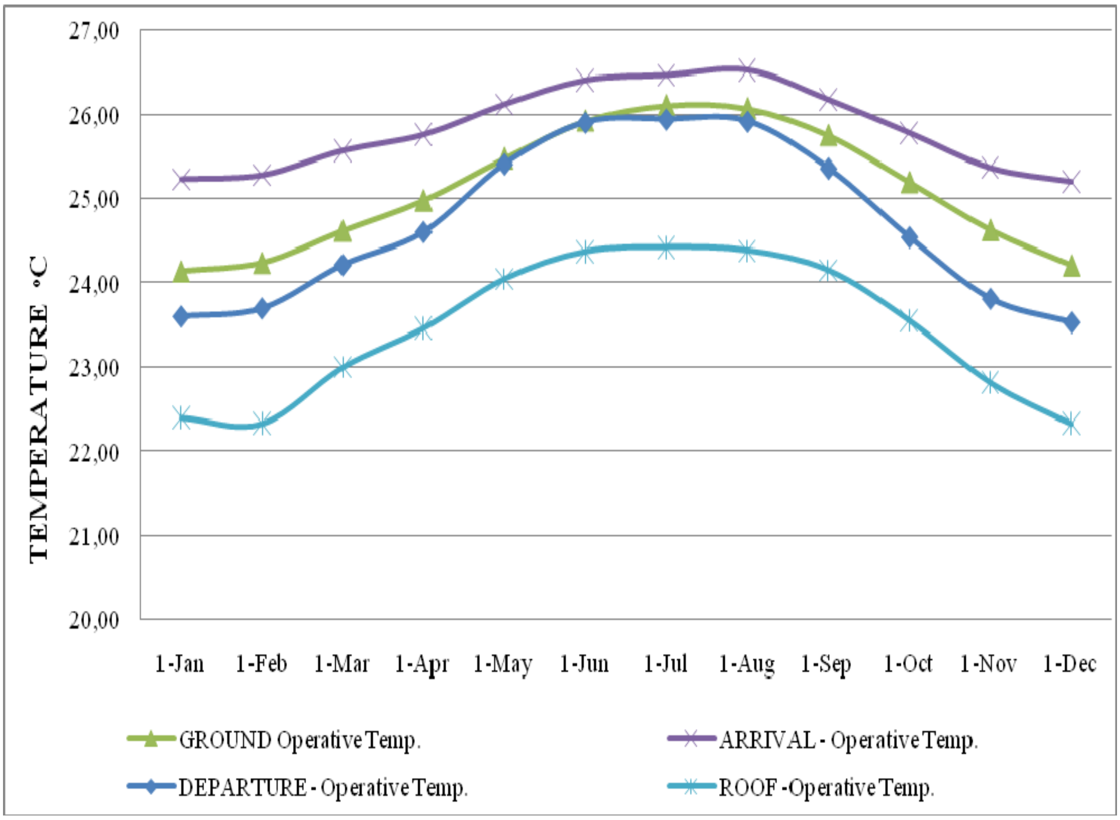


Figure 4.1. Internal Operative Temperatures for Each Floor (Zone).

Fanger PMV values of each floor are reported in Figure 4.2. Apart from Arrival, this value changes between -0.5 and 0.5 in all floors as seen in this figure. Moreover, this figure shows that Fanger PMV value can reach 1.2 for Arrival, especially in autumn and spring months.

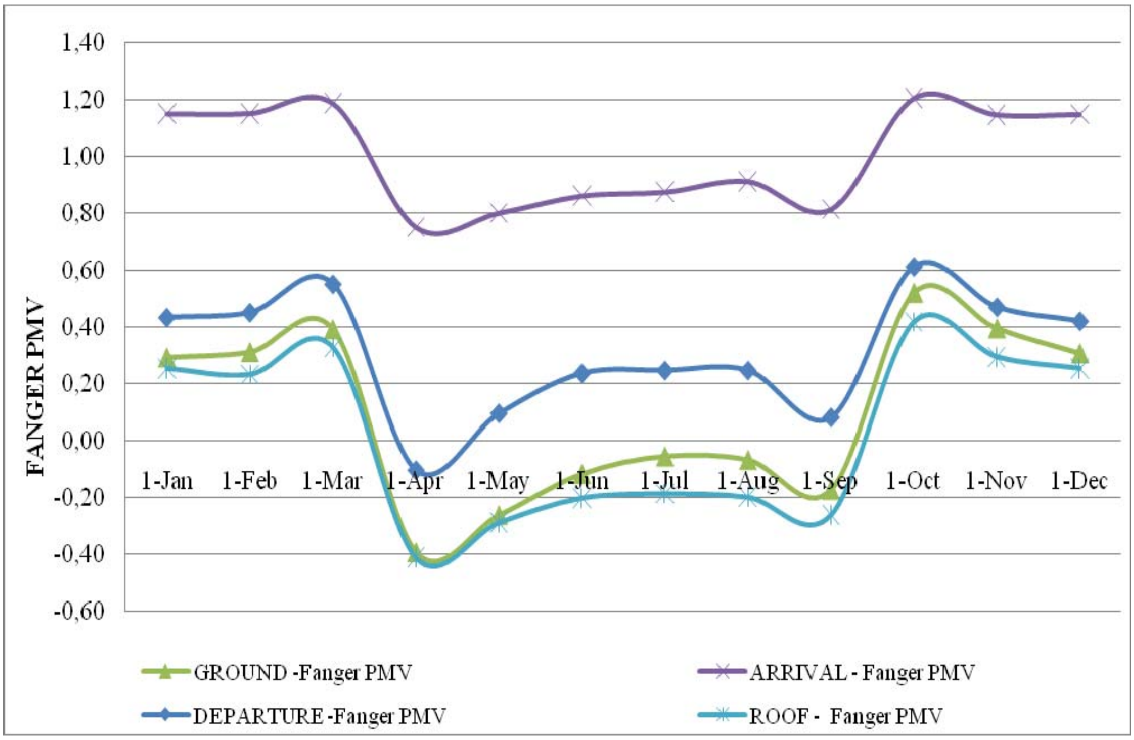


Figure 4.2. Fanger PMV for Each Floor (Zone).

It is also seen from the Figure 4.3 that cooling is needed all along the year in each floor. The maximum internal gain comes from Departure and Arrival as seen in the same figure. In addition, it reaches its peak value in July and August. The sensible cooling distribution in ADM building is 48% for Departure, 30% for Arrival, 13% for Ground Floor and 9% for Roof as shown in Figure 4.4.

