ENERGY EFFICIENCY IN A UNIVERSITY BUILDING: ENERGY PERFORMANCE ASSESSMENT OF IZTECH ADMINISTRATIVE BUILDING

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ABSTRACT

ENERGY EFFICIENCY IN A UNIVERSITY BUILDING: ENERGY PERFORMANCE ASSESSMENT OF IZTECH ADMINISTRATIVE BUILDING

Energy performance of the buildings can be evaluated by measuring energy consumptions or performing simple or detailed simulation methods. In this study, IZTECH Administrative Building which is a university building, is selected as case study and energy audit is performed to evaluate energy performance of the building. Indoor conditions are recorded with dataloggers and outdoor climatic data is taken from IZTECH Meteorological Station. Fuel consumption is tracked by two flowmeters and electricity consumption is measured with three power analyzer connected to heating, cooling and lighting and general use electricity meters. Energy consumption of the building is simulated by three different methods which are TS 825 (static), CIBSE Admittance (simple dynamic) and ASHRAE Heat Balance (full dynamic) methods. Sensitivity of these methods is tested by comparing energy consumption measurements and simulations and performance improving measures are proposed. Also a hypothetical no-HVAC case is simulated. ASHRAE Heat Balance Method is determined as the most accurate model compared to measurement results and performance improving measures are simulated with this method, reduction in energy consumption and greenhouse gas emissions are observed.

ÖZET

BİR ÜNİVERSİTE BİNASININ ENERJİ VERİMLİLİĞİ: İYTE İDARİ BİNA'NIN ENERJİ PERFORMANSININ BELİRLENMESİ

Binaların enerji performansı, farklı tüketim değerlerinin ölçülmesi ya da basit veya karmaşık hesaplama yöntemlerinin kullanılmasıyla belirlenebilir. Bu çalışmada bir üniversite binası olan Izmir Yüksek Teknoloji Enstitüsü İdari Bina'da enerji etüdü uygulanarak binanın enerji performansı belirlenmiştir. İç ortam koşulları binanın çeşitli bölgelerine yerleştirilen veritoplayıcılar tarafından kaydedilmiş, dış ortam verileri ise İYTE Meteoroloji İstasyonu'ndan alınmıştır. Yakıt tüketimleri kazanlara bağlanan debimetreler, elektrik tüketimi ise ısıtma, soğutma, aydınlatma ve genel kullanım sayaçlarına bağlanan üç adet güç analizörü ile ölçülmüştür. Ayrıca TS 825 (statik), CIBSE Isıl Girişkenlik (yarı-dinamik) ve ASHRAE Isıl Denge (dinamik) yöntemleri ile binanın enerji tüketimleri simüle edilmiştir. Yapılan ölçümler ve simülasyon sonuçları karşılaştırılarak kullanılan hesaplama yöntemlerinin hassasiyeti sınanmış, ısıtma sistemi ve bina kabuğunu kapsayan ve binanın enerji performansını artırıcı önlemler önerilmiştir. Ayrıca, binada HVAC sistemlerin çalışmadığı bir senaryo da, konfor şartları açısından simule edilmiştir. Sonuç olarak ASHRAE Isıl Denge metodunun ölçüm değerlerine en çok yaklaşan yöntem olduğu ve bu metodla sınanan performans artırıcı önlemlerin binanın enerji tüketimi ve sera gazı emisyonunu azalttığı belirlenmiştir.

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NOMENCLATURE

A	surface area (m^2)
A_d	area of the conjugate wall (m^2)
A_D	area of external wall (m^2)
A_i	area of the windows in "i" direction
A_G	area of glazings (m^2)
A_P	area of windows (m^2)
A_T	area of roof (m^2)
A_P	area of floor (m^2)
C_p	specific heat capacity (kJ/kgK)
d	thickness of building element (m)
F_{au}	room factor (-)
F_{ay}	room factor (-)
$g_{i,ay}$	solar transmission factor (-)
h	convective heat transfer coefficient (W/m^2K)
h_c	outdoor wall heat transfer coefficient (W/m^2K)
h_{ci}	indoor heat transfer coefficient (W/m^2K)
h_a	indoor wall heat transfer coefficient (W/m^2K)
h_i	indoor heat transfer coefficient (W/m^2K)
h_o	outdoor heat transfer coefficient (W/m^2K)
h_r	outdoor radiative heat transfer coefficient (W/m^2K)
h_r	indoor radiative heat transfer coefficient (W/m^2K)
H	total specific heat loss of the building (W/K)
H_i	total conductive specific heat loss (W/K)
H_h	ventilation heat loss (W/K)
I	length (m), solar intensity (W/m^2)
$I_{i,ay}$	monthly average solar radiation (W)
KKO_m	monthly gain/loss ratio (-)
n_k	air change rate(1/h)
$q_i''(t)$	time dependant heat flux (W)
Q	heat flux (W)
Q_a	gains to the air node (W)

Q_e	gains to the environmental node (W)
$\overline{Q}$	hourly fluctuating component of heat flow (W)
Q_c	internal gain (W)
$Q_{cond,in}$	heat flux to inside wall (W)
$Q_{cond,out}$	heat flux from outside wall (W)
Q_{ia}	convection to the air (W)
Q_{inf}	infiltration loss (W)
Q_{ir}	radiant flux from internal source (W)
Q_m	monthly heating energy demand (kJ)
Q_{oLW}	outside longwave radiation gain (W)
Q_{Pa}	plant load (W)
Q_s	solar gain (W)
Q_S	stored heat on wall (W)
Q_{Si}	radiant exchange from inside walls (W)
Q_{SW}	retransmission through glazing (W)
Q_{year}	yearly heating energy demand (kJ)
S	solar gain factor (-)
$r_{i,ay}$	shading factor in “i” direction (-)
t	time (sec)
t_{in}	working period of internal gain source (h)
T	temperature (°C)
T_a	air temperature (°C)
T_{ao}	sol-air temperature (°C), outside air temperature (°C)
$T_{d,m}$	monthly average outdoor temperature (°C)
T_{si}	temperature of inside surface (°C)
T_{so}	temperature of outside surface (°C)
T_e	environmental temperature (°C)
T_{MRI}	mean radiant temperature (°C)
U	overall heat transfer coefficient (W/m^2K)
U_d	overall heat transfer coefficient of the conjugate wall (W/m^2K)
U_D	overall heat transfer coefficient of the external wall (W/m^2K)
U_P	heat transfer coefficient of windows (W/m^2K)
U_T	overall heat transfer coefficient of roof (W/m^2K)

U_t	overall heat transfer coefficient of floor (W/m^2K)
U_L	longitudinal heat loss coefficient (W/mK)
V	volume (m^3)
V_h	ventilated volume (m^3)
X_j	outside conduction transfer function coefficient (-)
Y_j	cross conduction transfer function coefficient(-)
Y	admittance (W/m^2K), coefficient conduction transfer function
Z_j	inside conduction transfer function coefficient (-)

Greek symbols

η_h	air change rate ($1/m^3$)
η_m	monthly gain utilization factor (-)
ρ	density (kg/m^3)
φ_{in}	internal gain (W)
$\varphi_{i, m}$	monthly internal gain (W)
$\varphi_{g, m}$	monthly solar gain (W)
υ	volume (m^3)
λ	heat conduction coefficient (W/mK)

Special characters

$\underline{\square}$	notation for hourly fluctuating components

CHAPTER 1

INTRODUCTION

World energy consumption has reached 11.3 billion tonnes of oil equivalent in 2008 with 1.4% increase prior to 2007 while this consumption is supplied mostly from fossil fuels by 87% percent (BP 2008). Although there are many alternatives like wind, geothermal, solar and biomass energy; there is no sensible solution to fossil fuel independency yet.

In Turkey, yearly energy demand increased by 1.2% in 2008, reaching 102.6 million tonnes of oil equivalent. Projections indicate that Turkey's energy demand will reach to 126 million tonnes of equivalent oil in 2010 and up to 222 million tonnes of equivalent oil in 2020. Turkey is dependent on oil and natural gas and imported 58 million tonnes of oil equivalent natural gas and oil in 2007 resulting total dependency on imported energy sources to 72% (Ministry of Energy 2007). According to these data, energy status of Turkey can be summarized as follows:

1. Turkey is not self-sufficient on energy sources and dependency on imported energy sources is increasing year by year.
2. Cost of energy is increasing and competitivity in economics greatly bounded to the cost of energy.

Under these circumstances, energy efficiency and renewable energy sources hold an important role to overcome fossil fuel dependency and fluctuating energy costs. However, energy efficiency outshines as simplest, cheapest and fastest solution.

Energy efficiency or efficient energy use is on the forefront in the World since 1973 oil crisis, leading developed countries to discuss energy issues in an economic sense. However, in 2000's researches and reports concluded that energy efficiency is not only an "economic" view but also a" vital" aspect. This "vital" aspect of energy is supported by two facts; depletion of fossil fuels which World is highly dependent and global climate change (KEP-SDM 2008).

According to BP Energy Report (BP 2008), total proven oil reserves can last for 41 years, natural gas for 61 years and coal for 133 years. It can be seen that it will be unfeasible to explore new oil reserves with increasing capital and utilization cost hence easily accessible reserves are mostly used. Nuclear energy is problematic with radioactive wastes and security problems and far to meet the increasing demand of energy. Hydropower cannot be the energy solution for future because it will not supply enough energy even maximum potential is used. Renewable non-fossil sources like wind, solar, geothermal etc. holds only a small portion (3%) on energy production and it is unexpected to replace fossil fuels in near future.

Second fact, global climate change is the increase of the average temperature of Earth and projected continuation of that increase. Global temperature increased 0.74 ± 0.18°C during 100 years ending in 2005 and expected to rise 1.1 to 6.4°C during twenty-first century. Expected catastrophic results are rise in sea level, drought effecting agricultural production and extermination of species (Summary for Policymakers 2007).

Kyoto Protocol which is an international convention to act against global warming and aims to decrease the greenhouse gas intensity level to avoid adverse climatic effects. Kyoto Protocol is proposed in 1997 and came into force in 2005; forcing participating countries to release regulations to reduce greenhouse gas emission, encourage renewable energy use and to meet the emission limits as proposed in Protocol's Appendix (Kyoto Protocol 1997).

In Europe, residential and service buildings are responsible for more than 40% of primary energy consumption and this ratio is expected to rise. European authorities have undertaken the challenge to control domestic energy consumption of buildings to reduce greenhouse gas emissions and the studies on efficient energy use have been accelerated since 1992 (Miguez et al. 2006). Most important outcome of these studies is, the European Union Directive on the Energy Performance of Buildings (2002/92/EC) (EPBD 2002). Directive underlines the structure of methods which determine the energy performance of buildings for member states, suggests studies on existing building stock and energy performance certification procedure.

Energy performance evaluation methods should consider thermal and air tightness, natural ventilation, heating and cooling equipment, insulation, thermal bridging effect and indoor environmental conditions which refer to European standards. One of the leading standards which is EN ISO 13790 (2008) "Energy performance of buildings- Calculation of energy use for space heating and cooling" categorizes three different energy performance evaluation methods, their assumptions and minimum requirements. These methods are seasonal or monthly quasi-steady-state method, simple hourly dynamic method and full dynamic method.

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. "Energy Efficiency Law (2007)" is released in February 2007; urging industry, transportation and residential sectors to take measures on improvement of energy efficiency. The target of this law is to reduce energy intensity (kJ/$) of Turkey by 10% till 2020. Furthermore in December 2008, the Ministry of Public Works and Settlement introduced a regulation titled "Directive on Energy Performance of Buildings (2008)". According to this regulation, new buildings and buildings under major renovation are urged to obtain an "Energy Certificate" which includes heating, cooling, domestic hot water and lighting energy consumptions, as well as greenhouse gas emissions as a result of energy consumption. In July 2008, Turkey signed Kyoto Protocol and committed to reduce greenhouse gas emissions by 10% compared to 1998. (Kyoto Protocol, 1997).

Sectoral energy consumption (electricity and fuel) of Turkey is categorized into buildings (38%), industry (36%), transportation (20%) and the rest (6%) which are given in Figure 1.1 (Bolattürk 2006). Energy efficiency measures in industry and transportation is a long term and investment intensive process since it is difficult to change conventional systems. However, small modifications and plannings in residential and office buildings contribute in energy efficiency more quickly.

Energy efficiency potential of Turkey is defined as up to 30% by application of insulation in buildings, 20% in industry and 15% in transportation sectors by EIE (Electrical Power Resources Survey and Development Administration), predicting 3 billion USD energy saving (EIE 2004).

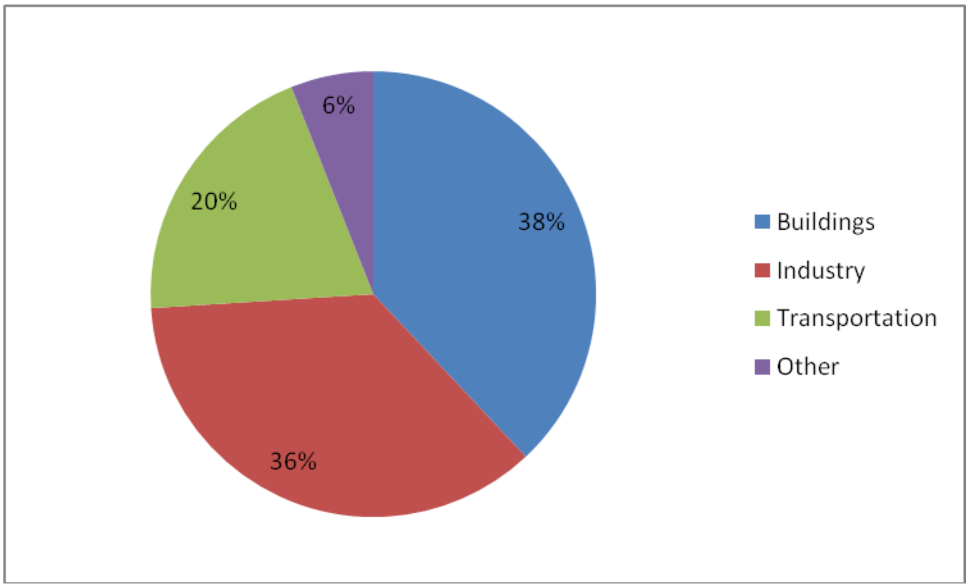


Figure 1.1. Distribution of energy consumption in Turkey
(Source: Bolattürk 2006)

Although laws and regulations on building energy performance have been released since 2007, comprehensive studies have not been published accordingly in Turkey.

The construction and operation of university buildings have been always problematic because of the insufficient budget, awarding of contract process and experienced technicians. The lack of comprehensive studies and the encountered problems with the university buildings is the motivation of this study which is focused on IZTECH Campus buildings. Taking advantage of the independent HVAC system which eases the data collection, Administrative Building is chosen as case study. Temperature and relative humidity data is collected for 3 years from 14 different spaces on different floors and directions. Besides indoor climatic data, outdoor meteorological data (temperature, relative humidity, wind speed, solar radiation etc.) are also collected. Fuel and electricity consumption of the building is observed and recorded. Static (TS 825), simple dynamic (CIBSE Admittance) and full dynamic (ASHRAE Heat Balance) methods which are comprised by EN ISO 13790 (2008) are performed via corresponding simulation software which are IZODER (2008), Ecotect (2008) and EnergyPlus (2008) respectively to evaluate the energy performance of the building taking into consideration of heating, cooling and electricity energy consumptions.

Thermal performance and energy analysis of a building are subject to a wide range of dynamic interactions between the building and its HVAC systems and greatly affected by the daily, seasonal and annual changes in local weather conditions (Lam et al. 2004). Therefore, local meteorological data is implemented into simulations where it is possible.

Energy consumption measurements are compared with the results of the simulations. Following the performance and verification of the simulations, renovation scenarios are proposed to reduce energy consumption thus increasing the energy performance of the building.

A hypothetical (no-HVAC) case, where there is no heating and cooling system operated in the building is also simulated by EnergyPlus.

In the second chapter of this thesis, a literature survey including the review on energy efficiency legislations of EU countries is presented. Third chapter consists of the introduction to IZTECH Administrative Building and its HVAC system, measurement equipment and thermal camera images of the building envelope. Building energy performance calculation methods which are TS 825, CIBSE Admittance and ASHRAE Heat Balance, and corresponding software are introduced in chapter four. Results of the measurements, simulations, no-HVAC case and renovation scenarios are given in chapter five. In the last chapter, important findings are presented as conclusions.

CHAPTER 2

LITERATURE SURVEY

2.1. European Union Directive on the Energy Performance of Buildings

EU Directive on the Energy Performance of Buildings (EPBD) was proposed in December 16th, 2002 and became core reference for future studies on energy performance of buildings. Objective of EPBD is to promote the improvement of the energy performance taking into account outdoor climatic and local conditions, as well as indoor conditions. Article 1 of EPBD refers to requirements such as;

(a) the general framework for a methodology of calculation of the integrated energy performance of buildings,

(b) the application of minimum requirements on the energy performance of new buildings,

(c) the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation,

(d) energy certification of buildings,

(e) regular inspection of boilers and air-conditioning systems in buildings.

EPBD do not only list the requirements of a building in terms of energy performance but also address Umbrella Document (CEN/TR 15615) and other 52 EN ISO standards to fulfill those requirements.

Important outcome of EPBD is the necessity of a national energy performance calculation method for buildings covering both new and existing buildings. Performance evaluation is followed by renovation if necessary, certification, and inspection of HVAC equipment. Detailed information about the EPBD and its articles is given in Figure 2.1.