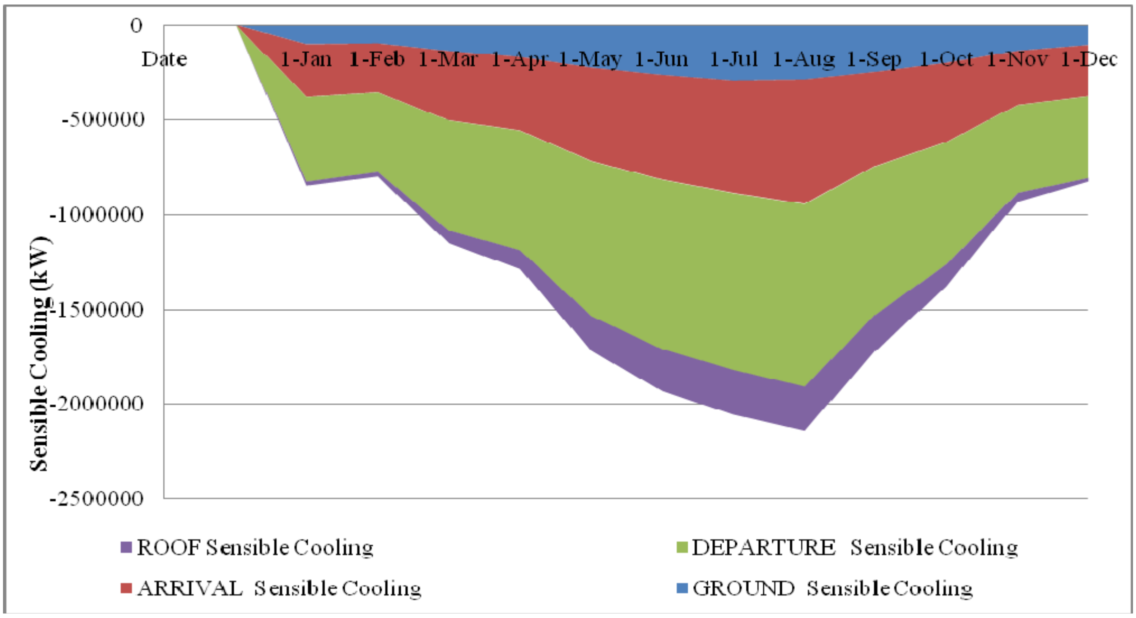


Figure 4.3. Cooling Energy Delivered to the Space from the HVAC System.

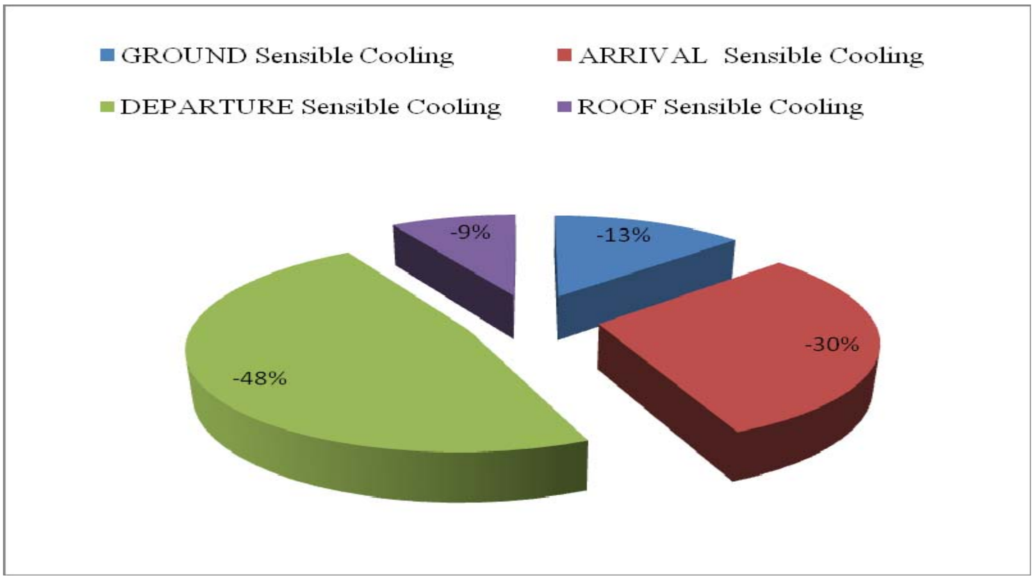


Figure 4.4. Cooling Energy Delivered Portion to the Space from the HVAC System.

Solar factor shortly is the percentage of heat that passes through the windows. This factor is the most important parameter used to evaluate the solar gains through the windows. Direct transmission through the glazing and absorption and re-emission of the glazing are almost equal the total amount of energy entering the building (Maccari and Zinzi 2001). Similarly, solar gains are usually very high in ADM building because of its large external glazing. When heat gains are compared for all the surface elements, as seen in Figure 4.5 the maximum heat gain in the summer or heat loss in the winter comes from the glazing.

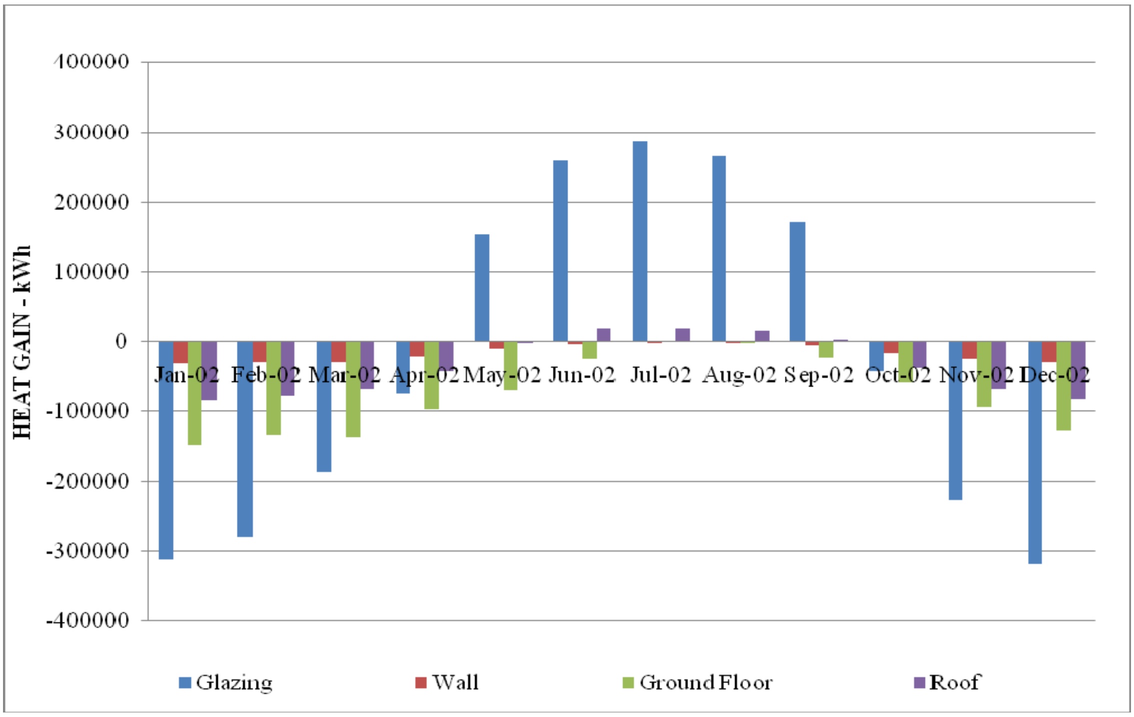


Figure 4.5. Heat Gain from Surface Elements (Glazing, Wall, Ground Floor, and Roof).

The values of July are given as an example; 94% of the total heat gain comes from the glazing (Figure 4.6). Moreover, Figure 4.7 indicates that 50% of heat gain originated from Departure's glazing and 24% of heat gain from Roof's glazing.

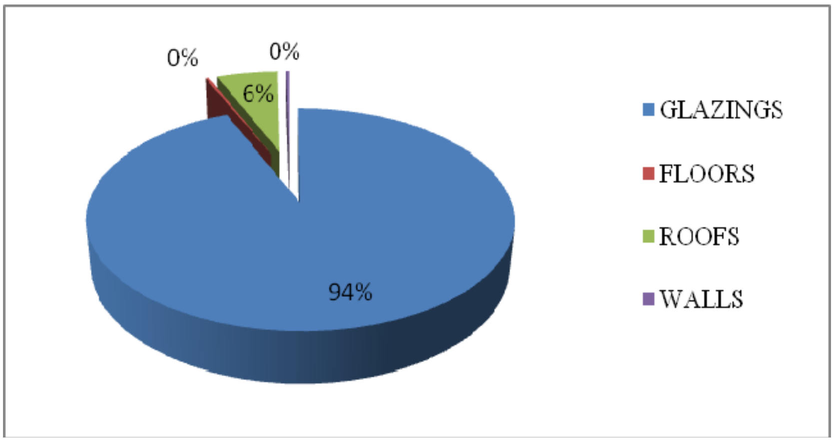


Figure 4.6.Heat Gain Portion from Surface Elements in July.

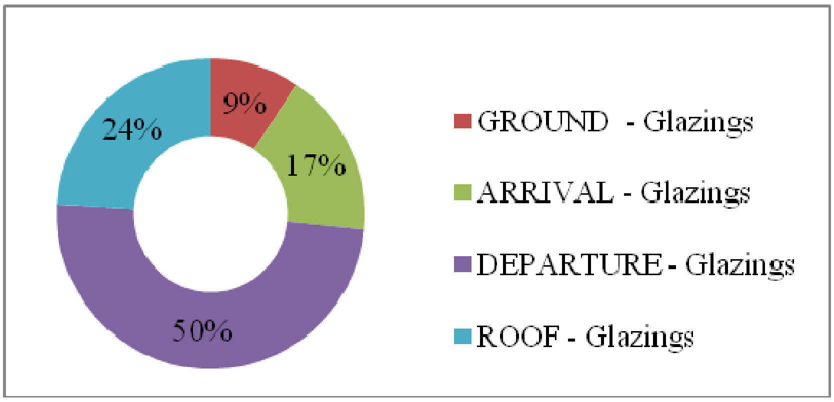


Figure 4.7.Heat Gain Portion from Glazing in July.

Based on simulation results, the heating energy consumption in ADM building is nearly zero compared to cooling energy consumption (Figure 4.8). In other words, analysis showed that ADM building requires year-round cooling and very little heating. In brief, the energy consumption of HVAC system is formed from cooling load.

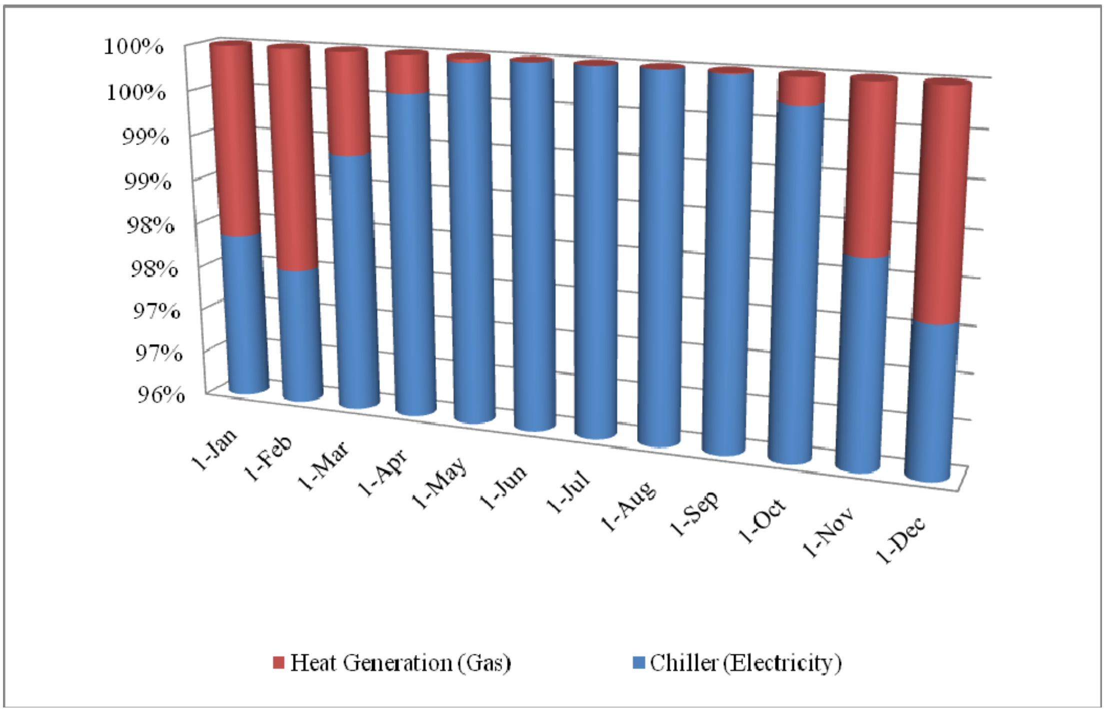


Figure 4.8. Fuel Consumption Broken Down by Heat Generation and Chiller.

Hourly Results of 11 January and 18 August

The results of simulations on 11 January and 18 August are reported in the following figures. The comfort temperatures on 11 January as a winter day are not provided during day time. Figure 4.9 shows Fanger PMV values of 11 January and 18 August. Fanger PMV values are not more than 0.5 on 18 August; however, on 11 January these values change between 0.4 and 0.7. This result is provided by the fact that the number of discomfortable hours decreased from 3.4 on 11 January to 2 on 18 August. Although summer averages may indicate better PMV index due to the night temperature falls, these can not compansate the unpleasant hours of the day time.

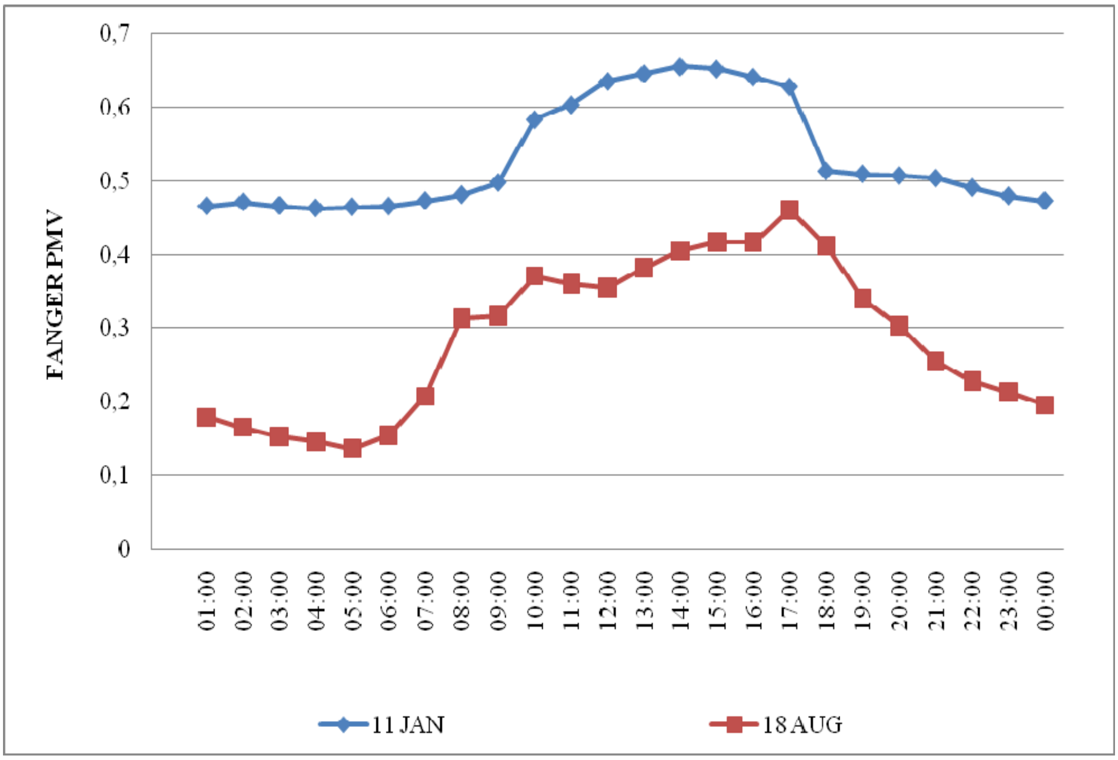


Figure 4.9. Fanger PMV from DesignBuilder for a Summer and Winter Day.