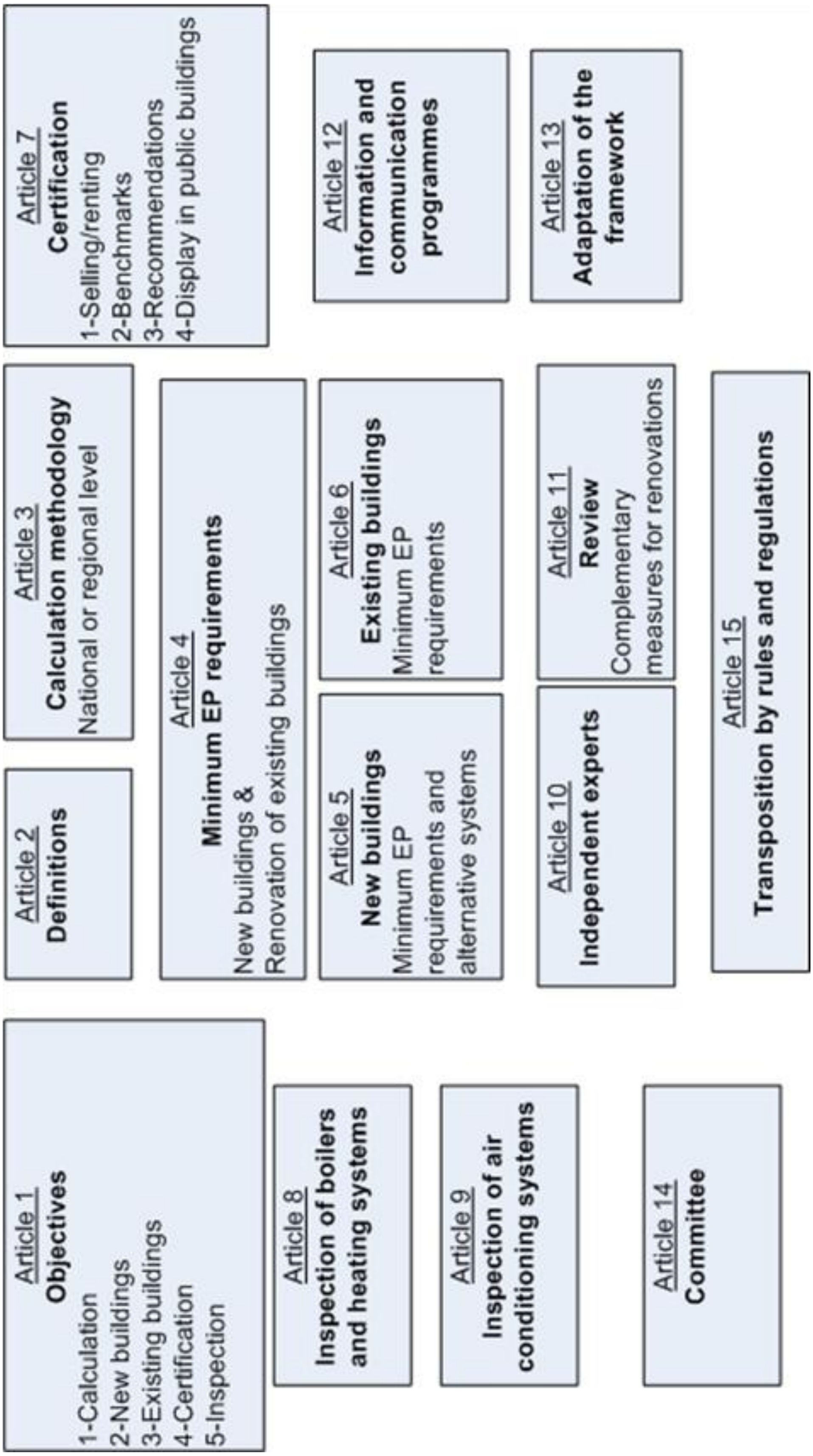


Figure 2.1. Summary of EPBD and its articles
(Source: Buildingsplatform 2008)

2.2. Building Energy Performance Regulations in Europe

As mentioned in introduction, European countries have been conducting studies on building energy performance since 1992. With the release of European Union Directive on the Energy Performance of Buildings (EPBD), every member state is responsible to propose its own national method to evaluate energy performance of the buildings.

In this section, the development of building energy performance evaluation methods of some EU countries is summarized.

2.2.1. Denmark

Denmark is the pioneer of energy audit and rating in Europe, creating a reference point for other member states. A compulsory inspection prior to the sale of dwelling is introduced in 1985 and "Act on Promotion of Energy and Water Conservation in Buildings" is released in 1996, which came into force in 1997. This act establishes three different types of energy audit; ELO (energy certificate for large buildings), EM/EK (energy certificates for small buildings) and certification of industrial buildings. Energy audit is carried out by a qualified energy consultant prior to the sale of the building.

Audit can be split into three parts as the first part includes energy rating, water and energy consumptions and CO_2 emissions. It also reports total expected consumption of energy and water for a 25- year period. Aim of the first part is to make owners more aware of how much energy they will consume and how much will it cost. Second part of the energy audit proposes energy and water saving measures including an estimation of investment needed and technical lifetime of each measure. Third and the final part of the document provide current state of the building and heating system, size of the building and current energy prices.

In Denmark between 45,000 and 50,000 audits have been carried out per year, almost 70% of the single family dwellings are rated at the time of sale and energy consumption on these dwelling has dropped by 20% (Miguez et al. 2006).

2.2.2. United Kingdom

SAP (Standard Assessment Procedure) and Part L (Conservation of fuel and power) have been in force since 1995 and compulsory for new buildings. SAP is based on annual costs of heating, lighting and domestic hot water per m^2 of floor area. Insulation of the building envelope, solar gains, efficiency of heating and hot water production systems, fuel prices are the factors effecting SAP rating which is ranging from 1-100. SAP do not take into account of the location of the building and consumption of domestic appliances, also do not recommend on how to make building more energy efficient. SAP has been applied to 170,000 houses per annum reaching total of three million audited building (Roberts 2008, Miguez et al. 2006).

2.2.3. France

Ministry of Housing and Transport released Decree 2000-1153 which is mandatory for new non-industrial buildings. According to this legislation, energy consumption in kWh for heating, hot water, ventilation, climate control and lighting is urged not be higher than a reference level which varies from region to region. Also indoor temperature should not be higher than a reference value. Limits are defined for minimum thermal insulation for outside walls, humidity level for air-conditioning systems, and heating and hot water production systems.

Two methods are suggested to calculate whether a building complies with the regulations: the first is a precise, complex method intended for use by technical building specialists, and the second is a simpler method intended for people who are not experts in heat-related matters, and even for private individuals. This second method has its limitations: it applies only to buildings with a surface area of less than 220 m² which are not climate-controlled, have internal but not external insulation which use materials that meet certain requirements (Policy 2009).

2.2.4. Ireland

HER (Heat Energy Rating) and ERBM (Energy Rating Bench Mark) are set up in 1997 and 1992 which are applied voluntarily to new buildings. ERBM can be also applied to existing buildings.

ERBM is the most widely used energy rating systems by builders and fuel suppliers to promote low-consumption buildings. It reports energy consumption per m² and CO_2 emission per annum while taking amount of performance of HVAC equipment installed on the building. Although ERBM is not an official certificate it includes recommendations on improving building envelope and heating systems, and savings for such improvements (SEI 2009, Miguez et al).

2.2.5. Germany

Although efforts on energy efficiency initiated in 1982, currently active legislation is “Energy Saving Decree” which is approved in 2001. It is compulsory for new and renovated buildings. There are two important results of this decree:

1- Energy consumption limitation of 7 liters of oil equivalent fuel per m² per annum.
2- Compulsory replacement of old boilers dating from 1978 till 2006.

Energy rating calculations are based on the limits on thermal insulation and overall heat transfer coefficients which are required under the current building regulations. Buildings that obtain 70% of their energy from renewable resources are granted with subsidies (Miguez et al. 2006).

2.2.6. The Netherlands

EPA (Energy Prestatie Advies-‘Energy Performance Study’) is the current regulation for buildings in the Netherlands. For new buildings regulation is EPB (Standard Energy Performance) but both of them are not compulsory.

EPA is proposed to encourage owners to take actions on energy saving and to provide an overall energy study for existing buildings in 1995. It looks at heating, hot water, lighting energy consumptions as well as consumption of pumps and fans (Miguez et al. 2006).

2.2.7. Belgium

Legislations are standardized as NBN B62-002 and NBN B62-004 in Belgium which have been in force since 1987. These regulations are compulsory for all new residential buildings. In Brussels and the Walloon region, they are also compulsory for all other new non-industrial buildings.

The limit coefficient for new residential buildings is K55, i.e. they are required to have an average overall heat transfer coefficient of no more than 0.55 $W/m^2°C$. As well as the overall coefficient for the building as a whole, upper limits are also set for some outside walls. For new buildings intended for non-industrial service use, the legislation varies from region to region. In Flanders, the K55 coefficient applies to all new service-sector buildings as well as to residential ones (Santamouris 2005).

2.3 Building Energy Performance Regulations in Turkey

TS 825 is currently the only legislation in Turkey, limiting heating energy demand of the building by area/volume ratio. In 2008, standard is revised forcing lower overall heat transfer coefficients for building envelope. TS 825 divides country into four climatic regions determined by heating degree-day values and contains useful tables for the properties of construction materials.

Studies on a methodology for energy performance evaluation of the buildings accelerated with the release of “Energy Efficiency Law” in 2007 and “Energy Performance of Building Regulation” in 2008. A calculation procedure including heating, cooling, domestic hot water production and lighting energy consumptions and CO_2 emissions is expected to be released in December 2009 to fulfill requirements of “Energy Performance of Buildings Regulation”.

2.4. Literature Survey on Energy Performance Evaluation Studies

Literature of energy performance of the buildings can be categorized as;

1- Measurements of energy consumptions,
2- Estimating energy consumption of buildings by simulation software only,
3- Comparison of measurements and simulation results,
4- Economic viability of building renovations,
5- Parametric and statistical studies based on the static properties of the building envelope, such as overall heat transfer coefficient (U), window/wall and area/volume ratio.

Mungwititikul and Mohanty (1996) performed an energy audit of the consumption of office equipment, operation patterns and energy saving possibilities. They conclude saving up to 25% in electricity can be achieved by managing idle times of the office equipment.

Energy consumption simulations constitute an important role in building energy performance evaluation. Crawley et al. (2008) reviewed approximately twenty simulation programs which are widely used such as BLAST, Ecotect, DOE, ESP-r, EnergyPlus, IES, and TRNSYS, and compared their capabilities and features. General modeling features, zone loads, building envelope treatment, day lighting, infiltration-ventilation and multi-zone airflow, renewable energy systems, electrical equipment, HVAC system and equipment, environmental emissions, economic evaluation, climate data availability, result reporting, validation and user interface capability issues are all discussed in detail.

Corgnati et al. (2008) focused on impact of internal thermal conditions on building energy demand exhibiting an example of "simulation only" performance evaluation study. A reference test room which is taken from EN 15265 (2007) (Thermal Performance of Buildings Calculation of Energy Use for Space Heating and Cooling. General Criteria and Validation Procedures) is modeled using EnergyPlus simulation to investigate the connection between indoor thermal comfort conditions and energy demand for both heating and cooling. Heating and cooling set point temperatures are calculated within an acceptable comfort band (-0.5<PMV<0.5) while simulating mechanically controlled heating and cooling. For non-mechanical systems, Dear's adaptive comfort theory is used. Single set point control for heating and cooling for entire season, single set point calculated per month, and finally dual set point control with dead band are investigated in terms of comfort and energy. Results are obtained for different cities representing different climatic conditions. Most important outcome of the study is to propose to use operative temperature for control instead of air temperature.

Masoso and Grobler (2008) focused on the phenomena of "insulation increases cooling load". Aim of this study is to determine "point of thermal inflexion" because of the cooling set-point temperature and internal loads. Simulations carried out by EnergyPlus on a hot climate (Botswana) on an existing building. Solar transmission factors and internal heat gains are derived from measurement data.

Conceição and Lúcio (2008) studied thermal performance of a school building located in a mild climate (Portugal) with a high solar radiation level. EnergyPlus software is used to be able to observe the effects of the temperatures of internal surfaces and glazing. Simulation is performed with actual occupancy, infiltration and ventilation data to derive PMV (Predicted Mean Vote) thermal comfort index for different zones.

After uncomfortable zones are identified, two solutions are proposed to improve thermal comfort, namely electrical air heaters and air solar collectors.

Papadapoulos et al. (2008) presented the empirical comparative results related to three most popular heating systems operated in Greek multi-apartment and mixed-use buildings which consume different fuels. Selected building for the simulation has three floors with 114 m^2 apartments on each floor. Every apartment has a living room, a kitchen, a bathroom and two bedrooms. Those rooms are assumed as a different zone for thermal simulation. U value of the openings is 2.8 W/m^2K. For internal gains (lighting, equipment and occupancy) ASHRAE assumptions are used. Infiltration is calculated with an algorithm introduced in EnergyPlus taking into account design airflow, schedule, indoor temperature and wind speed. Occupancy distribution and heating patterns are determined from field surveys. Results are discussed in terms of primary energy, CO_2 emission and cost. Primary energy factors, fuel emission factor and cost due to current tariffs are used in a realistic way.

Tronchin and Fabbri (2008) used different simulation methods supported by consumption measurements. The study has been conducted considering a single-family house in Italy, and focused the differences among software and real consumption in relation with flexible architectural solutions. Three different models for EPB software calculations have been analyzed and compared, in order to quantify their gap with the actual energy consumptions.

(a) evaluation of effective energy consumption by energy bills of three previous years. The evaluation is based on the CEN-Umbrella prEN 15603 clause 7,
(b) evaluation based on the CEN-Umbrella: prEN15217, prEN 13790, and prEN 15316-x standards (Design Builder software),
(c) evaluation based on the EN 832 (currently in force) and the Italian law recommendations.

Results show that EN 832 based BESTCLASS software overpredicts energy consumed in winter (37%) while Design Builder has more precise approximation (1%). For summer season Design Builder software again has close results to the consumption measurements (9%) while BESTCLASS do not calculate cooling energy consumption.

Karlsson and Moshfegh (2005) used ESP-r software to simulate energy requirement and indoor climate in a well-insulated terraced house in Sweden. A computational fluid dynamics model (CFD) is used to simulate and visualize the airflow and temperature distribution in a selected room. Simulation cases are selected as rotation of the building, changing indoor temperature, changing U value, applying load management and using different climatic conditions. Results indicate that 1°C increase in indoor air temperature (from 23°C to 24°C) increases energy demand by 21% without major improvement on indoor comfort (PPD index). It is concluded that high level of insulation (U values of 0.25 W/m^2K for building envelope) is not a problem for cooling in cold climates but it causes overheating problems in mild or hot climates. Load management supported by differentiated electricity prices are economically profitable.

Becker and Goldberger (2006) focused on energy efficiency-thermal comfort-indoor air quality dilemma. The study developed from a national research program to establish Building Energy Code for all building occupancy. School buildings are selected as case study due to high internal gains preventing to achieve thermal comfort in summer period. Simulations are performed regarding occupancy period, indoor climate control, ventilation provision, lighting control, location of the building, construction features and internal gains. Results indicate implementation of improved ventilation schemes in well designed energy-conscious building lead up to 30% and 18% energy savings in northern and southern classrooms respectively.

Economic viability of building renovations are usually supported by simulations which estimates the response of the building to the retrofit. Florides et al. (2002) used TRNSYS software to simulate thermal loads of houses. TMY (typical meteorological year) and a typical house model for Cyprus is selected for simulations. Controlled variables which are natural and mechanical ventilation, solar shading, glazing type, orientation and shape of the building, insulation and thermal mass are examined. Energy load calculations are supported with economical analysis. Life-cycle cost method is used to show effectiveness of the measures to lower the consumption. Results indicate that for hot climates roof insulation and solar shadings pay back in 3-5 years while wall insulation pays back up to 10 years.

Fumo et al. (2009) investigated CHP (Combined Heat&Power) systems for different cities in the USA for a hypothetical office building simulated in EnergyPlus. Total energy consumption of heating, cooling and other equipment are derived from EnergyPlus simulation and scaled to primary energy for each city. Different control strategies for PGU (Power Generation Unit) show that options based on primary energy, not only economic feasibility, results in energy saving.

Parametric and statistical studies on buildings are performed to identify important properties which effect the energy performance of the buildings. Andersson and Olofsson (2007) conducted a methodology on multi-family Swedish Buildings based on monthly electricity and fuel consumption data. Missing data is compensated with assumed consumption profiles. Results show that K_{tot} (overall heat transfer coefficient) is the most significant output for energy performance. When used together with total energy consumed, it can strongly predict the indoor air temperature. It is also concluded that energy consumed per m^2 of the building is a questionable indicator of performance of the building because it is directly bounded to the operation profile thus changing comfort levels.

Corgnati et al. (2008) worked on a data set of 50 residential buildings to find simplified correlations to determine energy demand for heating. Relations between shape ratio, window to wall ratio, internal and external temperatures, wall transmittances and their effect on energy demand is investigated. On statistical study FEN number is generated (with assumptions of single zone and steady state) with a unit of kJ/m^2DD. Results of FEN have an R value of 0.98. Results can be applied to the building stock and be used for energy certification.

Ghiaus (2007) proposed a methodology to use the 1st and 3rd quartile of (q-q) plot to check heating load and outdoor temperature have the same distribution, then to perform regression analysis between heating load and outdoor air temperature. Result of the model gives overall heat transfer coefficient and base temperature; they may be used to estimate the energy consumption for the specific building in given climatic conditions. Regression results are also powerful and simple concepts for energy labeling of buildings. They give idea about the design, execution and operation of the building.

In Turkey, the studies on building energy performance are focused on determination of optimum insulation thickness, performance of HVAC systems and building design. Ucar and Balo (2009) studied the optimum insulation thickness of the external wall for four cities representing different climatic regions proposed in TS 825. Energy savings and payback periods for different fuel types and insulation materials are investigated. Results show optimum insulation thickness vary between 1-7 cm, savings up to $47\$/m^2$ and payback period up to 3.7 years.

Aktacir et al. (2008) investigated the influence of different design conditions of air-conditioning systems. A sample building in Adana (hot climatic region) is chosen for cooling load and capacity of air conditioning system calculations. RTS (Radiant Time Series) Method which is a simplification of ASHRAE Heat Balance Method is used to evaluate cooling loads. Usually accepted design conditions, maximum dry and wet bulb temperatures in July 21, and other pre-determined design conditions are used to calculate cooling loads and to compare the cost of the air conditioning system. It is concluded that selection of outdoor design conditions is a very critical step to size air-conditioning equipment.

Oral and Yılmaz (2003) proposed a methodology to determine optimum building form which is represented by area/volume ratio depending on the U-value of opaque elements and window frames. Methodology is valid for cold climatic zones with long heating periods and it is able to minimize heating energy demand of the building.

The only study published for Turkish buildings, on the comparison of energy consumption measurements and simulation software results is by Eskin and Turkmen (2008). Eskin and Turkmen focused on the energy demand change with climatic conditions (location), insulation, thermal mass, aspect ratio, shading and color of external surfaces, window area including properties of glazing, ventilation rates and control strategies. EnergyPlus was used to simulate a base case building in Istanbul. In order to validate the simulation, results of the EnergyPlus are compared with measurements. After validation of the energy simulation, the effects of various low-energy design strategies for heating and cooling are evaluated. Insulation, windows system retrofitting, changing window to wall ratio and aspect ratio to decrease total thermal conductivity of the building; shading, changing ventilation rate and control strategies to reduce energy consumption are all investigated. Results show reduction in energy demand up to 50% (25% from insulation, 15% from using appropriate aspect ratio and glazing system, 5% shading and color of the external surface, 5% from control of indoor air and ventilation).

Studies on university buildings are focused on applying energy survey and proposing improvements to reduce energy consumption and greenhouse gas emissions.

Di Stefano (2000) studied on the energy efficient lighting at Melbourne University, Australia. Cost effectiveness of replacing 1.2 meter fluorescent lightning with different ballast alternatives and reduction due to replacements is examined. Results indicate energy saving up to 64.9% and carbon dioxide emission reduction up to 10%. However, none of the alternatives are cost effective because of the low operation time of lighting, high cost of replacement and low cost of electricity.

Barelli and Bidini (2004) suggest a methodology for energetic diagnosis for Perugia University. Electricity consumption for didactic, administrative and laboratory activities are examined by area and user indexes defined by area and population of the buildings. Thermal and electrical consumptions were analyzed by yearly energy amount and specific consumption of each activity. Results are used to propose improvement on insulation and boilers and air heating systems.