Sensible cooling is is thermodynamically defined as the cooling with temperature drop (contrary to latent cooling where no temperature drop occurs), however; DesignBuilder user manual defines it as “*cooling energy delivered to the space from the HVAC system, including any “free cooling” due to introduction of relatively warm outside air and any heating effects of fans*” (DesignBuilder 1.2, User Manual). Sensible cooling is needed both on a summer and a winter day (Figure 4.10). There is also a minute amount of sensible heating is needed in some winter days. Figure 4.10 shows a comparison between August 18th and January 11th day time cooling energy requirements. It is seen that the day time cooling energy requirement for a summer night is twice as large as a winter night, whereas, day time cooling requirement is quadruples between winter and summer, clearly the indication of solar gains.

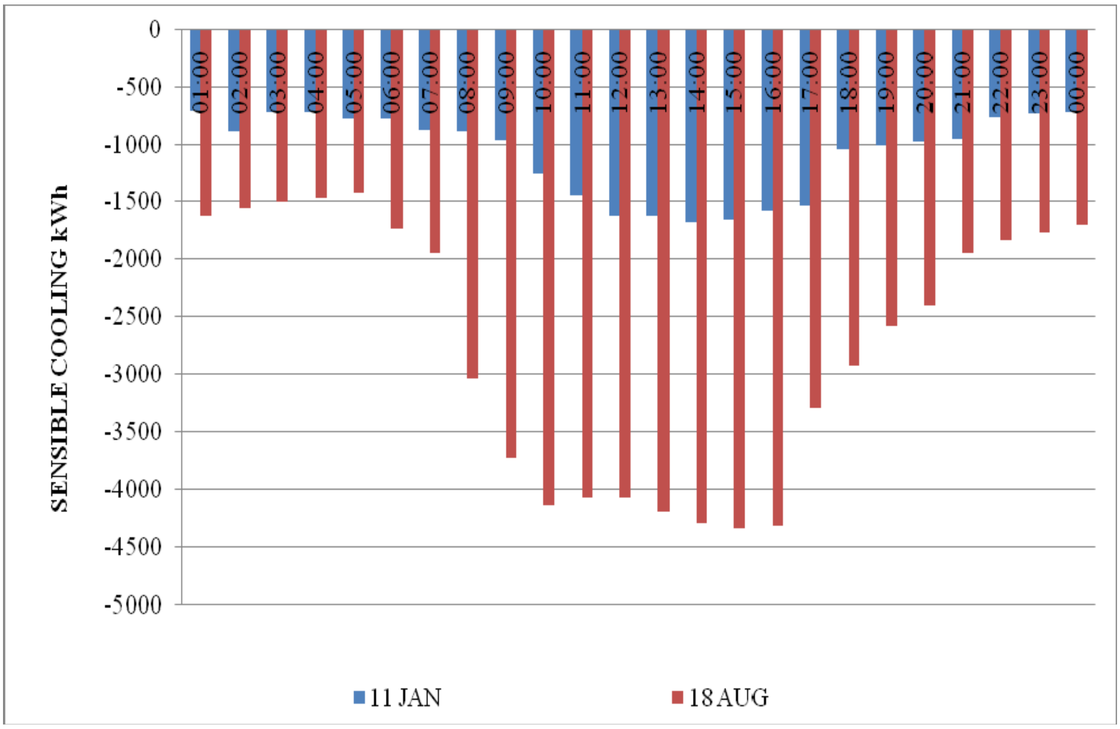


Figure 4.10 For Cooling Energy Delivered to the Space From the HVAC System on 11 January and 18 August.

Heat gain and loss from surface elements are largely from glazing like mentioned monthly results. Figure 4.11 indicated heat gain and loss from glazing on 11 January and 18 August. There is not any heat gain on 11 January as expected. Besides, there is a bit heat loss at noon hours on 11 January. Whereas, there is lots of heat gain during day time and some heat loss at night hours on 18 August as seen in Figure 4.11.

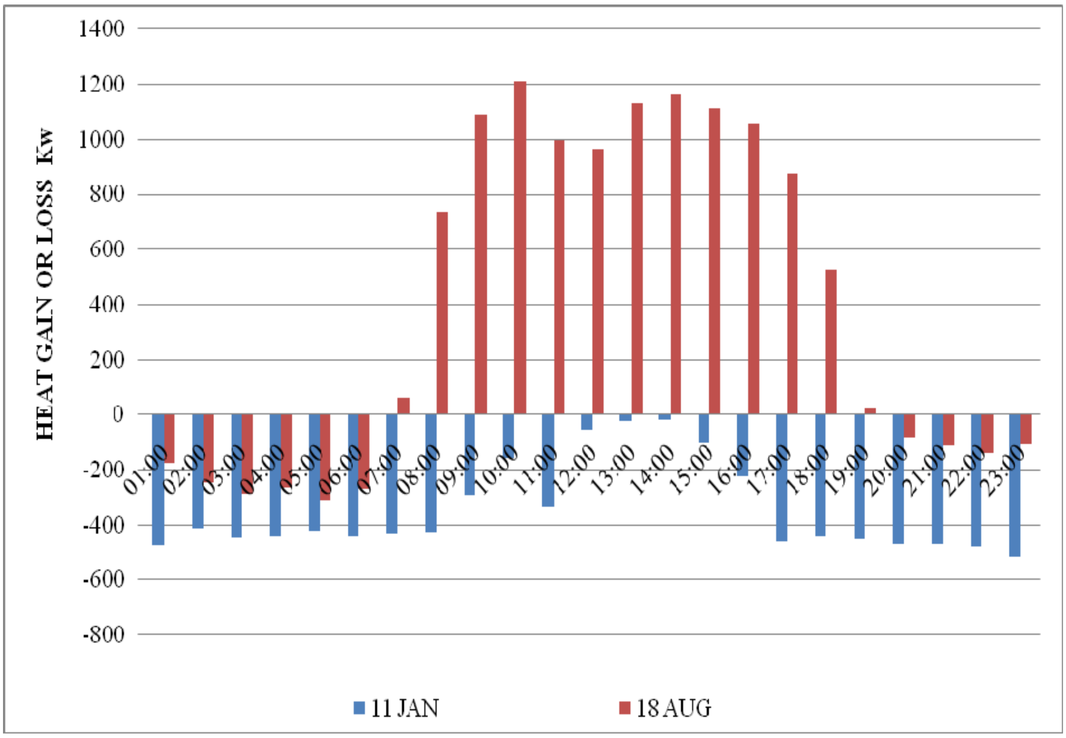


Figure 4.11 Heat Gain and Loss From Glazing on 11 January and 18 August.

Figure 4.12 shows chiller electricity consumption of a summer and winter day. It is seen that there is 2.4 times more electricity consumption on 18 August when compared to 11 January.