Neto and Fiorello (2008) compared a simple artificial neural network (ANN) and simulation based (EnergyPlus) model to predict building energy consumption using physical properties of the building. An office type building (Administration Building of the University of Sao Paulo) is selected as case study. EnergyPlus simulation is carried out with surveyed energy consumption profiles. 80% of the results are within a ±13% confidence interval. Error occurs because of the change in electrical equipment usage, lighting and occupancy levels. ANN models predict energy consumption within a ±%10 range. It is concluded that 2 powerful methods; EnergyPlus (with physical insight and useful scheduling) and ANN model (able to predict future consumption by previous data) are quite useful to predict energy demand of a building when properly calibrated.

Lukman et al. (2009) studied on the thermal performance of the University of Maribor considering construction, maintenance, heating, lighting and water consumption as well as consumption of sundries. In order to reduce the environmental impacts, replacing the conventional gas-fired boiler with a combined wood and solar heating system is proposed and estimated to reduce greenhouse gas emissions up to 82%.

Coşkun and Oktay (2009) performed an energy audit on Building of Engineering Faculty at Balikesir University and proposed three sets of performance improvement measures are proposed. These are external insulation on building envelope, using a boiler with higher efficiency and use of natural lighting. Results showed energy saving potential up to 32% and greenhouse gas emission reduction of 89 tonnes.

In this thesis, considering the lack of comprehensive studies on energy performance of buildings in general and university buildings in specific in Turkey, a detailed study is conducted in one of the buildings of Izmir Institute of Technology.

CHAPTER 3

DESCRIPTION OF THE BUILDING

3.1. General Information about IZTECH Administrative Building

The Administrative Building is a 3+1 storey building with 5090 m^2 floor area locating on east-west axis on open ground. Layout of the building is given in Figure 3.1. The building is utilized by academic, administrative and technical staff for various purposes (Table 3.1).

Figure 3.1. Location of IZTECH Administrative Building.

Table 3.1. Distribution of spaces in the Administrative Building (2007).

Space	**Number**	**Total Area (m^2)**
Computer lab. (0-50 m^2)	1	152
Other labs	15	734
Canteen	1	172
Meeting room	6	200
Office (academic staff)	40	860
Boiler room	1	153
Office (Administrative staff)	47	1541
Warehouse	1	140
WC	14	246
Archive	2	54
Hallway + stairs	3	654
Workshop	2	184
Total	**133**	**5090**

Administrative building originally designed as an office building. However lack of space for educational facilities such as classrooms and laboratories because of the earthquake occurred in 2005 and expansion of the campus, urged the building to be used for another purposes. Regarding with the current state of the building, total number of 87 office and 6 meeting rooms covers more than half of the floor area. Therefore Administrative Building can be classified as an office building.

IZTECH Administrative Building is constructed in 1995-1996 which is long before TS 825 came into force. Properties of the building envelope materials are listed in Table 3.2 taken from Office of Buildings and Ground (OBG 2007).

Table 3.3 gives an overview of electricity and fuel consumption data of the Campus and the Administrative Building itself between 2006 and 2008 (OBG 2008). The share of the Administrative Building in total energy consumption is approximately 10%.

Table 3.2. Properties of the building envelope of the Administrative Building (Source: OBG 2007).

Material	**Thickness (m)**	**Heat transfer coefficient (W/mK)**
Outside wall		
Plaster	0.015	0.87
Brickwork	0.19	0.58
Plaster	0.015	1.4
Concrete surfaces		
Plaster	0.015	0.87
Concrete, high density	0.2	2.1
Plaster	0.015	1.4
Floor		
Medium concrete	0.15	1.74
Mortar	0.1	1.1
Slag	0.15	0.7
Roof		
Plaster	0.02	0.87
Concrete, high density	0.15	2.1
XPS insulation	0.03	0.04
Window		**U value (W/m^2K)**
Aluminum frame double pane with 9 mm spacing		3.9

Table 3.3. Electricity and fuel consumption of the Administrative Building and Campus (Source: OBG 2008).

	Administrative Building (kWh)	**Campus Total (kWh)**
2006-Electricity	331,860	3,225,096
2006-Fuel	244,247	1,819,537
2007-Electricity	246,680	4,274,359
2007-Fuel	217,655	2,007,642
2008-Electricity	316,260	4,734,764
2008-Fuel	280,483	N/A

3.2. Heating and Cooling System of the Building

Two- pipe fan coil system is used for heating and cooling. Heating energy is supplied by two fuel-oil boilers with a capacity of 291 kW/each while peak heating load of the building is 446 kW. Boilers and burners of the building are shown in Figure 3.2.

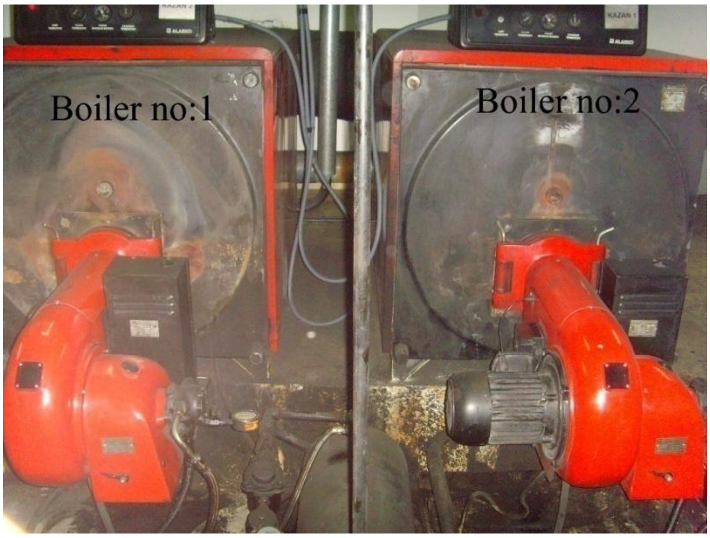


Figure 3.2. Boilers and burners of the heating system.

Cooling system shown in Figure 3.3 consists of 3 air-cooled condenser units with a capacity of 311.9 kW/each.

Figure 3.3. Cooling system of the the Administrative Building.

The building's energy performance is observed and evaluated between 2006 and 2008. Each year, different heating regimes which aim increase the comfort level of the occupants, are adopted (Table 3.4).

Table 3.4. Heating regimes between 2006-2008.
(Source: OBG 2008).

	Office-hours	**Non office-hours**
2006	Fixed boiler water exit temperature	Off
2007	Adjusted manually depending on outdoor temperature	45 °C
2008	Adjusted automatically depending on outdoor temperature	Adjusted automatically depending on outdoor temperature

Flue gas emission measurements are performed in 2007 and 2008 to evaluate efficiency of the boilers which is used to predict heating energy consumption of the building (Table 3.5, Figure 3.4).

Table 3.5. Flue gas emission measurements for boilers in the Administrative Building (March 12th, 2008).

Measurements	Boiler no:1	Boiler no:2
Gas temperature (°C)	348.7	255.9
Ambient temperature (°C)	22.9	22.6
O_2 (%)	10.8	10.1
CO_2 (%)	7.6	8.2
CO (ppm)	96	24
NO (ppm)	385	112
NO_x (ppm)	387	81
NO_2 (ppm)	1	0
SO_2 (ppm)	608	307
Efficiency (%)	**81.5**	**78.7**

Figure 3.4. Flue gas emission measurement (2008).

3.3. Energy Auditing

Energy audit studies of the building were first initiated in 2006 to collect temperature and relative humidity data using 14 dataloggers (Figure 3.5) distributed on three floors and four directions (Figure 3.6). Measurements which give information about the comfort level of the spaces are taken at 10 minute intervals for three years.

In 2007, to be able to compare comfort level with energy consumption, two fuel flowmeters (Figure 3.7) and three power analyzers were installed. The flowmeters were located at burner inlets to monitor daily fuel consumption. Electricity consumption of the building is measured by three electricity meters; one for electricity consumption of equipment and lighting, second one for pumps and burners of heating system and the last one for cooling system. Power analyzers (Figure 3.8) were installed to these electricity meters to track electricity consumption in 10 minute intervals. The properties of the measurement devices are given in Table 3.6.

Figure 3.5. Datalogger installed in an office.

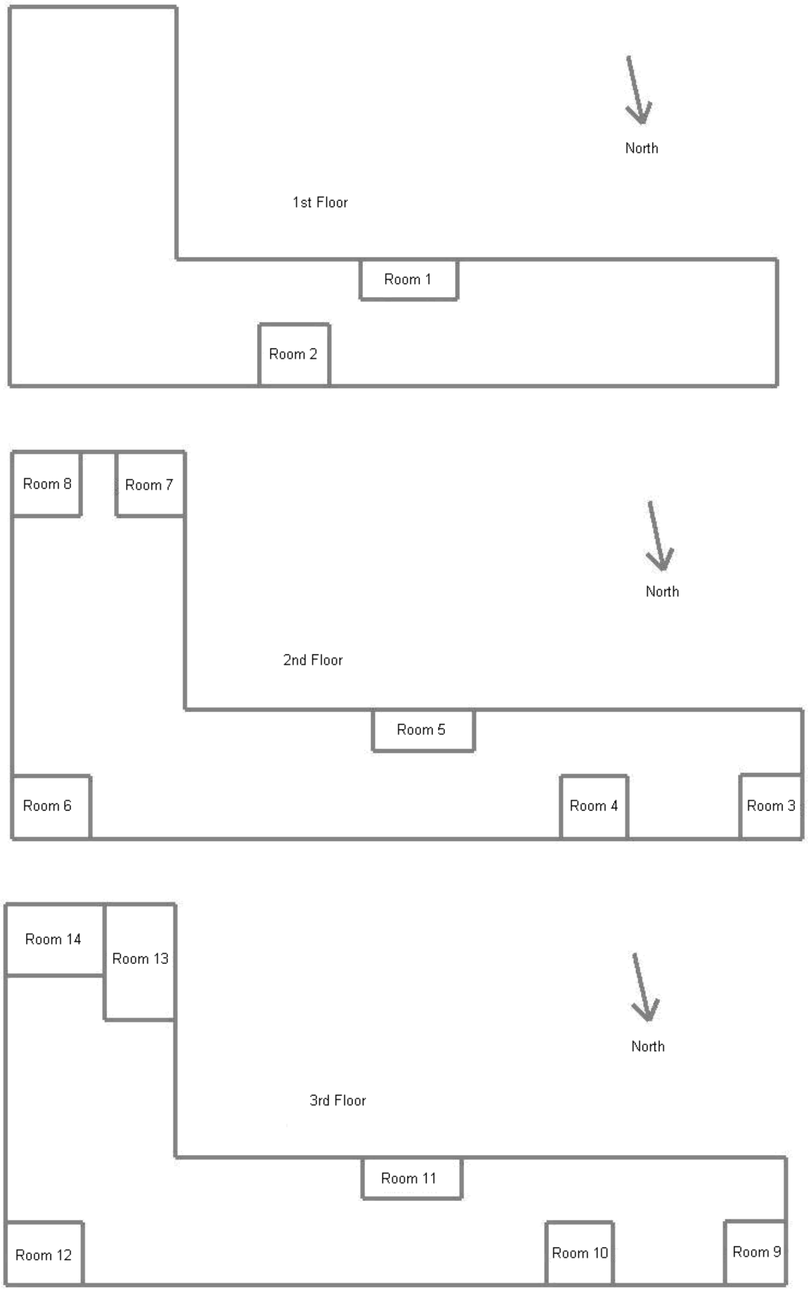


Figure 3.6. Distribution of dataloggers in the Administrative Building.

Figure 3.7. Flowmeter for boiler no:1.

Figure 3.8. One of the power analyzers in the Administrative Building.

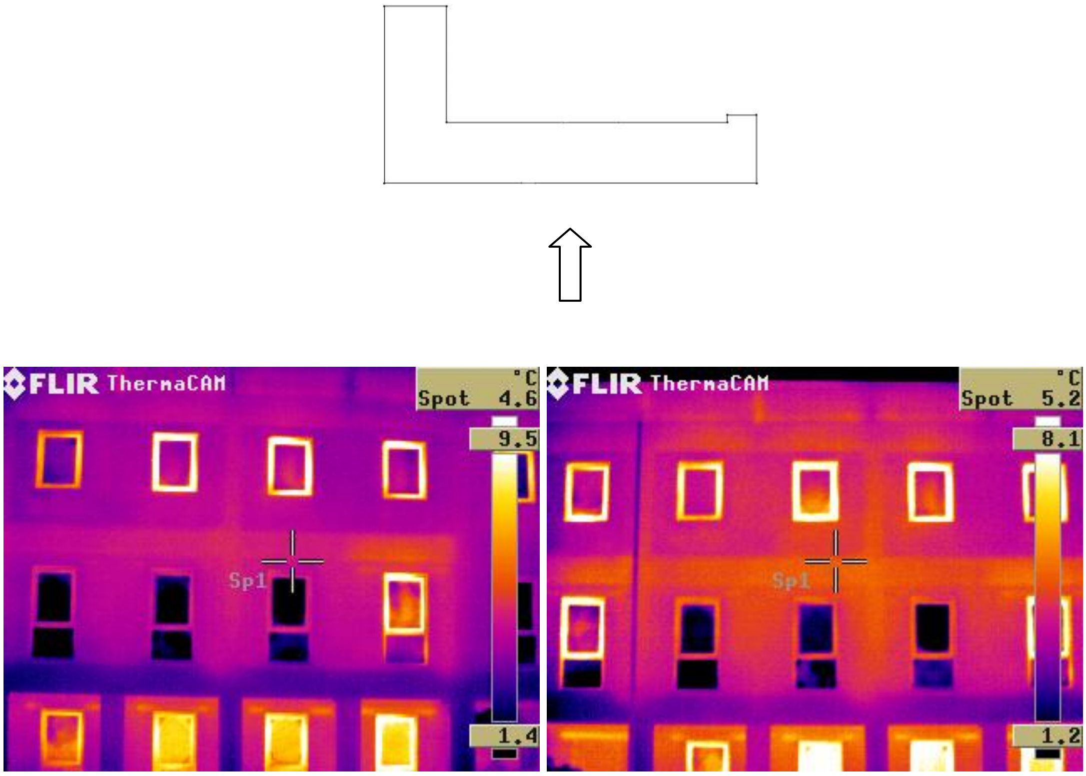
Table 3.6. Properties of measurement devices.

Device	Brand	Measurement range	Sensitivity (%)
Datalogger	Hobo H-08	-20 to 70°C	± 1
Power Analyzer	Case PA-300	0.1 to 999 kWh	± 1.5
Flowmeter	Aquametro VZF 15-RC	10 to 600 L/h	± 1
Thermal camera	Flir Thermocam PM 695	-40 to 2000°C	± 2

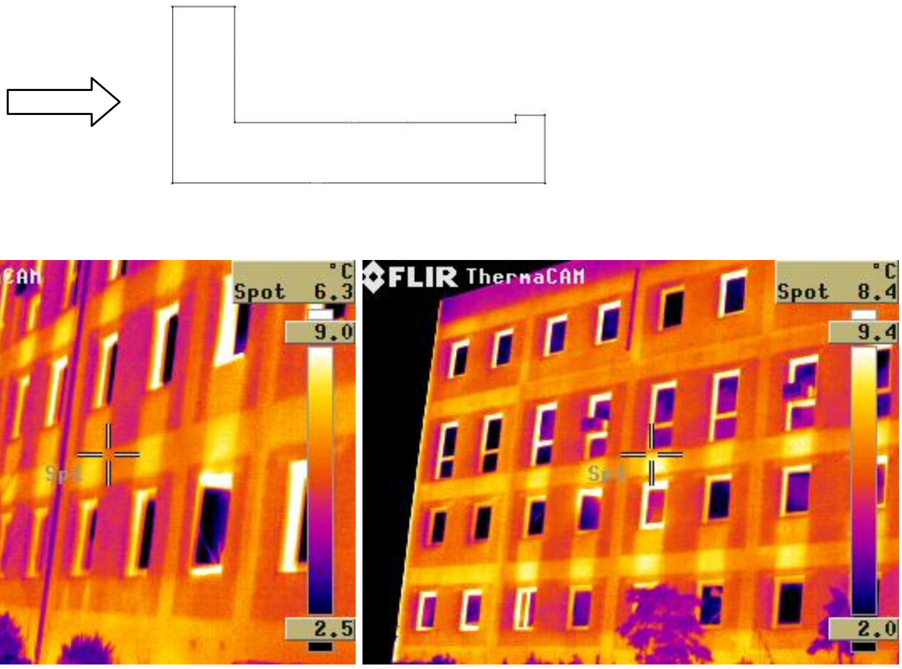
3.4. Thermal Camera Images

Thermal imaging is a qualitative method to get an opinion on heat losses from a building. Figure 3.9 and 3.10 show thermal camera images taken on February 15th, 2006 and December 24th, 2007, respectively. All images indicate that a great proportion of heat loss occurs from window frames. While wall surface temperatures are ranging 1 to 6°C, window frame temperatures are recorded as 8-12°C at an outdoor temperature of 4.6°C, a relative humidity of 40% and a wind speed of 3.5 m/s in February 15, 2006. The reasons of encountering high frame temperatures are aluminum frame material, absence of thermal break in the frame and infiltration. On the other hand, high temperature regions are also observed on beams and columns where thermal bridging effect occurs, and on the wall where fan-coil devices are installed nearby due to lack of insulation.

In December 24, 2007, surface temperature difference between south facade and corner of north & east facade is obvious. Due to longer exposure to solar radiation and sheltered from wind, south facade surface temperature is 7-8°C higher.

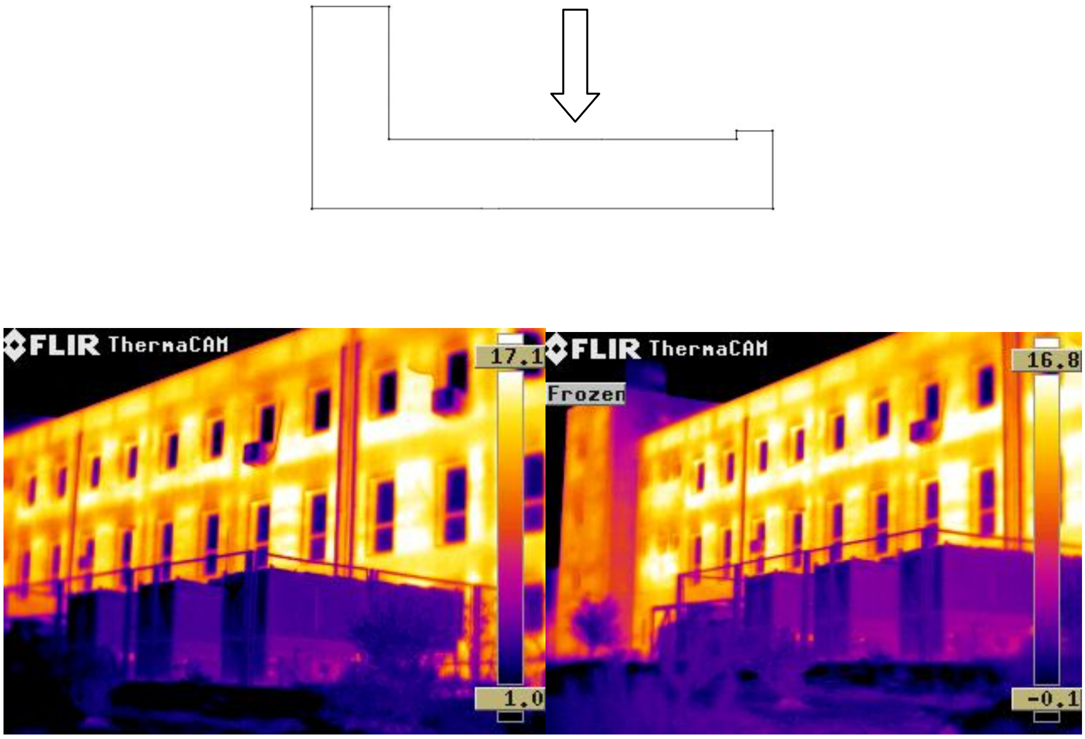


a) North facade

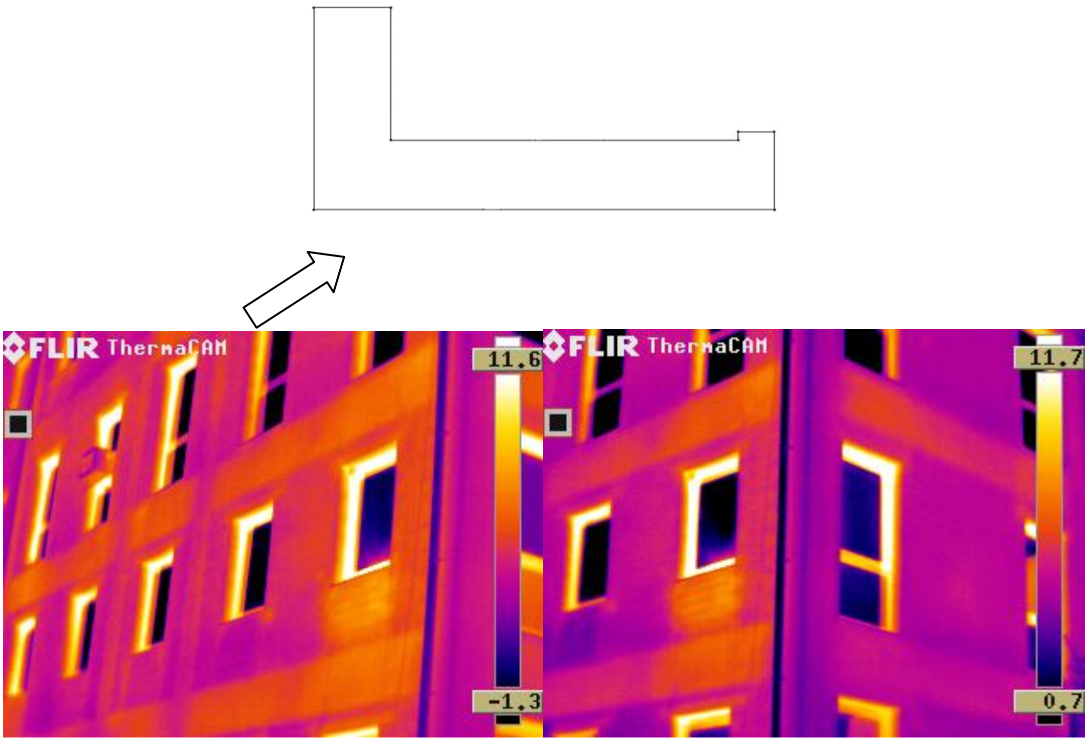


b) East facade

Figure 3.9. Thermal camera images of the Administrative Building (February 15th, 2006).



a) South facade



b) North- East facade corner

Figure 3.10. Thermal camera images of the Administrative Building (December 24^{th}, 2007).

CHAPTER 4

METHODS

Energy consumption of a building is related with physical properties of the building such as characteristics of building envelope, HVAC system and equipment installed in the building, sources of internal heat gain and losses, outdoor and indoor climatic conditions and most importantly operation profile of the HVAC system and behaviour of the occupants in the building.

Calculation of heating and cooling consumptions is an essential task in the design of HVAC systems and evaluation of energy performance of buildings. The complex models and calculation methods revealed to development of many numerical codes which take into account several parameters in static and dynamic conditions. The outcome of numerical codes should be supported or validated by energy consumption measurements.

In this study, TS 825 (static) which is mandatory procedure in Turkey, CIBSE Admittance (simple dynamic) and ASHRAE Heat Balance (full dynamic) methods and corresponding software are selected to evaluate energy performance of the IZTECH Administrative Building. Electricity and fuel consumption, indoor air comfort and outdoor meteorological data are collected for comparison with the simulation results.

4.1. Introduction to Calculation Methods

Energy performance evaluation methods can be classified as seasonal or monthly static method, simple hourly dynamic method (simple dynamic) and detailed hourly dynamic method (full dynamic) according to EN ISO 13790 (2008). In this study, TS 825 (static) which is mandatory procedure in Turkey, CIBSE Admittance (simple dynamic) and ASHARE Heat Balance (full dynamic) methods are chosen.

In static methods, construction material properties which are the base of any thermal modeling, such as U-value, are determined and/or calculated. Results of the static methods give an estimate of monthly heating load and idea about applicable measures to reduce the heat loss of the building.

Dynamic methods can be used for HVAC system sizing, especially for cooling, with the help of simplified tables for dynamic parameters. During past 10 years, dynamic methods have been used for calculation of long period energy consumption by computer implementation. As the popularity of dynamic methods is increasing, new feautures like comfort and lighting calculations are being implemented into them. Dynamic methods calculate gains and losses from different elements in a building, giving details about different zones and their interactions with the building.

4.2. TS 825 Standard

TS 825 “Thermal Insulation Requirements for Buildings” is an official obligatory standard of Turkey derived from DIN V 18599. TS 825 has been in use since 2000 which is revised in 2008 by lowering maximum allowable total heat transfer coefficient. Main purpose of TS 825 is to limit building’s energy demand according to exposed area to volume (A/V) ratio. The code contains useful property tables for various construction materials used in Turkey.

TS 825 uses solar radiation and outdoor air temperature values which are tabulated according to climatic regions (Figure 4.1) specifically determined for Turkey using degree-day method.

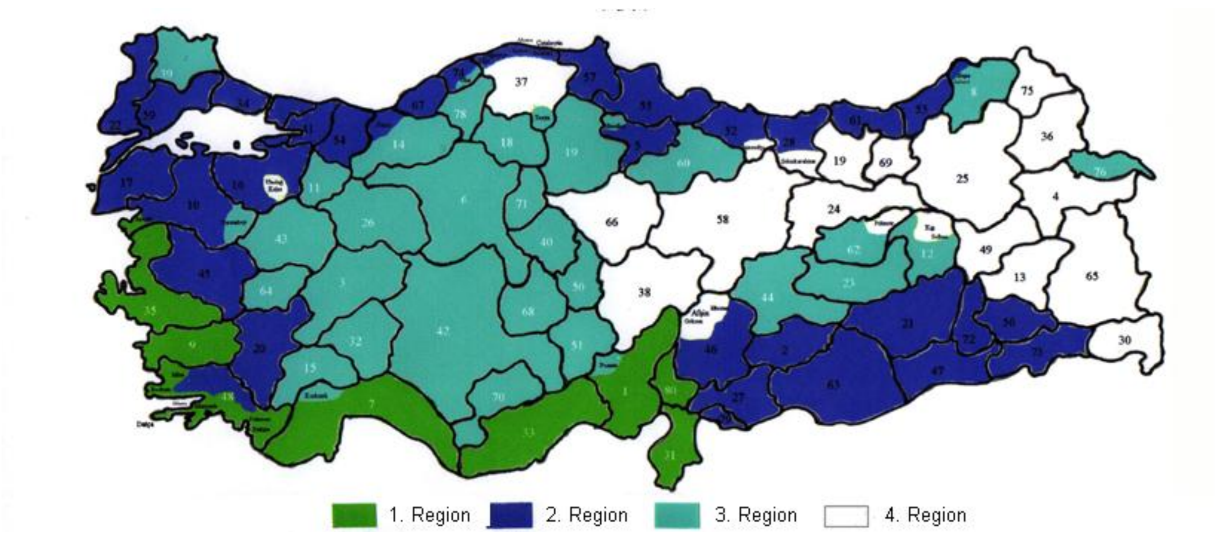


Figure 4.1. Climatic regions of Turkey
(Source: TS 825 2008).

Heat demand is calculated monthly including specific heat loss, efficiency factor, internal and solar gains in Equation 4.1 and 4.2.

$$Q_{year} = \sum Q_m \tag{4.1}$$

$$Q_m = \lfloor H(T_{i,m} - T_{d,m}) - \eta_m(\varphi_{i,m} + \varphi_{g,m}) \rfloor t \tag{4.2}$$

H, building's specific heat loss which is defined as sum of ventilation specific heat loss (H_i) and and conductive specific heat loss (H_h).

$$H = H_i + H_h \tag{4.3}$$

Ventilation specific heat loss due to infiltration is calculated as given in EN ISO 13790 (2008).

$$H_h = 0.33.n_h.V_h \tag{4.4}$$

Air change rate per hour is taken as 1 for all types of buildings while EN ISO 13790 (2008) refers values ranging from 0.5 to 1.3 depending on construction type and exposed surface of the building.

Conductive specific heat loss is the sum of heat loss due to building elements (ΣAU) and thermal bridging effect (IU_L).

$$H_i = \sum AU + IU_L \tag{4.5}$$

Thermal bridging effect is taken into account with length of the element (I) and longitudinal heat loss coefficient (U_L) according to TS EN ISO 14683 (2004).

Specific heat loss due to building elements is given in Equation 4.6 including external walls, windows, floor and roof.

$$\sum AU = U_D A_D + U_P A_P + 0{,}8 U_T A_T + 0{,}5 U_t A_t + U_d A_d \tag{4.6}$$

Overall heat transfer coefficient (U) of building elements is determined by Equation 4.7 where h_i and h_o are indoor and outdoor convective heat transfer coefficients, respectively.

$$U = \frac{1}{h_i + \sum \frac{d}{\lambda} + h_o} \tag{4.7}$$

In TS 825, internal gains are simplified as 5 W/m^2 for net floor area. Monthly solar gains are calculated by Equation 4.8.

$$\varphi_{g,m} = \sum r_{i,m} x g_{i,m} x I_{i,m} x A_i \quad (4.8)$$

$r_{i,ay}$ and $g_{i,ay}$, shading and transmission factors, values is listed in TS 825 and EN ISO 13790 (2008).

Gain utilization factor (η) is used to correct the total of internal and solar gains to calculate average monthly useful gains in a statistical way (Equation 4.9 and 4.10).

$$\eta m = 1 - e^{(1/KKO_m)} \quad (4.9)$$

$$KKO_m = (\varphi_{i,m} + \varphi_{g,m}) / H(T_{i,m} - T_{d,m}) \quad (4.10)$$

Flow diagram of TS 825 calculation procedure is summarized in Figure 4.2.

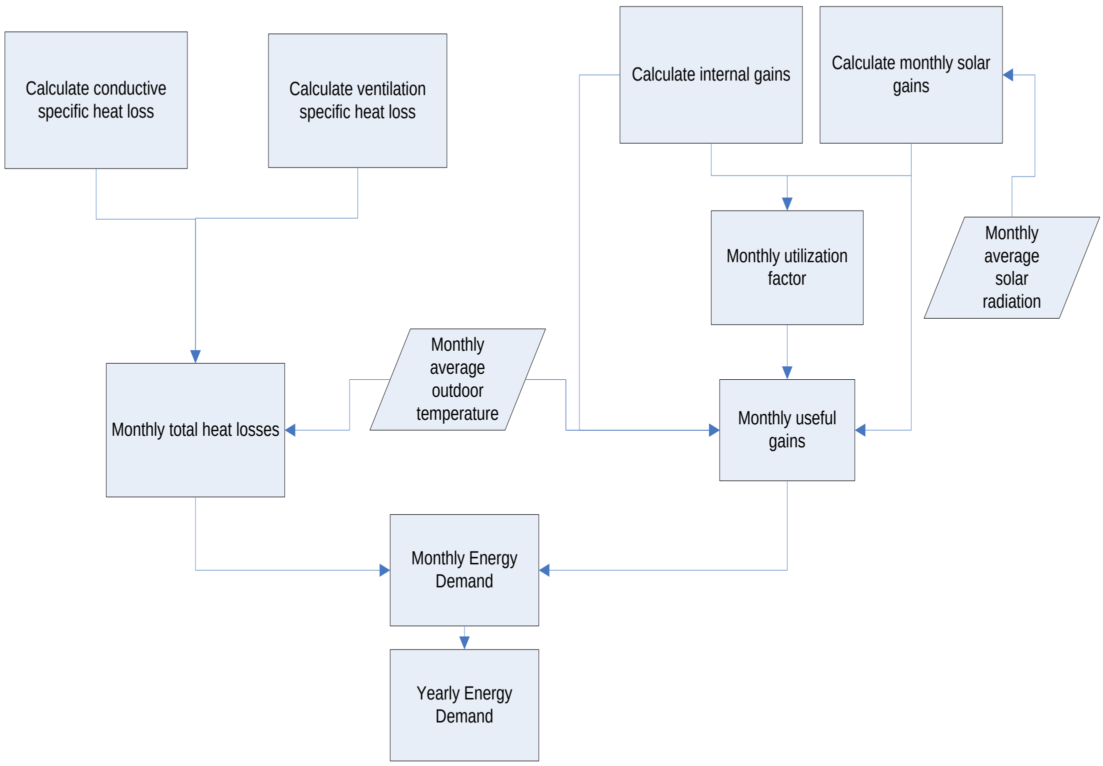


Figure 4.2. Flow diagram of TS 825.

Calculation of yearly heat demand is followed by comparison of limiting values given in TS 825 according to A/V ratio. If the yearly heat demand is within the limits, the procedure is completed; otherwise properties of the building elements should be re-evaluated and re-calculated. Table 4.1 shows recommended values of total heat transfer coefficient (U) for construction elements in TS 825.

Table 4.1. Recommended U values for construction elements (W/m^{2}K).
(Source: TS 825 2008)

Climatic Regions	**U_D (W/m²K)**	**U_T (W/m²K)**	**U_t (W/m²K)**	**U_P (W/m²K)**
1st	0,7	0,45	0,7	2,4
2nd	0,6	0,4	0,6	2,4
3rd	0,5	0,3	0,5	2,4
4th	0,4	0,25	0,45	2,4

TS 825, as a static method, is well established to control overall heat transfer coefficent and limit heating energy demand of a building. However, using monthly average climatic values, single zone assumption, ignoring thermal mass, assuming continiuous heating regime, lack of internal gain details and control of HVAC systems leads inaccurate results compared with measurements.

4.3. CIBSE Admittance Method

CIBSE Admittance Method is a cyclic simple dynamic model presented by Chartered Institution of Building Service Engineers (CIBSE)-England. Cyclic refers to the assumption of all heat flows and loads consist of a daily mean (steady state) and an alternating component which has a period of 24 hour. In admittance method, all parameters associated with thermal storage can be represented by the response to a sinusoidal excitation with a period of 24 hours.

Method covers conductive heat flow through building envelope, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, internal gains from equipments, lighting and occupancy and inter-zonal heat flow.

The underlying idea of the Admittance Method is the internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside climatic conditions or indoor operation profile of equipment and HVAC systems will cause internal air temperature to change in a similar way though delayed and dampened by thermal capacitance of the building envelope. This method has 3 important assumptions:

1- Sol-air temperature (solar radiation effect is added to outside surface temperature for approximate conduction gain/loss calculation),
2- Internal gains are treated as 1/3 convective and 2/3 radiant components.
3- Environmental temperature is defined to calculate combined radiant and convective heat exchange with the room surfaces.

First step of the Admittance Method is steady-state (daily mean) calculation procedure which is summarized in Figure 4.3 as a resistance scheme (Rees et al. 2000).

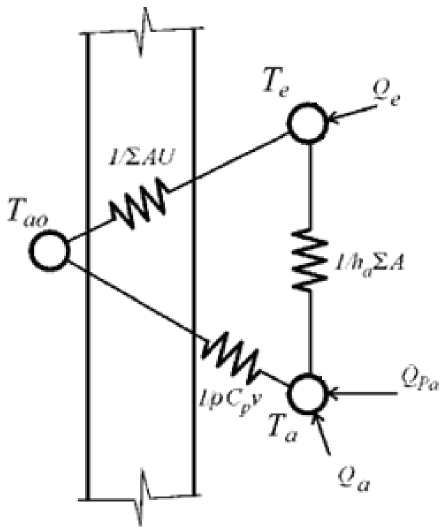


Figure 4.3. Resistance diagram of CIBSE Admittance Method for mean components (Source: Rees et al. 2000).

Heat balance equation of resistance diagram in Figure 2.3 is given in Equation 4.11. Resistance scheme is simplified by introducing F_{au}, room factor in Equation 4.12 (Rees et al. 2000).

$$Q_a + Q_{Pa} + F_{au}Q_e = \{c_p \rho \upsilon + F_{au}\Sigma AU\}(T_a - T_{ao}) \tag{4.11}$$

$$F_{au} = \frac{h_a \Sigma A}{h_a \Sigma A + \Sigma AU} \tag{4.12}$$

Q_a and Q_e are the sum of each individual gains for air and environmental node respectively. They consist of internal and solar gain as given in Equation 4.13.

$$Q_{a,e} = Q_S + Q_c \tag{4.13}$$

Solar heat gain is derived from Equation 4.14. Glazing area is obtained from building plan and mean solar intensity is obtained from meteorological data. However, solar gain factor depends on glazing and glass type of the windows frame, also changing for environmental and air node. Solar gain factors are given in Table 5.7 in CIBSE Guide A, Environmental Design (CIBSE Guide 2004).

$$Q_S = S.I.A_g \tag{4.14}$$

Q_c, mean internal gain is calculated according to Equation 4.15, which is simply daily average of gains distributed among 24 hours.

$$Q_c = \frac{\sum(\phi_{in} t_{in})}{24} \tag{4.15}$$

After Q_c is calculated, it is distributed among air and environmental node as 1/3 and 2/3, respectively.

Q_{Pa}, plant load, can be extracted easily from Equation 4.11 after all unknown terms of gains and losses are calculated. Thus steady state (mean) calculation step is completed.

Figure 4.4 is the resistance scheme of the second part of CIBSE Admittance Method, which is fluctuating (hourly) calculation step. Hourly fluctuating components and heat balance diagram for second step is given in Equation 4.16 (Rees et al. 2000).