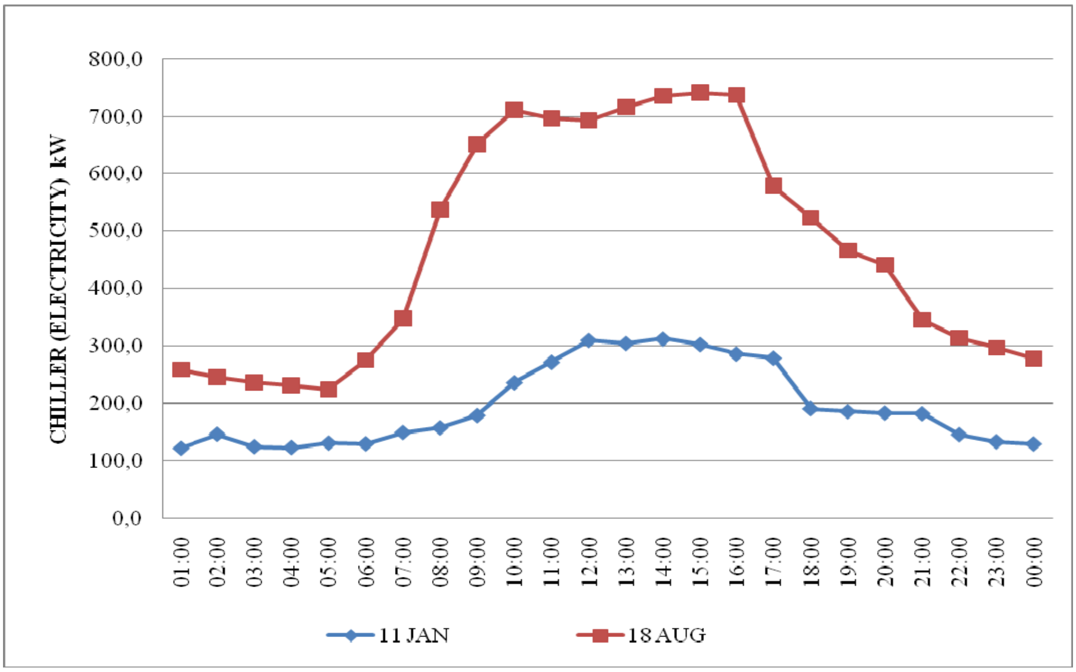


Figure 4.12. Chiller Electricity Consumption on 11 January and 18 August.

4.2. Simulation of HVAC – Direct Expansion System

Central heating and cooling with all-air systems are preferred in ADM building as mentioned in Chapter 2. DesignBuilder program was used for different HVAC system as a parametric study. Direct Expansion system was selected from software's library which indicates that position of the evaporator with respect to the airside loop. Comfort is provided with the conditioned air using the heated or cooled water. But, the evaporator is in contact with the air directly.

Direct expansion system can provide the same comfort level with more electricity consumption as expected. Cooling electricity consumption increases 2.8 times in each month as shown in Figure 4.13. All in all, the decrease in Fanger PMV indicates that the building comfort can be provided with direct expansion system. Figure 4.14 shows this situation.

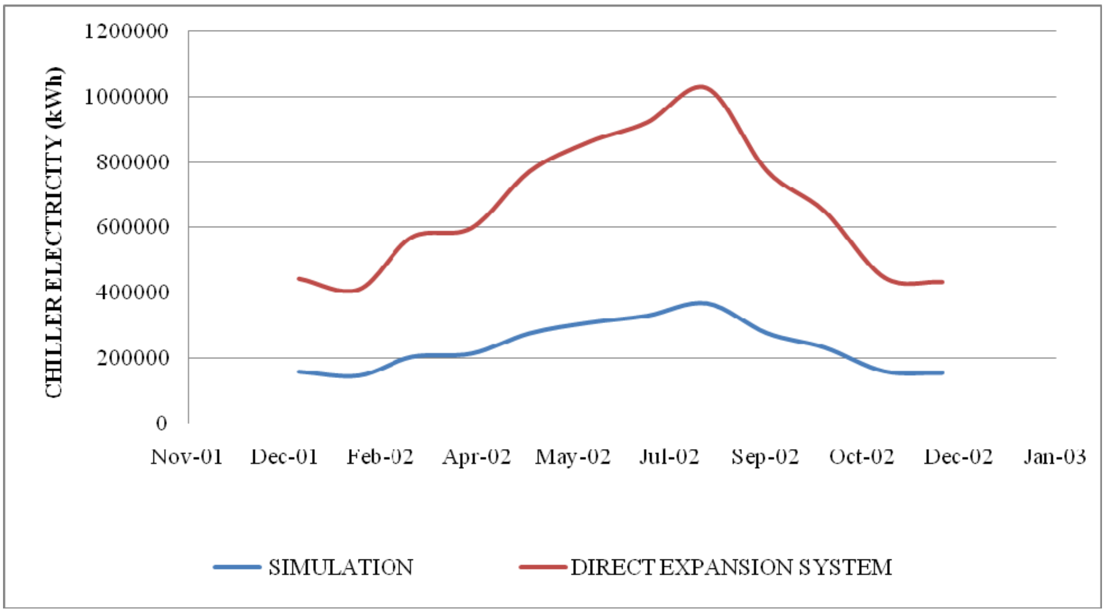


Figure 4.13. Fuel Consumption Broken-down by Chiller.

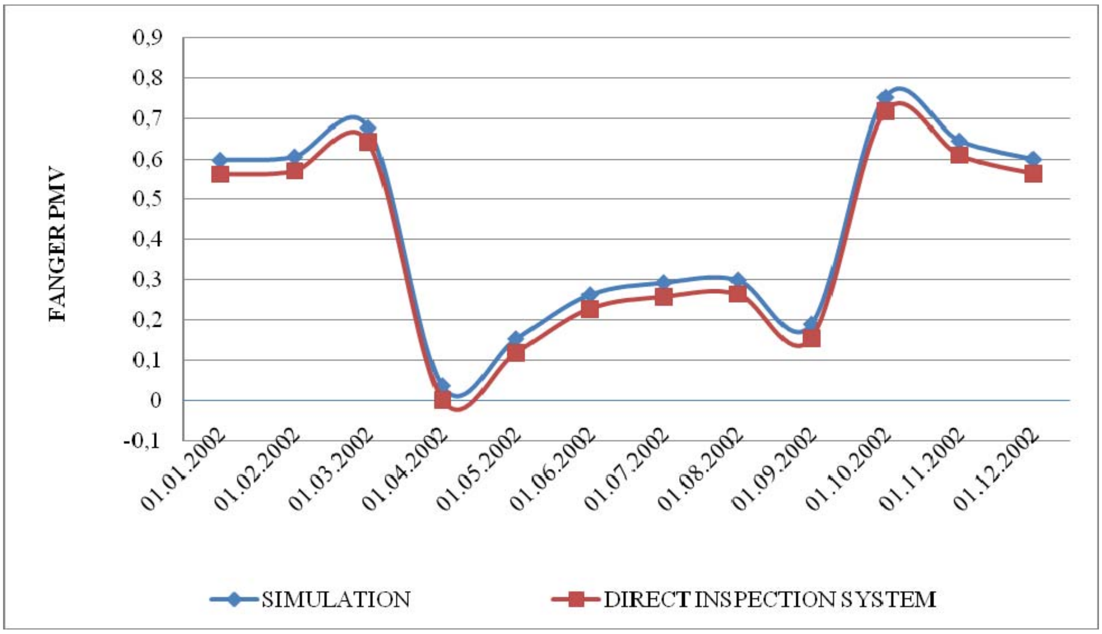


Figure 4.14. Fanger PMV.

4.3. Simulation of Different Orientation

The building orientation was changed and calculated by DesignBuilder software. The new orientation of the building was arranged as 180 degree rotated version of the original one. Figures 4.15 and 4.16 show these orientations. When comparisons between simulation and east orientation were made, it is seen that the internal gains (equipment, lighting, occupancy, solar, and HVAC) have increased for all months (Figure 4.17).