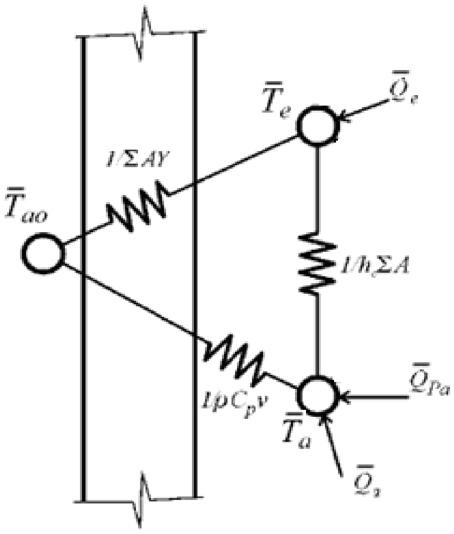


Figure 4.4. Resistance diagram of CIBSE Admittance Method for fluctuating components. (Source: Rees et al. 2000).

$$\overline{Q_a} + \overline{Q_{Pa}} + \overline{F_{ay}}\overline{Q_e} = \{c_p \rho \upsilon + F_{ay}\Sigma AY\}(\overline{T_a} - \overline{T_{ao}}) \qquad (4.16)$$

Equation 4.16 is quite similar to the steady state calculation part of CIBSE Admittance Method except Y (Admittance) is introduced instead of overall heat transfer coefficient "U", replacing indoor-outdoor temperature and gains.

$\overline{Q_S}$ and $\overline{Q_c}$, internal and solar gains for environmental and air node fluctuates as time dependant heat sources and solar intensity as in Equation 4.17 and 4.18.

$$\overline{Q_S} = S.(I - \overline{I}).A_g \tag{4.17}$$

$$\overline{Q_c} = \frac{\sum(\phi_{in} t_{in})}{24} - \sum\overline{\phi_{in}} \tag{4.18}$$

Admittance value (Y) is the rate of heat flow between internal surfaces of the building element and the environmental node which is quite similar to overall heat transfer coefficient (U). However, admittance is a dynamic parameter related with the heat capacity, decrement factor (f) and surface factor (F).

Decrement factor (f) is the ratio of the rate of heat flow through building element due to variations of external temperature, to the steady state conduction. As thermal capacity of a building element increases, decrement factor decreases due to time lag caused by high thermal capacity.

Surface factor (F) is the ratio of the variation of radiant heat flow re-admitted to the space from the surface, to the variation of heat flow value incident upon the surface. Radiant heat flow represents gains from the sun. Definition of surface factor can be simplified as the penetration ratio of the solar gain into the building element. The amplitude of the surface factor decreases with increasing thermal conductivity.

Detailed information on admittance, decrement factor and surface factor is found in CIBSE Guide A, Environmental Design (CIBSE Guide 2004).

Equation 4.11 and 4.16 can be solved individually with only unknowns are Q_{Pa} and $\overline{Q_{Pa}}$. After daily mean plant load (Q_{Pa}) and fluctuation in plant load for an hour ($\overline{Q_{Pa}}$) are found, net hourly plant load (Q_h) is the sum of mean and alternating loads as in Equation 4.19.

$$Q_h = Q_{Pa} + \overline{Q_{Pa}} \tag{4.19}$$

Figure 4.5 is the flow diagram of CIBSE Admittance Method summarizing the steps of the calculation process.

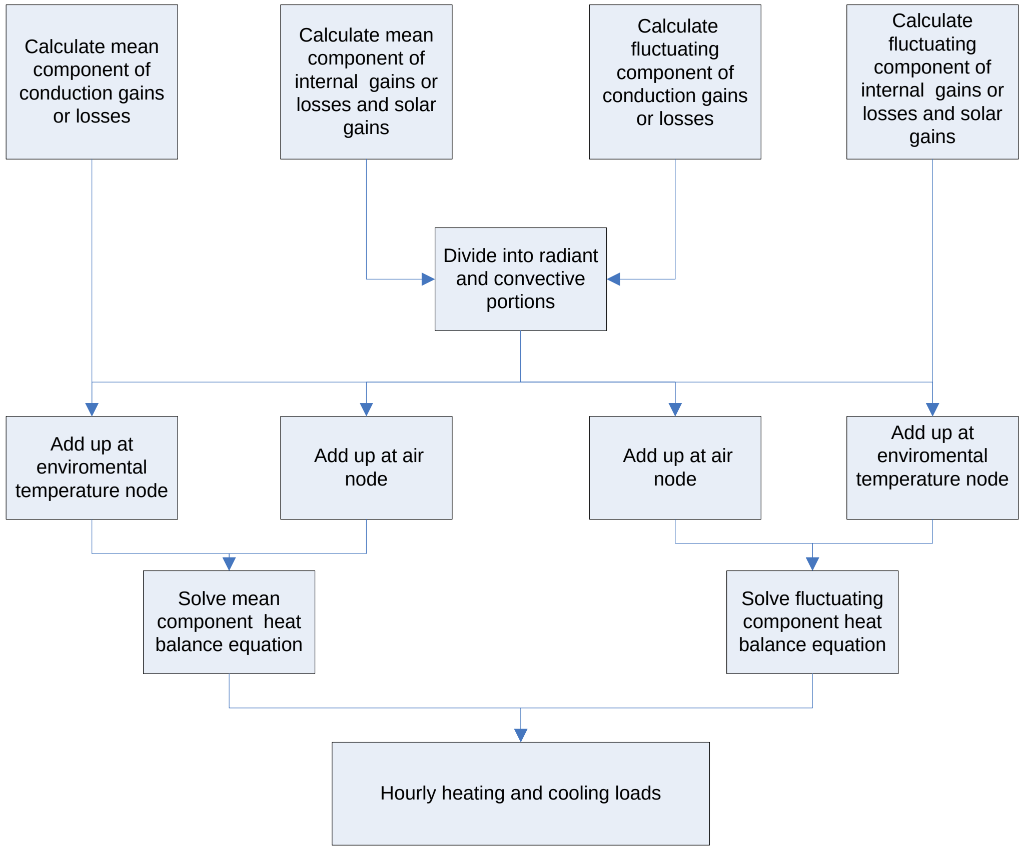


Figure 4.5. Flow diagram of CIBSE Admittance Method.

As seen in the figure, procedure is split into two steps, daily mean and hourly fluctuating components to ease dealing with dynamic parameters. Admittance Method is free from iterative processes hence easy to calculate.

On the other hand, method cannot handle sudden changes in temperature and solar gains because every hourly calculation includes corresponding daily mean values. Solar radiation is not tracked on individual surfaces; it is merged in environmental node assumption. Natural ventilation is not calculated by stack effect or bulb air flow rates; user defined leakages and air change rates are used. Besides operation of HVAC system is neglected. Distribution of internal gains to 1/3 convective and 2/3 radiant components lead over-estimation in cooling and under-estimation in heating loads.

4.4. ASHRAE Heat Balance Method

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)-The USA, Heat Balance Method (1996) is a result of "Advanced Methods for Calculating Peak Cooling Loads" research project, covering all research efforts of ASHRAE since 1948. It is the first method to rely completely on computer implementation. Introduction of Heat Balance Method marks a crossover of technology from energy analysis load calculation methods to design day calculation methods.

ASHRAE Heat Balance Method offers closest approximation to physical conditions by forming four heat balance equations for outside surface, wall capacitance, inside surface and zone air nodes. Nodal representation of this method can be seen in Figure 4.6.

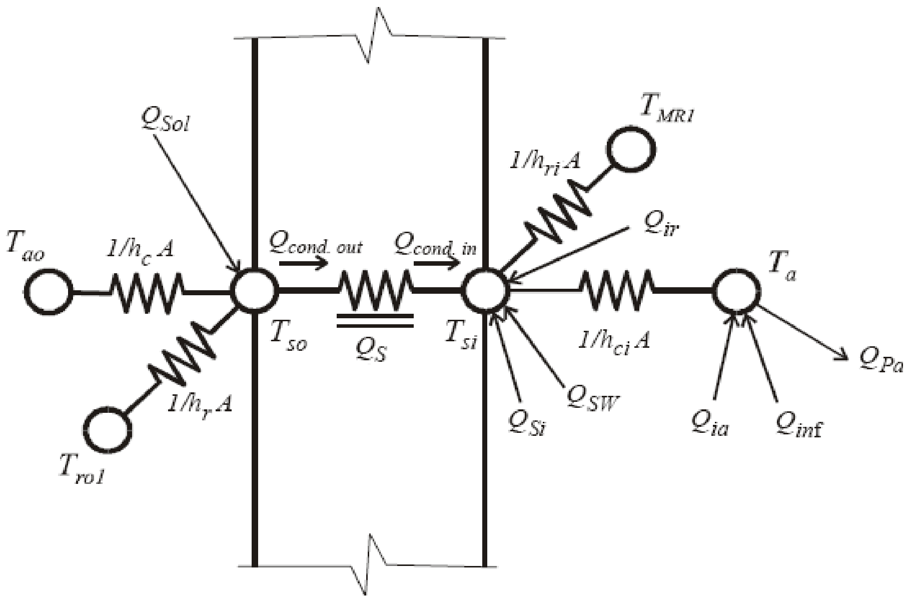


Figure 4.6. Nodal representation of ASHRAE Heat Balance Method (Source: Rees et al. 2000).

Exterior surface heat balance is formed in Equation 4.20, including solar gains into the wall and glazing, long-wave radiation and convective load.

$$Q_{SOL} + Q_{olW} + Q_{co} - Q_{cond,out} = 0 \tag{4.20}$$

Equation 4.21 is the inside wall heat balance. Energy stored in the wall is represented as a capacitance.

$$Q_{cond,out} - Q_S - Q_{cond,in} = 0 \tag{4.21}$$

At the interior surface, the conduction out of the wall is balanced by convection to the room air, radiant exchange with the other surfaces, radiant fluxes from internal sources including lightning and retransmitted fluxes through the glazing (Equation 4.22).

$$Q_{Si} + Q_{Ir} + Q_{sw} + Q_{ILW} + Q_{ci} + Q_{cond,in} = 0 \tag{4.22}$$

Total convection from inside zone surfaces, interior convective load, infiltration load and plant load is balanced in Equation 4.23.

$$Q_{ci} + Q_{ia} + Q_{\inf} + Q_{Pa} = 0 \tag{4.23}$$

Conduction loads in Heat Balance Method is solved by conduction transfer functions (CTF) which is given in Equation 4.24.

$$q_i^{''}(t) = -Z_0 T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\sigma} + Y_0 T_{0,t} + \sum_{j=1}^{nz} Y_j T_{0,t-j\sigma} + \sum_{j=1}^{nq} \Phi_j q^{''}_{i-j\sigma} \tag{4.24}$$

This equation states that heat flux at either face of the surface of any building element is linearly related to the current and some of the previous temperatures at both interior and exterior surface as well as some of the previous flux values at the interior surface.

There are two methods to solve CTF (conduction transfer functions); first one is state space method and second one is using Laplace transform as used in BLAST simulation software. More information about solution of CTFs can be found in EnergyPlus Engineering Reference (EnergyPlus 2008).

Convection from surfaces is calculated by Equation 4.25 while heat transfer coefficient is modeled from a choice of correlations depending on wind speed, heat conduction coefficient and position of the surface.

$$q_c = \sum_{i=1}^{nsurfaces} h_{c,i} A_i (T_a - T_{s,i}) \tag{4.25}$$

Solar, radiative and internal gains are evaluated with hourly complex algorithms considering shading and reflecting elements, scheduling effect, occupancy and operation profile of HVAC system and equipment. Detailed information can be found in EnergyPlus Engineering Reference (EnergyPlus 2008).

Equations formed for ASHRAE Heat Balance Method (Equation 4.20-23) are coupled with conduction and convection terms, therefore the set of equations have to be solved simultaneously. Detailed hourly procedure and simultaneous solution process requires computer aid for this method. Flowchart of ASHRAE Heat Balance Method is shown in Figure 4.7.

As a result, ASHRAE Heat Balance Method takes an approach that is least abstracted from physical zone heat transfer surfaces by modeling each heat flux and gain explicitly for each hour.

4.5. Comparing Calculation Methods and Simulation Software

In this section, software used to perform methodologies mentioned in previous sections and their importance in energy performance evaluation are described briefly.

IZODER software, containing TS 825 calculation method is applied to the IZTECH Administrative Building prior to other methods for its simplicity and to have valuable information about building envelope which will be needed for future steps of energy performance evaluation. Result of IZODER software is the annual heating demand of the building.

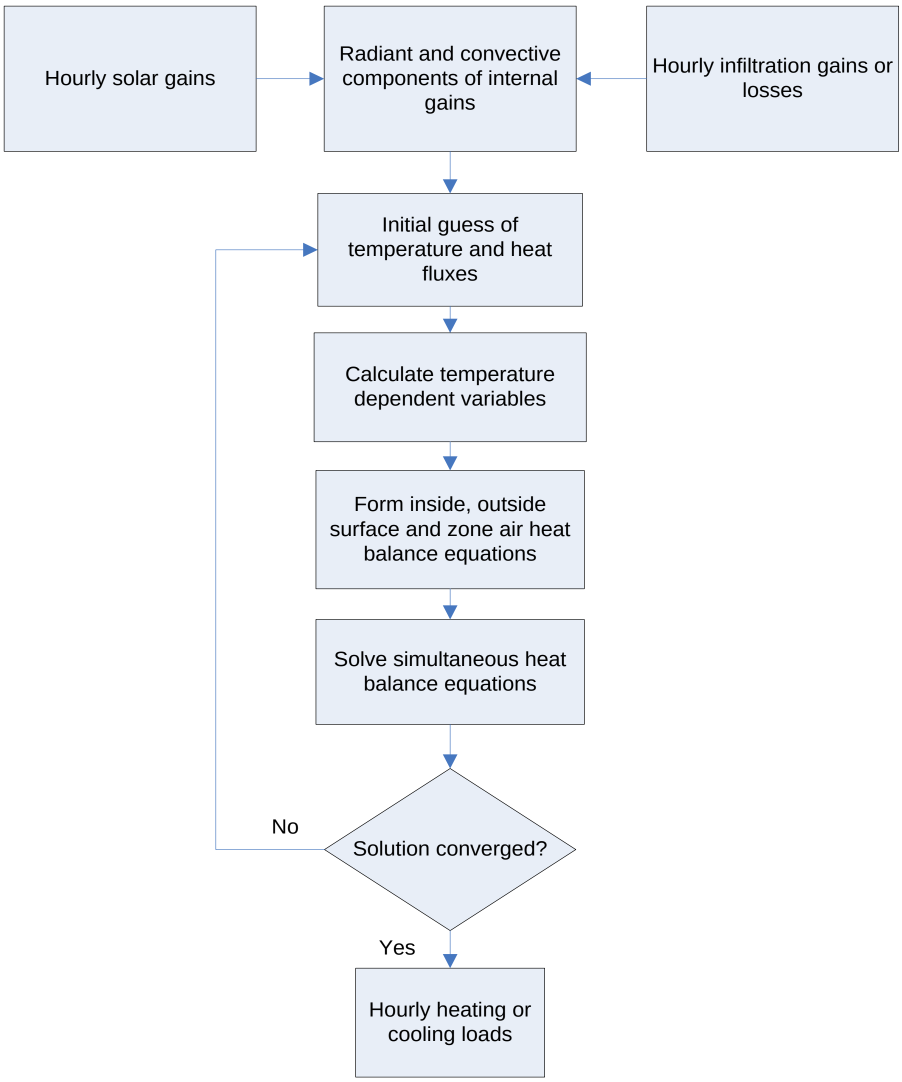


Figure 4.7. Flowchart of ASHRAE Heat Balance Method.

Ecotect is a useful tool to model the building, widely used by architects. It contains thermal modeling of CIBSE Admittance method and powerful weather data application embedded in software. In this step of the study, building is modeled easily with the help of the software, material properties are adopted from the IZODER software and climatic data is converged with WeatherTool to be able to use in Ecotect. Result of the CIBSE Admittance method is hourly heating or cooling load detailed with the division of conduction and ventilation load, zonal gains and interzonal heat flows for any chosen zone or temperature profiles for any given zone and time.

EnergyPlus is a detailed building energy simulation software supported by Department of Energy, USA, using ASHRAE Heat Balance Method. EnergyPlus software is not a whole solution from the design stage to graphical and customizable results. It is a compiler which contains solution algorithm, gathering input data from specially prepared text files and showing results as text file outputs. Preparing input files and arranging results in a sensible manner for a detailed building are complex. Therefore, a software containing EnergyPlus code with interfaces capable of modeling the building is used. In this study, DesignBuilder user interface is used for ASHRAE Heat Balance Method with EnergyPlus. Results of EnergyPlus are hourly energy consumption from all sources of building, comfort data, indoor and outdoor air conditions.

Table 4.2 summarizes capabilities of the software and consequently the calculation methods.

Table 4.2. Calculation methods, software and their capabilities.
(Source: Crawley et al. 2008).

Method	**TS 825**	**CIBSE Admittance Method**	**ASHRAE Heat Balance**
Software	**IZODER**	**Ecotect**	**EnergyPlus**
Time step	Monthly	Daily and hourly	Hourly
Zoning	Single-zone	Multi-zone	Multi-zone
Heating regime	Continuous	Intermittent or continuous	Intermittent or continuous
Heating set point temperature	19 °C	Optional	Optional
Cooling calculation	Not included	Simple dynamic	Detailed dynamic
Internal gains	Monthly average	Daily + hourly values	Hourly
Outside conditions	Average monthly values of the climatic zones	Local meteorological data can be implemented	Local meteorological data can be implemented
HVAC equipment	Not included	Only efficiency of equipment is included	Heating type (radiant, convective or both), pump and fan consumptions are included.
Thermal mass	Not included	Included	Included
Thermal bridging	Included	Not included	Included
Surface temperatures	Not included	Average surface temperature	Each surface treated differently
Natural ventilation and infiltration	User defined air change rate	User defined air change rate	Natural ventilation can be calculated from buoyancy and pressure difference
Mechanic ventilation	Included	Not included	Included

CHAPTER 5

RESULTS AND DISCUSSION

In this section, energy consumption of the Administrative Building is simulated by three different methods and corresponding software between 2006 and 2008 that different heating regimes have been adopted each year. Furthermore; assumptions, input data and meteorological data used by simulation software are explained. Performance improvement measures are proposed and results are discussed.

5.1. Measurements

In this study, measurements are grouped into three sections; local meteorological, energy consumption and comfort data. Each section is detailed below.

5.1.1. Meteorological Data

Outdoor air temperature and wind speed are the most significant parameters effecting heating-cooling loads of a building. Meteorological data including temperature, relative humidity, wind speed and direction, solar radiation, precipitation, etc. for the Campus have been recorded since 2005. Monthly average outdoor temperature and wind speed data are compiled from IZTECH Meteorological Station is given in Figure 5.1 for 2006-2008. As seen from the figure, wind speed fluctuates between 2.5 and 6.1 m/s which increases outdoor convective heat transfer coefficient and consequently the heat loss.

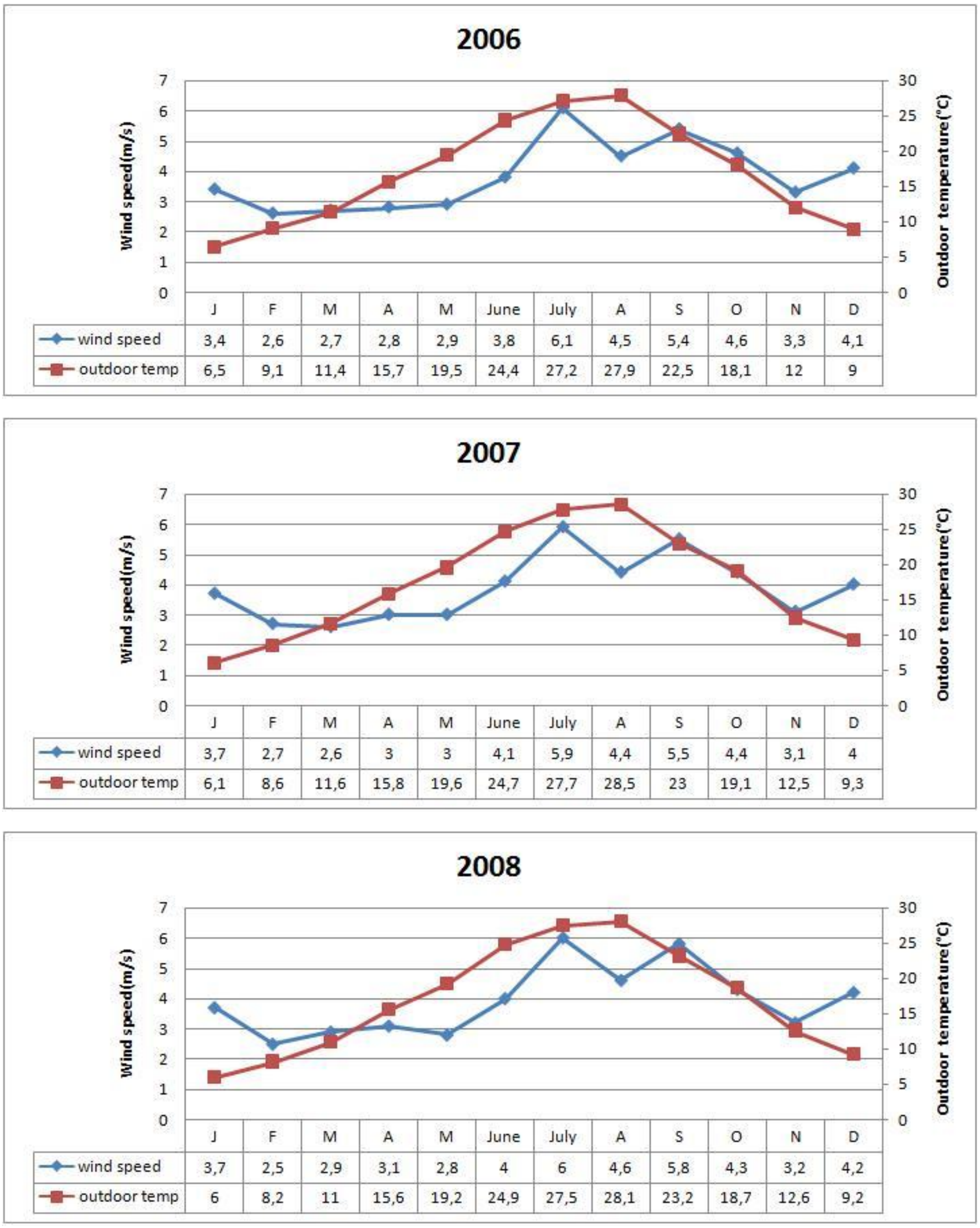


Figure 5.1. Meteorological data taken from IZTECH Weather Station (2006-2008).

5.1.2. Energy Consumption Data

Electricity and fuel consumptions of the IZTECH Administrative Building is measured by three power analyzers and two fuel flowmeters as mentioned in Section 3.3. Table 5.1-5.3 shows electricity consumption data of lighting and equipment (Q_E), boilers and pumps (Q_B), chillers (Q_C), and fuel(Q_F) consumption between 2006 and 2008.

Table 5.1. Energy consumption of the Administrative building in 2006.

	Lighting+equipment	**Boilers&pumps**	**Chillers**	**Fuel**
	Q_E (kWh)	**Q_B (kWh)**	**Q_C (kWh)**	**Q_F (kWh)**
January	20200±303	1260±19		74738±747
February	20400±306	1110±17		67417±674
March	19200±288	470±7		28109±281
April	19600±294	250±4		13019±130
May	23600±254	10±0.15	200±3	
June	21200±318		17100±257	
July	22000±330		17900±269	
August	21200±318		34200±513	
September	15200±228			
October	13800±207			
November	16000±240	240±4		16637±166
December	15100±227	870±13		53500±535
Total	**227500±3413**	**4210±63**	**69400±1041**	**253420±2534**

Table 5.2. Energy consumption of the Administrative building in 2007.

	Lighting+equipment	**Boilers&pumps**	**Chillers**	**Fuel**
	Q_E (kWh)	**Q_B (kWh)**	**Q_C (kWh)**	**Q_F (kWh)**
January	21400±321	1290±19		44315±443
February	17000±255	1110±17		43131±431
March	13800±207	1310±20		42256±423
April	12600±189	160±2		4768±48
May	16200±243			
June	19400±291		18000±270	
July	17600±264		44200±663	
August	22200±333		39200±588	
September	15800±237		8400±126	
October	9600±144			
November	16900±254	510±8		17931±18
December	16600±249	1880±28		65254±653
Total	**201200±3018**	**6260±94**	**109800±1647**	**217655±2177**

Even though total energy consumption of the building increases by year, the portion for lighting and equipment decreases because of the improved heating regime of the building. The electricity consumption of chillers is increased in 2007 due to higher temperatures are encountered in summer comparing with the other years. Boiler and pumps consumed more electricity in 2007 and 2008 due to continuous heating regime. Fuel consumption increase in 2008 as a result of change in the heating regime.

Table 5.3. Energy consumption of the Administrative building in 2008.

	Lighting+equipment	**Boilers&pumps**	**Chillers**	**Fuel**
	Q_E (kWh)	**Q_B (kWh)**	**Q_C (kWh)**	**Q_F (kWh)**
January	16600±249	2260±34		80490±805
February	16400±246	2140±32		79185±792
March	14200±213	1140±17		41659±417
April	14600±219	260±4		9131±91
May	15400±231			
June	13000±195		12600±189	
July	10800±162		26000±390	
August	16800±252		26600±399	
September	12200±183		3000±45	
October	12600±189			
November	13400±201	220±3		8428±84
December	14800±222	1660±25		61590±616
Total	**170800±2562**	**7680±115**	**68200±1023**	**280483±2805**

5.1.3. Comfort Data

Temperature and relative humidity data are collected from 14 spaces during 2006-2008. Figure 5.2 and Figure 5.3 show the average indoor temperatures of the building by floors and directions. 3rd floor is colder in winter and hotter in summer due to gains and losses from the roof. Also south and east side of the building is generally hotter than north side because of higher solar gains.

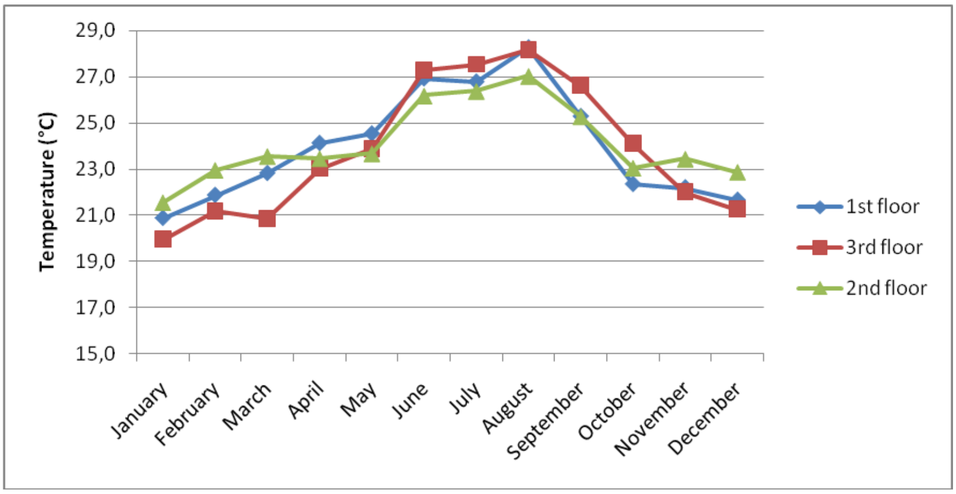


Figure 5.2. Three years average temperatures of the floors (2006-2008).

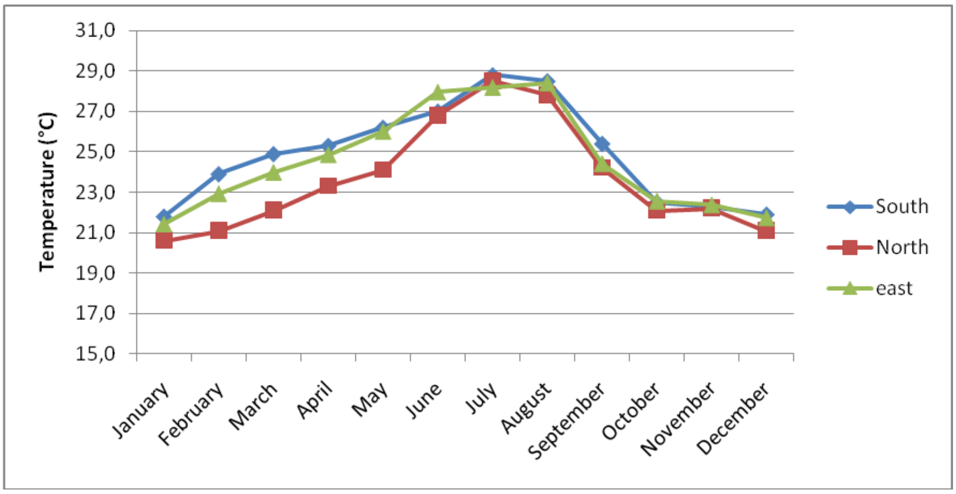


Figure 5.3. Monthly average temperatures of the directions between 2006 and 2008.

Comfort charts including indoor air temperature and relative humidity data are drawn for winter and summer periods to identify indoor comfort conditions in a detailed way. Data shown on Figure 5.4-5.10 are monthly averages of 1st, 2nd and 3rd floors of the Administrative Building.

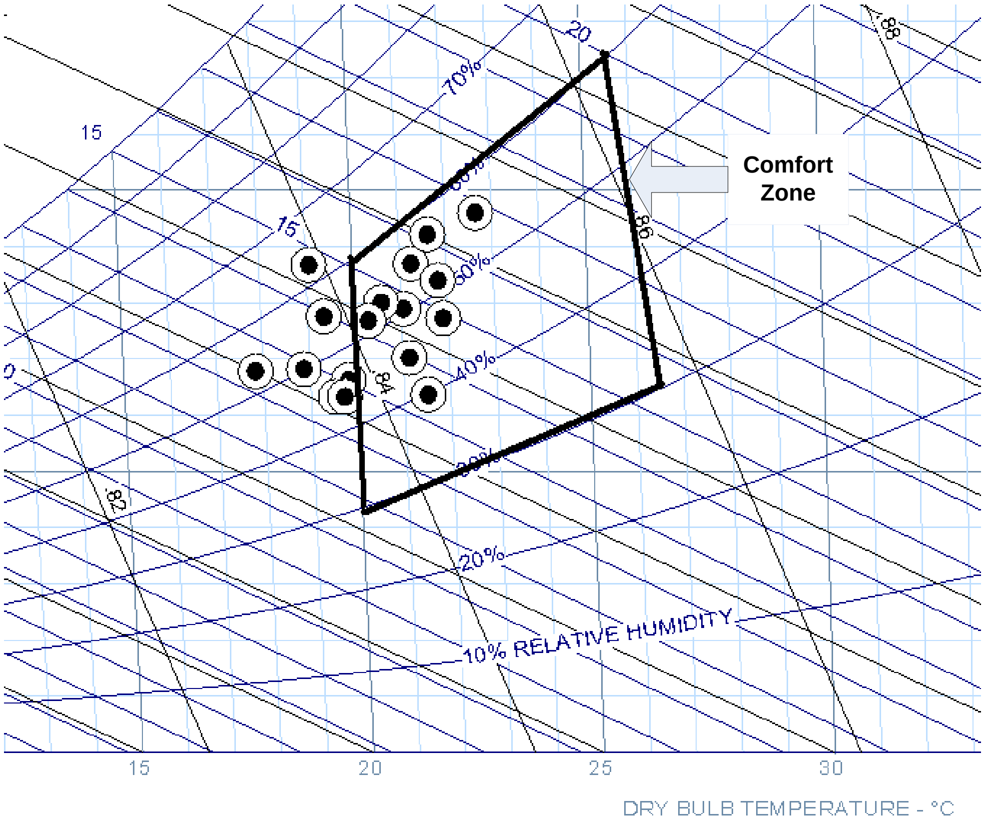


Figure 5.4. Comfort chart for 2006 winter.

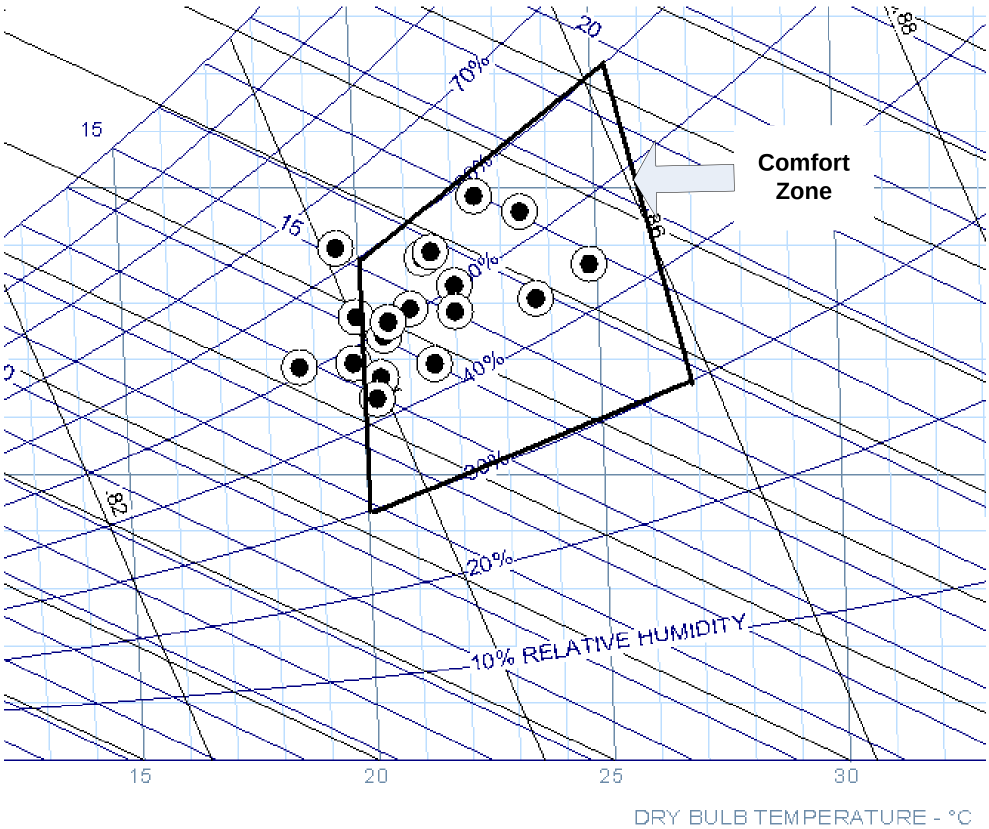


Figure 5.5. Comfort chart for 2007 winter.

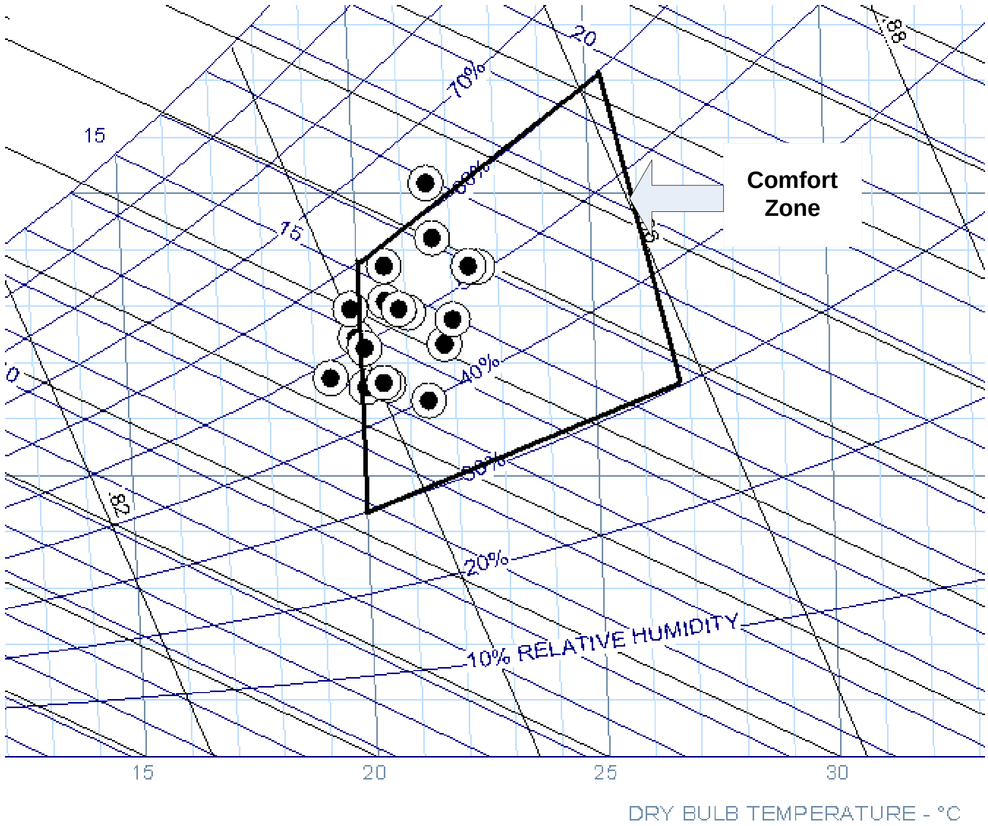


Figure 5.6. Comfort chart for 2008 winter.

Figure 5.4-5.6 are the comfort charts of the Administrative building for the winter season. From 2006 to 2008, the data are tending to move into comfort zone. 39% of the data are out of comfort zone in 2006 while this ratio decreases to 22% in 2007 and 17% in 2008. It is observed that there are still discomfortabilities in 2008 even with continuous heating regime.