Heat gain and loss from building surface elements are affected by changing of building orientation. According to simulation and east orientation results, there is a decrease between 2% and 11% in winter, autumn and spring months and an increasing between 3% and 14% in summer months. These heat gain and loss are largely from glazing as in the other simulation results. This difference can be seen in Figure 4.18

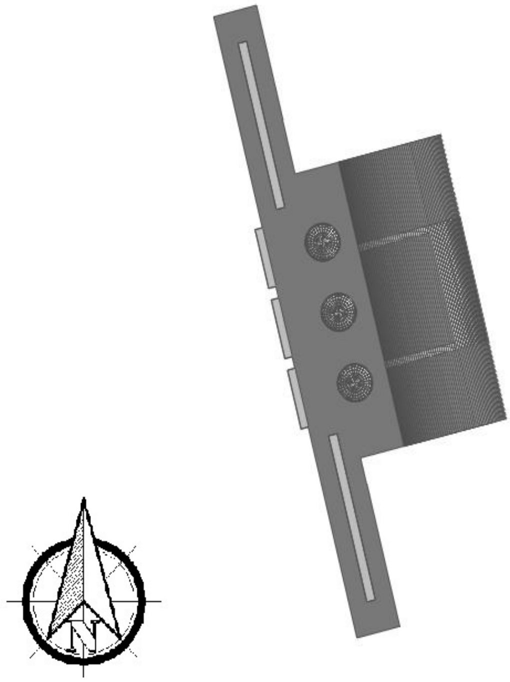


Figure 4.15. Simulation Model in DesignBuilder.

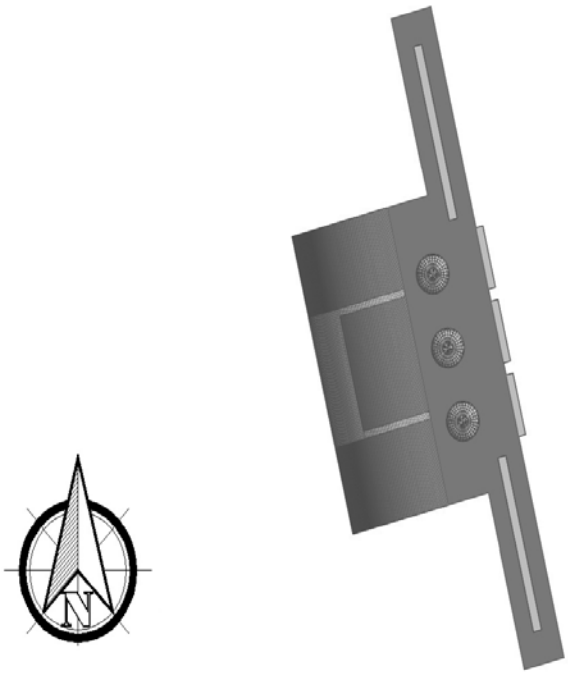


Figure 4.16. East Model in DesignBuilder.

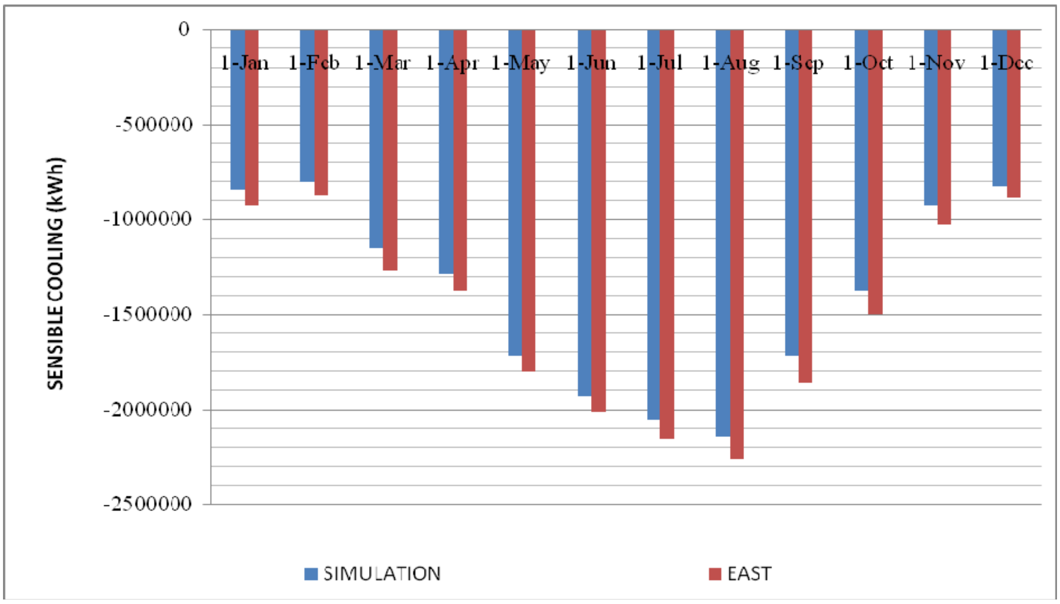


Figure 4.17. Cooling Delivery of Equipment, Lighting, Occupancy, Solar, and HVAC System.

4.4. Evaluation of Measurements and Simulation Results

Building and energy related data was collected from ADM building in 2007 and 2008 by means of the building scada system. During this study, the available data was analyzed in order evaluate the effectiveness of different HVAC system and orientation of ADM building and energy conservation measures.

The measured and the calculated energies are compared for further understanding of the building energy efficiency. But ADM building simulation results and measured consumption are not matched. This is due to the factors such as, the lack of building geometry detail in the simulation, lack of time depended model and materials, the uncertainty in the local climate data, the DHW consumption, the lighting use, and so on. Nevertheless, we could still use our simulation data to make educated comments on the heat transfer characteristics of the ADM building.

Although ADM building's geometry and construction materials could be determined accurately, other variables such as HVAC system details and occupancy rate could not be determined accurately.

Internal energy gain obtained from computers, electrical domestic appliance, electrical and gas cooking use.etc are all standardized to the unit area [W/m^2] parameter or assumed not applicable. DHW consumption depends on several factors: use destination, number of user, number of end user (washer.etc) all of which can only be determined with large margins. The electrical lighting consumption (i.e. energy gain) is standardized and based on W/m^2 parameter (according to ASHRAE). Moreover, all these depend on users' habit. Also, ADM airport was constructed for 5.000.000 people/year, however it highly underused.

On account of all these, the difference between measured and simulation consumption values are greater more than 70% as shown in Figure 4.18. This gap is not related with the calculation model but rather it depends on the input data. Moreover, the difference should be based on the calculation algorithm of software. On the other hand this enormous difference in some way indicates the potential of energy conservation available.