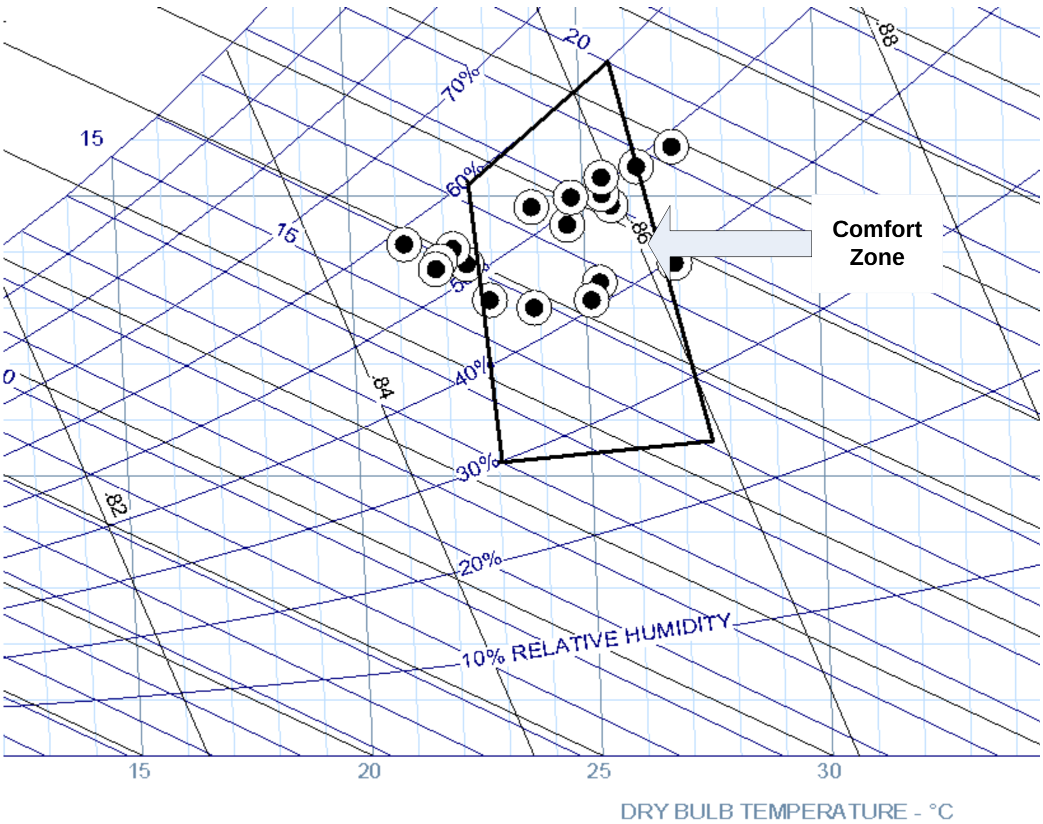


Figure 5.7. Comfort chart for 2006 summer.

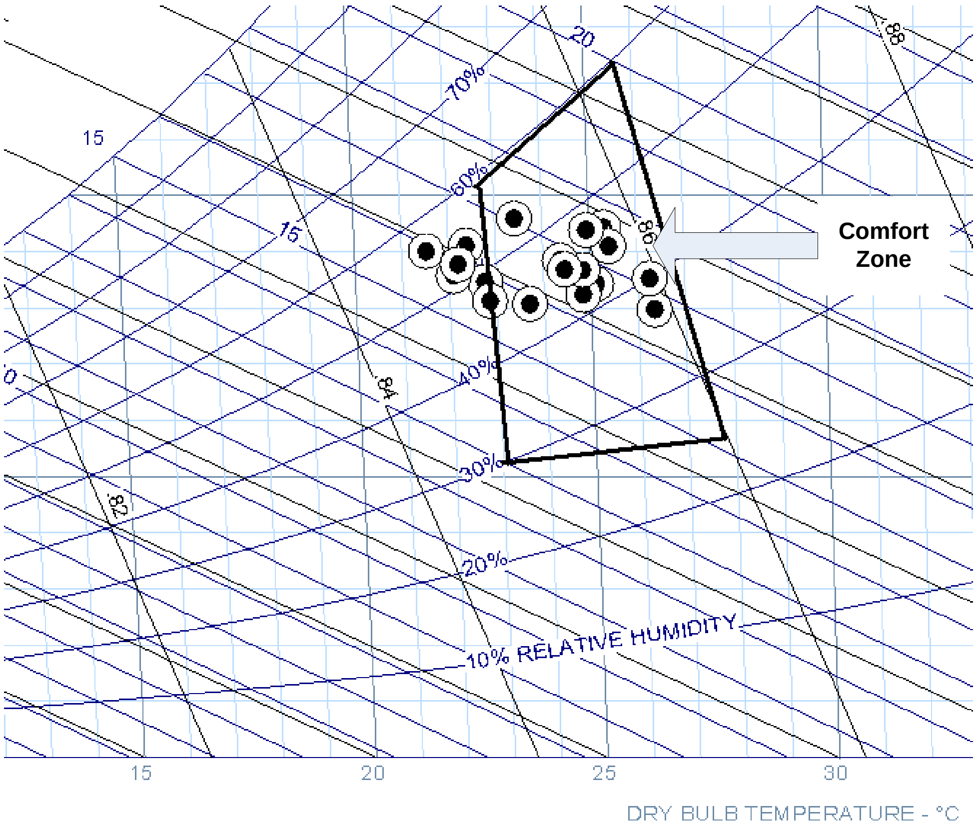


Figure 5.8. Comfort chart for 2007 summer.

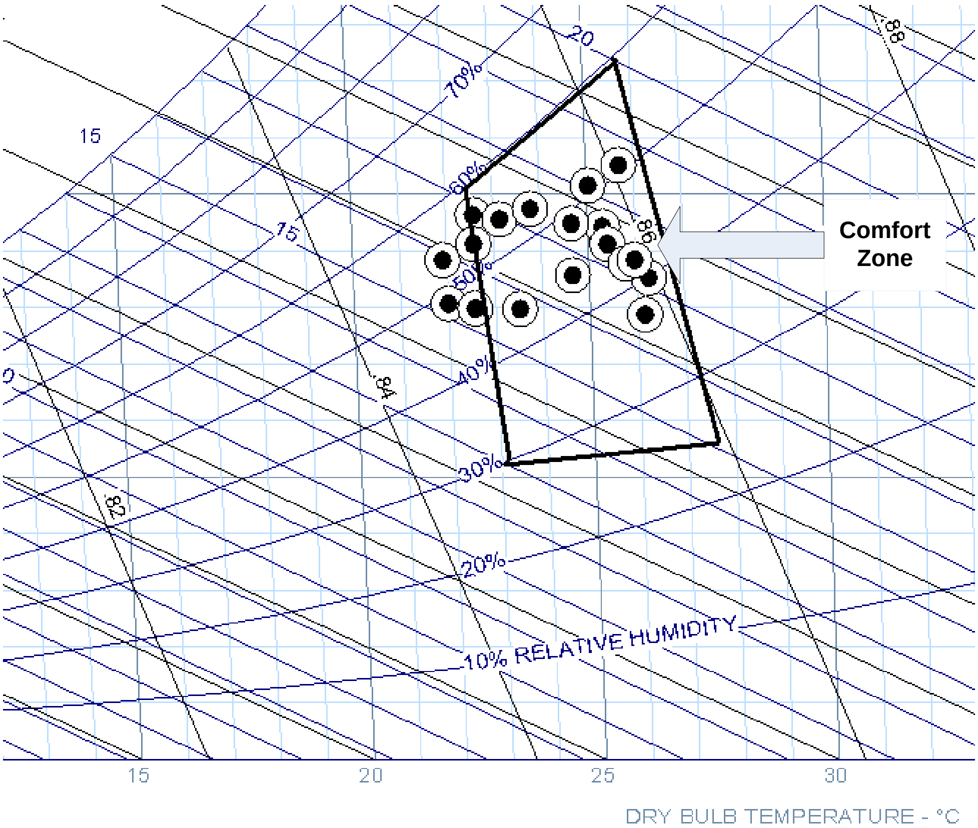


Figure 5.9. Comfort chart for 2008 summer.

Figure 5.7 to 5.9 exhibit the comfort charts for summer 2006-2008. Similar to the improvement encountered in winter season, comfort in summer season is also improved by years. In 2006, 27% of the data are out of comfort zone while this ratio is 22% in 2007 and 17% in 2008. Depending on improvement of comfort in 2007, electricity consumption of chillers increased by 57% (Table 5.2).

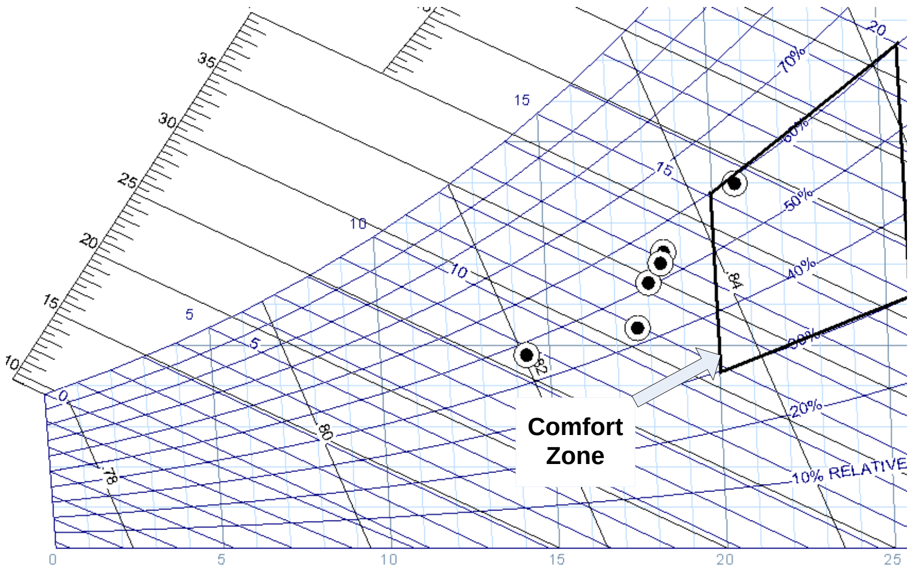


Figure 5.10. Comfort chart of Room 9 (2006 winter).

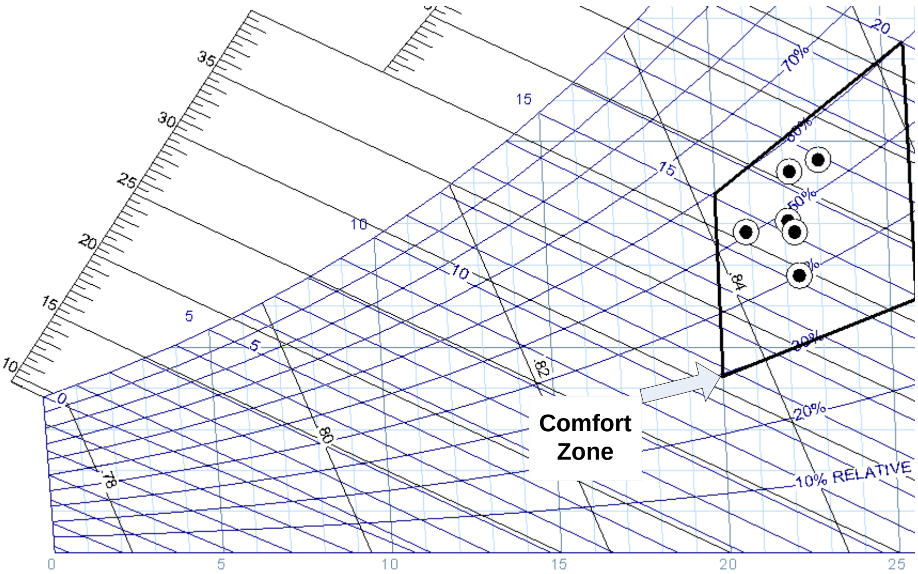


Figure 5.11. Comfort chart of Room 1 (2006 winter).

Figure 5.10 and 5.11 are good examples of difference in comfort of the building in 2006. Room 9, located on the 3rd floor at intersection of north and west, used as a class and often heated during class hours, is out of comfort region during winter. However Room 1, located at south and used by administrative staff fulfills comfort requirements in winter.

5.2. Simulations

In this section, assumptions used in simulations are given with a data set denoting the differences between methods. After the input data is clearly determined, results of the consumption and comfort simulations are given.

5.2.1. Assumptions

The assumptions are made for the simulations referring either measurements or EN and ASHRAE standards.

1. Internal gain caused by office equipment is taken as 15 W/m^2 from the measurements which is also valid for EN ISO 13791 (2007) and ASHRAE 55 (2000).
2. Heated zones in the building are treated as office rooms and according to ASHRAE 55 (2000) and EN ISO 13789 (2007), metabolic gains are 70 W/person, clo value is 1 for heating and 0.5 for cooling season, occupation density is calculated as 0.11 $person/m^2$ based on data collected from department secretaries.
3. Lighting load is assumed $15W/m^2$ when activated with target illuminance of 300 lux for office spaces.
4. Occupancy schedule and operation time is applied to infiltration, internal gains, metabolic gains and heating regime which are adopted from EN 15232 (2007) and shown in Figure 5.12.

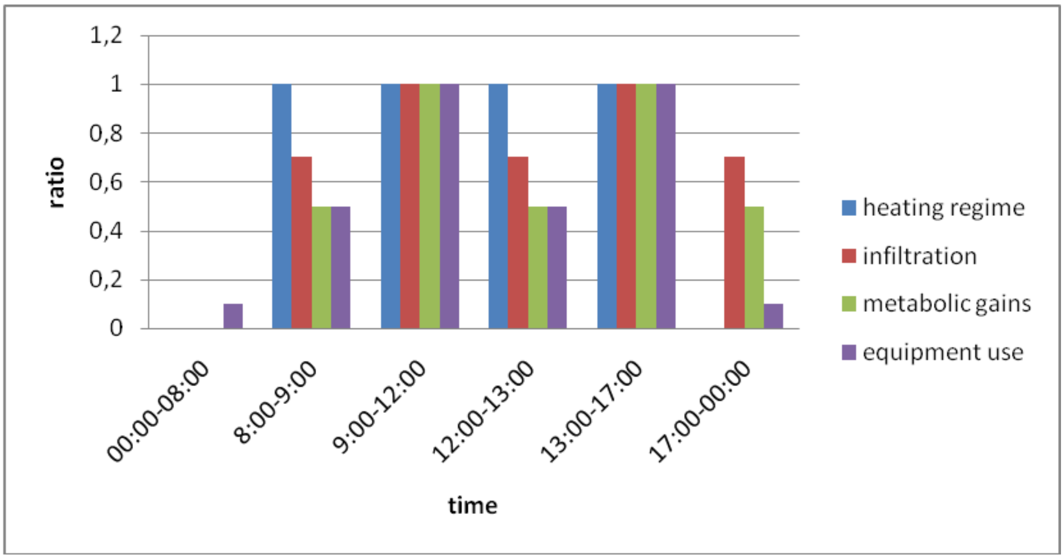


Figure 5.12. Occupancy schedule and operation time for heating regime, infiltration, metabolic gains and equipment use.

5. Heating (24°C) and cooling (25°C) set point temperatures are the average temperatures of heated and cooled zones at office hours.
6. Because of the decrease in the number of occupants in 2007, occupation density is reduced to 0.09 person/m^2, electricity consumption of office equipment is decreased to 12 W/m^2. Therefore, heating set point temperature is taken as 23°C.
7. Despite the heating system is operated only during office-hours in 2006, boiler temperature is set to 40°C at non-office hours in 2007 and an automation system is installed to set boiler temperature depending on outside air temperature in 2008. Figure 5.13 represents heating regimes of 2007 and 2008 derived from fuel consumption measurements.

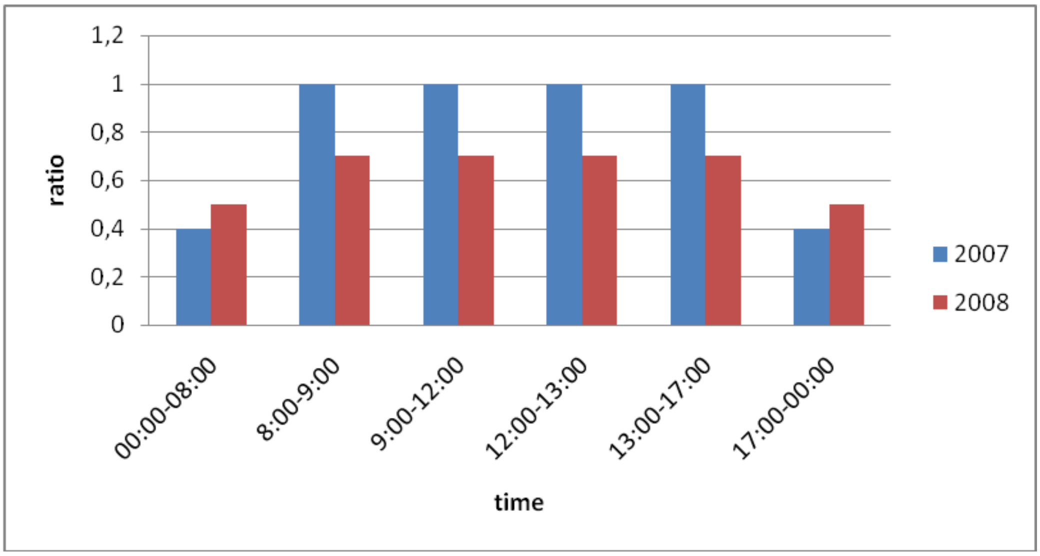


Figure 5.13. Operating profile for heating in 2007 and 2008.

8. Meteorological data used in the simulations are taken from three sources. IZODER uses monthly average data of climatic zones as it is mentioned in Chapter 3. Ecotect is capable to implement the local data of IZTECH Campus as well as to use predefined Izmir downtown data (43 km far from the Campus) (Figure 5.14). On the other hand, EnergyPlus uses only Izmir downtown data. Dry bulb temperature, relative humidity, global solar radiation, wet bulb temperature, pressure and wind speed is taken from IZTECH Meteorological Station and used in Ecotect software.

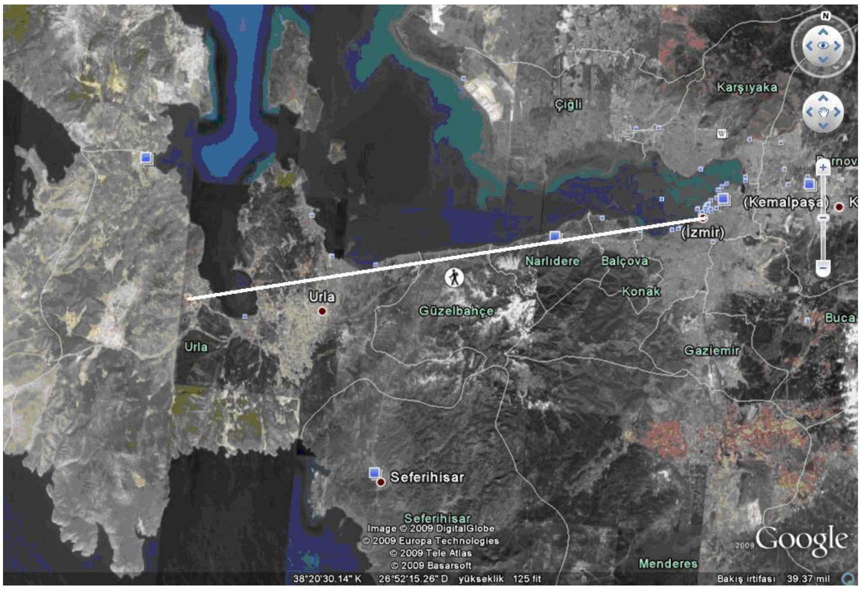


Figure 5.14. Locations of IZTECH Campus and Izmir downtown.