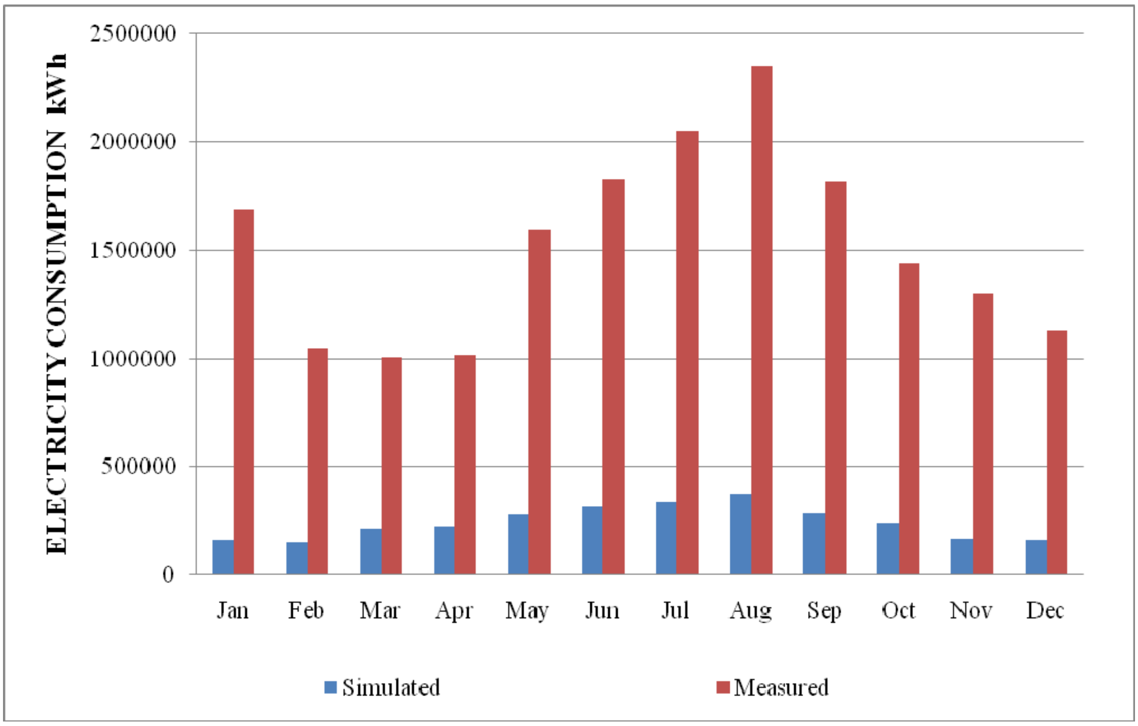


Figure 4.18. Simulation and Measured Electricity Consumption.

Figure 4.19 and table 4.1 show the results of the evaluation. Table 4.1 includes three data series by month. The first is the series of measured data collected from electricity bills of ADM building. The second and third series include data generated from the simulation model.

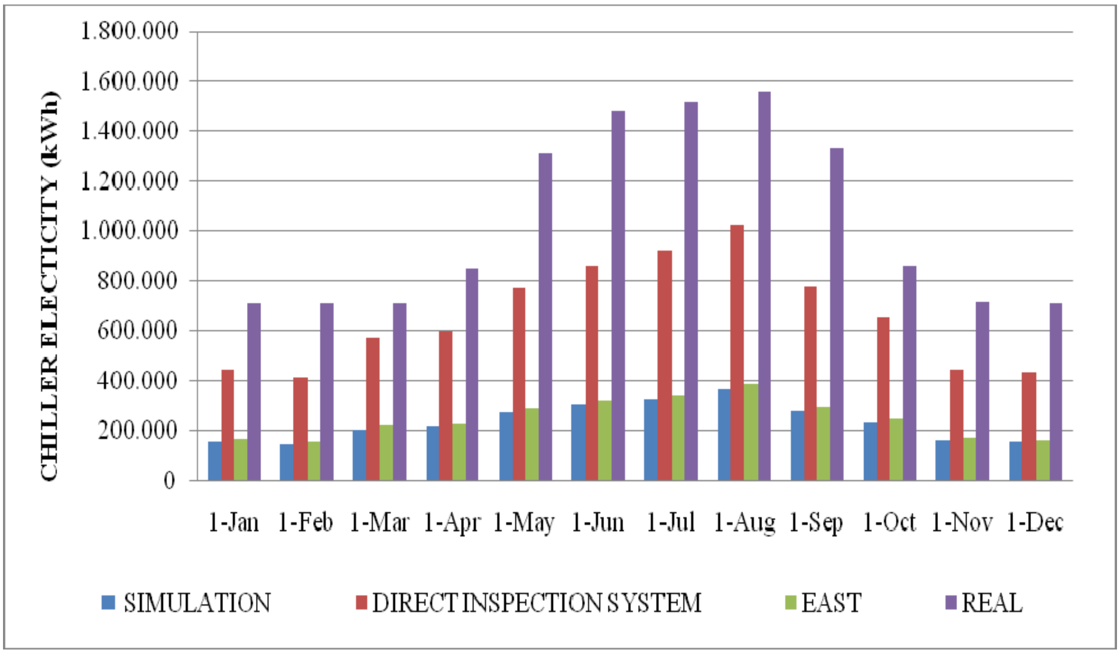


Figure 4.19 Fuel Breakdowns for Different Scenarios

Table 4.1. Electricity Consumption by Different Scenarios.

Measured and simulated electricity consumptiion - kWh x 1000												
Month	January	February	March	April	May	June	July	August	September	October	November	December
Actual	1690	1048	1007	1017	1597	1827	2050	2350	1816	1437	1297	1128
Simulation	165	154	211	221	283	316	337	374	284	239	167	162
Direct Expansion	489	461	616	653	835	937	1003	1117	853	715	504	494

When it is checked the daily results for four months (September, October, November, and December), it is seen that measured and simulation values on September and October conflict each other. However, the values on November and December are seen almost parallel as shown in Figure 4.20.

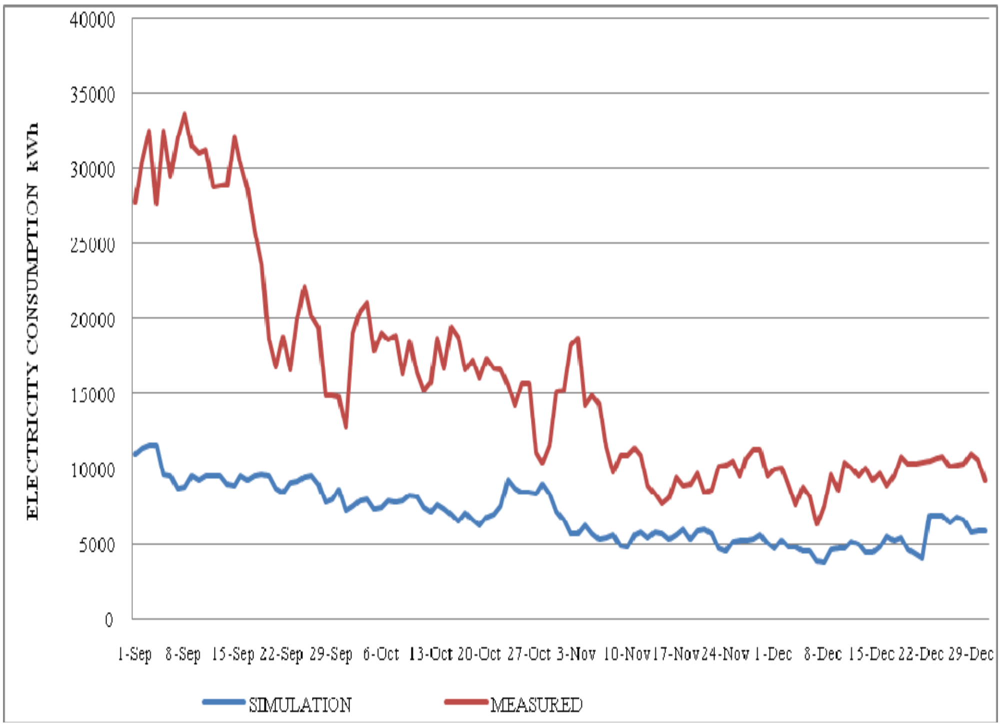


Figure 4.20. Electricity Consumption of Daily Results for Simulation and Measured.

CHAPTER 5

CONCLUSION

Nowadays decreasing the energy consumption of buildings is of importance for all developed and developing countries due to rapidly growing world population and its energy needs. In EU, energy performance of buildings has been seriously regulated by laws since 2002. In 2007 “Energy Efficiency Law” and “Energy Performance of Building Regulation” in 2008 provide accelaration for studies on a methodology for energy performance evaluation of the buildings in Turkey.

Building energy performance calculation software provide the means to easily calculate energy demands that is declared in related laws and regulations. In this thesis study, a commercial software EnergyPlus was used in order to simulate ADM building for evaluation of energy performance of this building.

EnergyPlus is simulation software for modeling building heating, cooling, lighting, ventilating, and other energy flows. But, it requires interface software such as DesignBuilder by to obtain new simulation capabilities such as time steps, modular system, thermal comfort, etc. In order to understand the affects of different conditions on ADM building energy consumption, on-site measurements and computer simulations by EnergyPlus code have been used.

It has been observed that the more basic the building, it is more likely to get meaningful results with EnergyPlus and DesignBuilder codes. As mentioned in description of ADM building, construction of the building consist of largely glazing area. This building feature and high solar loads of Izmir cause the need of very high cooling capacity and therefore very high electric energy consumption. Because of these reason, ADM building always requires cooling even in the winter times. The results collected from this study can lead to future works in the subject of commercial building constructions with large glazing area. Additionally, this study can help designers compare various design option and lead them to energy efficient designs in manner of cost-effectiveness.

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APPENDIX A

DATA TEMPLATES FOR ACTIVITIES IN DESIGNBUILDER

Table A.1. Data Templates for Activities in DesignBuilder

ACTIVITY	GROUND FLOOR	ARRIVAL	DEPARTURE	ROOF
ACTIVITY TEMPLATE	AIRPORT_ MEETRM	AIRPORT_ CIRCULATION	AIRPORT_ CHECK	AIRPORT_ CHECK
ZONE MULTIPLIER	1	1	1	1
DENSITY [PEOPLE/m²]	0,2	0,2	0,25	0,25
METABOLIC ACTIVITY	LIGHT OFFICE WORK	LIGHT OFFICE WORK	STANDING/ WALKING	STANDING/ WALKING
FACTOR MEN=1 / WOMEN=0,85 /CHILDREN=0,75	0,90	0,90	0,9	0,90
WINTER CLOTHING [clo]	1	1	1	1
SUMMER CLOTHING [clo]	0,5	0,5	0,5	0,5
DWH CONSUMPTION RATE [l/m²-day]	0,06	0,06	0,75	0,75
ENVIRONMENTAL CONTROL				
HEATING SET POINT TEMPERATURE ˚C	22	18	18	18
HEATING SET BACK TEMPERATURE ˚C	12	12	12	12
COOLING SET POINT TEMPERATURE ˚C	24	25	23	23
COOLING SET BACK TEMPERATURE ˚C	28	28	28	28
MECHANICAL VENT. COOLING ˚C	10	10	20	20
MECHANICAL MAX IN-OUT DELTA T ˚C	-50	-50	-50	-50
MIN FRESH AIR [l/s-PERSON]	10	10	10	10
MECH. VENT. PER AREA [l/s-m²]	0	0	0	0
LIGHTING ILLUMINANCE [lux]	300	200	500	500
EQUIPMENT				
COMPUTERS	NA	NA	NA	NA
OFFICE EQUIPMENT (W/m^2)	5	5	15	15
MISCELLANEOUS	NA	NA	NA	NA
CATERING	NA	NA	NA	NA
PROCESS	NA	NA	NA	NA

APPENDIX B

DATA TEMPLATES FOR HVAC SYSTEM IN DESIGNBUILDER

Table B.1. Data Templates for HVAC System in DesignBuilder

HVAC TEMPLATE	**SIMULATED**	**DIRECT EXPANSION SYSTEM**
TEMPLATE	AHU and FANCOIL	Package Direct Expansion
AUXILIARY ENERGY [kWh/m²]	9	8,7
MECHANICAL VENTILATION		
OUTSIDE AIR DEFINITION METHOD	MIN FRESH AIR [PER AREA]	MIN FRESH AIR [PER AREA]
OPERATION	AIRPORT CHECK Occ	AIRPORT CHECK Occ
FAN TYPE	Intake	Intake
PRESSURE RISE [Pa]	700	700
TOTAL EFFICIENCY %	70	70
FAN IN AIR %	100	100
HEATING		
FUEL	NATURAL GAS	ELECTRICITY FROM GRID
HEATING SYSTEM COP	0,8	3,5
HEATING TYPE	CONVECTIVE	CONVECTIVE
SUPPLY AIR TEMPERATURE ˚C	35	35
SUPPLY AIR HUMIDITY RATIO [g/g]	0,009	0,010
OPERATION	AIRPORT CHECK HEAT	AIRPORT CHECK HEAT
COOLING		
FUEL	ELECTRICITY FROM GRID	ELECTRICITY FROM GRID
COOLING SYSTEM COP	7	2,5
SUPPLY AIR TEMPERATURE ˚C	12	12
SUPPLY AIR HUMIDITY RATIO [g/g]	0,009	
OPERATION	AIRPORT CHECK COOL	AIRPORT CHECK COOL
DHW	NA	NA
NATURAL VENTILATION	NA	NA
AIR TEMPERATURE DISTRIBUTION	MIXED	MIXED

APPENDIX C

DATA TEMPLATES FOR GLAZING IN DESIGNBUILDER

Table C.1. Data Templates for Glazing in DesignBuilder

TYPE	U-VALUE (W/m2-K)	Total Solar Transmission	Direct Solar Transmission	Light Transmission	Outermost layer		Layer 2		Innermost layer	
					Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)
SSVG	1,643	0,163	0,085	0,2	Visteon Versalux Green 2000 R	6	AIR	12	Guardian ClimaGuard RLE 71/38 Low-E on clear	4
PFI	1,829	0.608	0.456	0.7	PPG Industries Clear Glass	10	AIR	16	SHANGHAI YAOHUA PILKINGTON GLASS CO.LTD Solar Control LowE on Clear 2X side	6
FVG	1,64	0,164	0,084	0,199	Visteon Versalux Green 2000 R	6	AIR	12	Guardian ClimaGuard RLE 71/38 Low-E on clear	4
SKY-VG	1,64	0,164	0,084	0,199	Visteon Versalux Green 2000 R	7	AIR	13	Guardian ClimaGuard RLE 71/38 Low-E on clear	5
SVG_A	2,696	0,719	0,635	0,787	Pilkington North America Optifloat Clear <Clear6m.LOF> Pilkington North America Optifloat Clear	6	AIR	12	Pilkington North America Optifloat Clear <Clear6m.LOF> Pilkington North America Optifloat Clear	6

APPENDIX D

DATA TEMPLATES FOR CONSTRUCTION MATERIAL IN DESIGNBUILDER

Table D.1. Data Templates for Construction Material in DesignBuilder

	Design U-VALUE (W/m^2-K)	U- VALUE (W/m2-K)	Outermost layer		Layer 2		Layer 3		Layer 4		Innermost layer	
			Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)
External Walls	0,6	0,38	Lightweight Metallic Cladding	3	MW Stone Wool (Standard board)	50	Concrete Block (Light weight)	200	--	--	Gypsum Plaster board	25
Flat Roof	0,4	0,334	Asphalt	10	MW Stone Wool (Roofing board)	100	--	--	--	--	Zinc	3
Standing Seam Roof	0,4	0,227	Aluminium	5	MW Stone Wool (Roofing board)	150	--	--	--	--	Zinc	5
Internal Floor	--	1,114	Gypsum Plasterboard	30	Air gap (R=0.18 m2/K/W)	1000	Cast Concrete	150	Screed	40	Ceramic / Porcelain	30
Ground floor	0,6	0,414	UF Foam	70	Cast Concrete	400	Screed	40	--	--	Ceramic / Porcelain	30
External floor	0,6	0,568	MW Stone Wool (Standard board)	50	Cast Concrete	150	Screed	40	--	--	Ceramic / Porcelain	30