9. Adminisrative Building is divided into 2 zones including 14 conditioned and 11 unconditioned zones to simplify modeling of the building. Figure 5.15 to 5.18 shows zoning and modeling of the building by Ecotect and DesignBuilder.

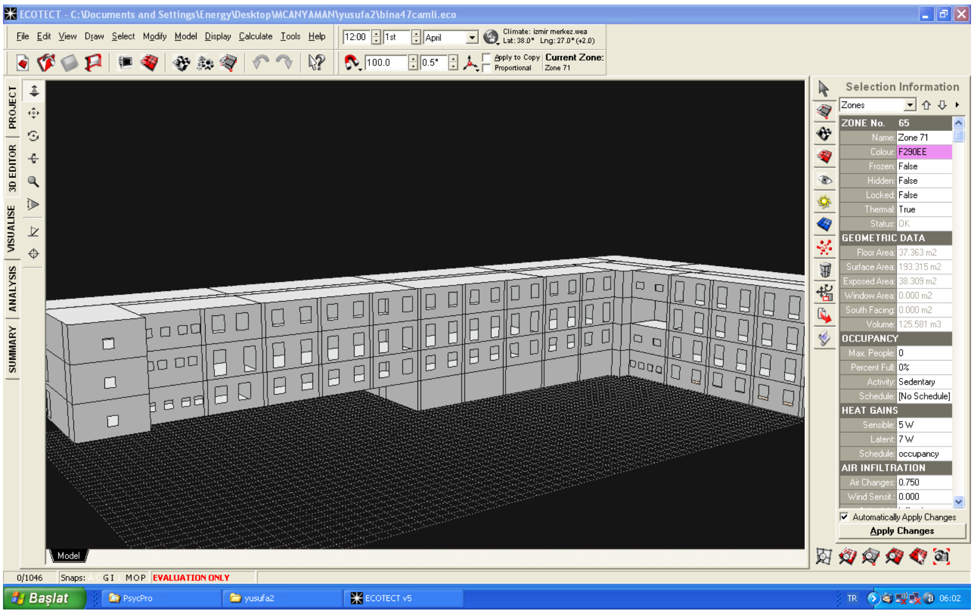


Figure 5.15. A view from southwest of the building modeled in Ecotect.

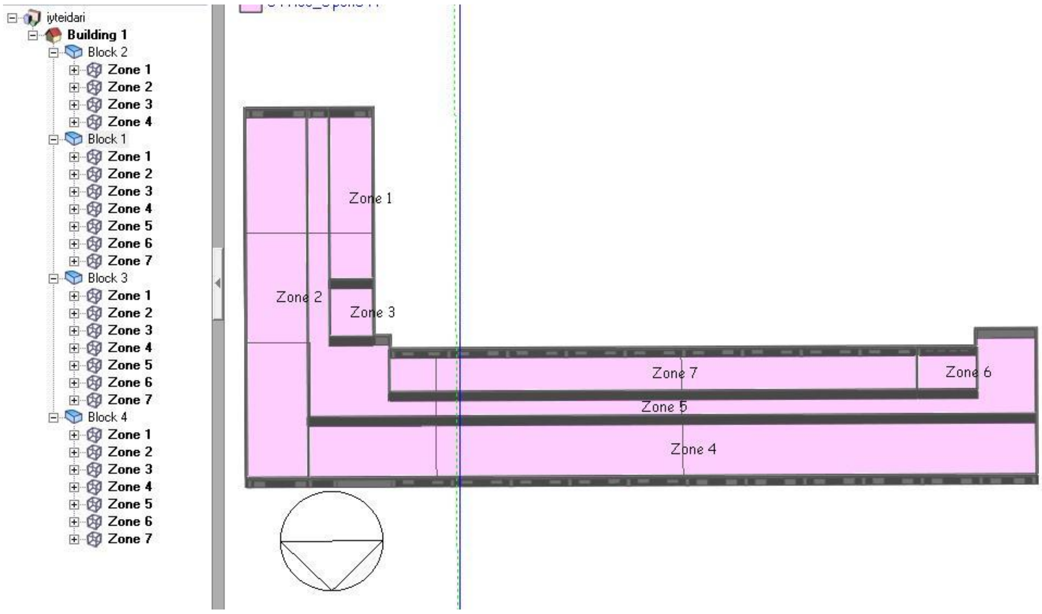


Figure 5.16. Zone division of 1st, 2nd and 3rd floor of the building modeled in DesignBuilder.

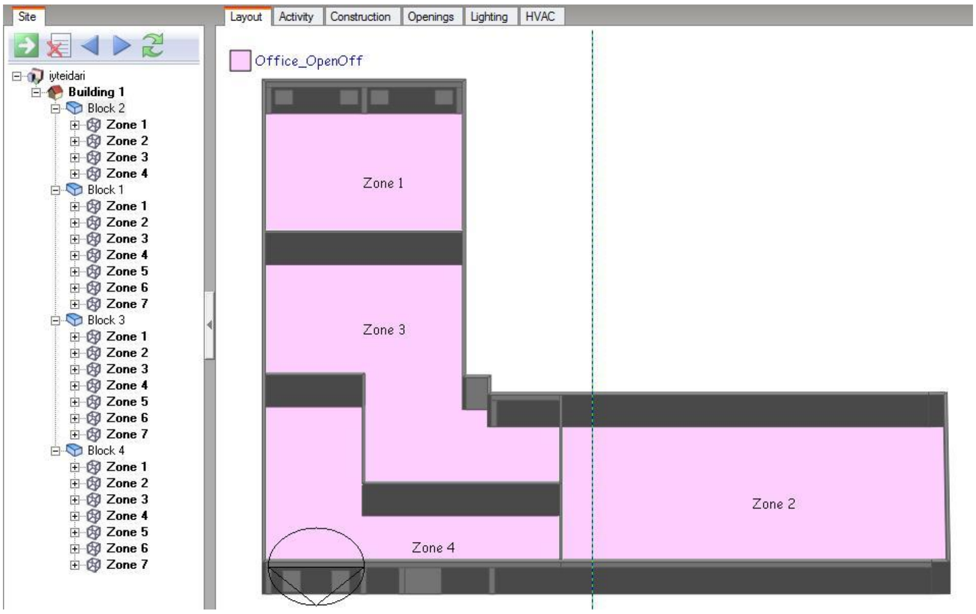


Figure 5.17. Zone division of floor of the building modeled in DesignBuilder.

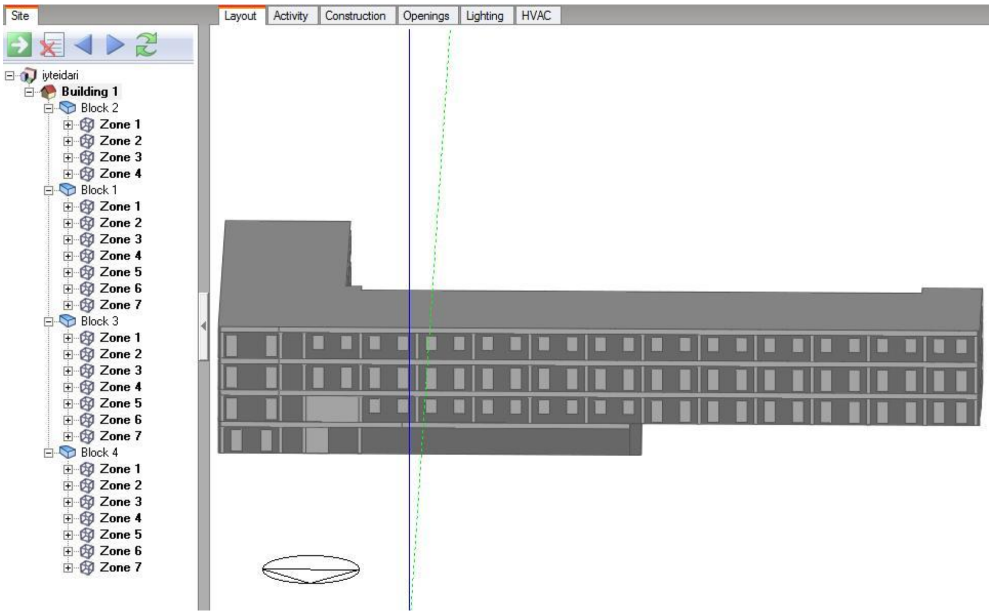


Figure 5.18. A view from north of the building modeled in DesignBuilder.

An input data set is formed for each software and listed in Table 5.4.

Table 5.4. Input data set for software.

Method	**TS 825**	**CIBSE Admittance Method**	**ASHRAE Heat Balance**
Software	**IZODER**	**Ecotect**	**EnergyPlus**
Heating set point temperature	19 °C	24 °C	24 °C
Cooling set point temperature	Not included	25°C	25 °C
Internal gains	5 W/m^2	15 W/m^2 + occupation	15 W/m^2 + occupation+ lighting
Outdoor data	Average monthly values of the climatic zones	Local meteorological data (IZTECH)	Local meteorological data (city centre)
Natural ventilation and infiltration	1 ach	1 ach	1 ach

5.2.2. Comparison of measurements and simulation results

Time period, year, is taken from April to April to be able to cover full heating and cooling season otherwise calendar based year would split heating season into two.

Figure 5.19 exhibits the simulation results and measurements of heating energy consumption for the year of 2006. Because of the continuous heating regime and single zone assumptions, IZODER estimates energy consumption 66±0.7% higher than the measurements. Since IZODER is a static method it gives the same consumption results for each year, thus it will not be repeated for 2007 and 2008. While Ecotect using Izmir downtown meteorological data deviates from the measurements by 26.6±0.3%, deviation of Ecotect results with Campus meteorological data is 21.4±0.24%. Therefore, for the preceeding years, only Campus data will be used. On the other hand, EnergyPlus simulation gives closest approximation to the measurements with a sufficiently high confidence level of 1.6%±0.02.

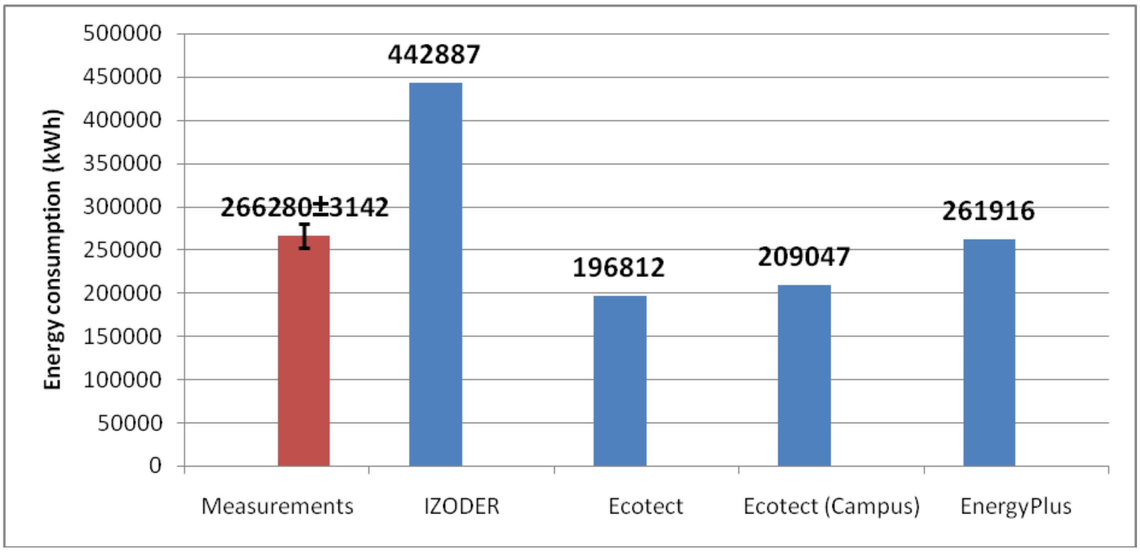


Figure 5.19. Heating energy consumption in 2006.

Gains to the building can be separated into lighting, equipment, occupancy and solar gains as shown in Figure 5.20. Solar gains hold a portion of 43% due to high window to wall ratio of 0.26. Temperature increase in the building due to gains is calculated as 1.48 K by dividing total gains into total specific heat loss of the building.

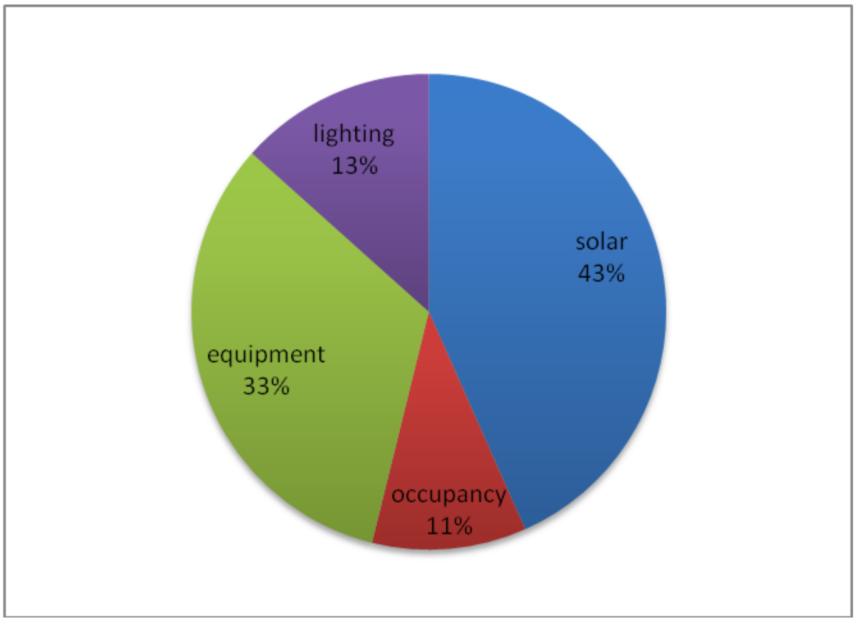


Figure 5.20. Breakdown of gains in the Administrative Building.

Simulation results and measurements of cooling energy consumption for 2006 are given in Figure 5.21. Ecotect over-estimates the cooling consumption by 6.8±0.1% for Campus data. This is because of the internal gain treatment of the CIBSE Admittance Method. On the other hand, EnergyPlus under-estimates cooling energy consumption by 5.8±0.1% considering shading elements on windows and natural convection effect.

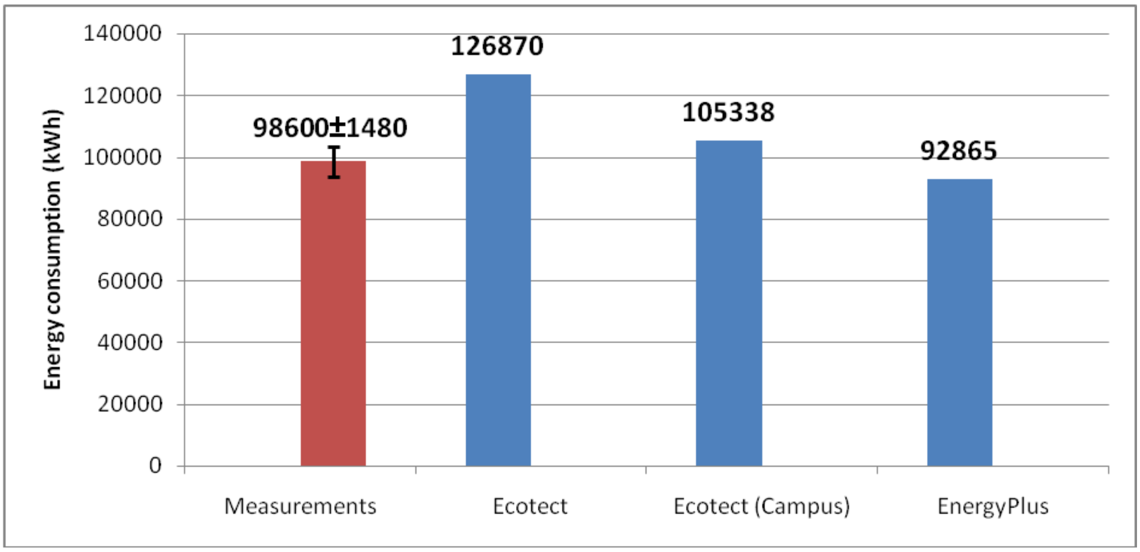


Figure 5.21. Cooling energy consumption in 2006.

Figure 5.22 displays measurement and EnergyPlus results of equipment and lighting electricity consumption by office equipment and lighting in 2006. EnergyPlus estimates the general electricity consumption with an approximation of 3.3±0.1% with a share of 67.4% office equipment and 32.6% lighting.

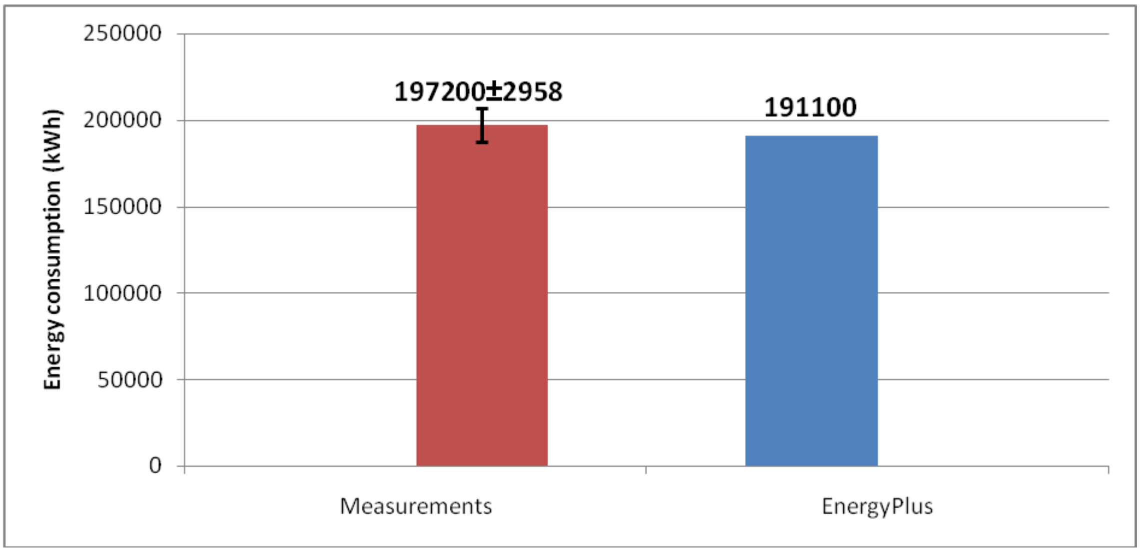


Figure 5.22. Electricity consumption in 2006.

For 2007 and 2008, IZODER is discarded from the results as it gives same value regardless of the year due to fixed monthly average climatic data. Ecotect is simulated only with Campus data because local meteorological data proved to be more effective.

In the year of 2007, measured and simulated heating, cooling, lighting and equipment energy consumption data are reported in Figure 5.23. While EnergyPlus estimates heating energy consumption with a good approximation of 2.2±0.1%, it fails with estimating cooling energy consumption by 27.8±0.4%. Changes in ventilation rates, system operation time and user behavior cause overestimation in cooling season. On the other hand, Ecotect deviates by 16.5±0.4% for heating and 17.3±0.26% for cooling.

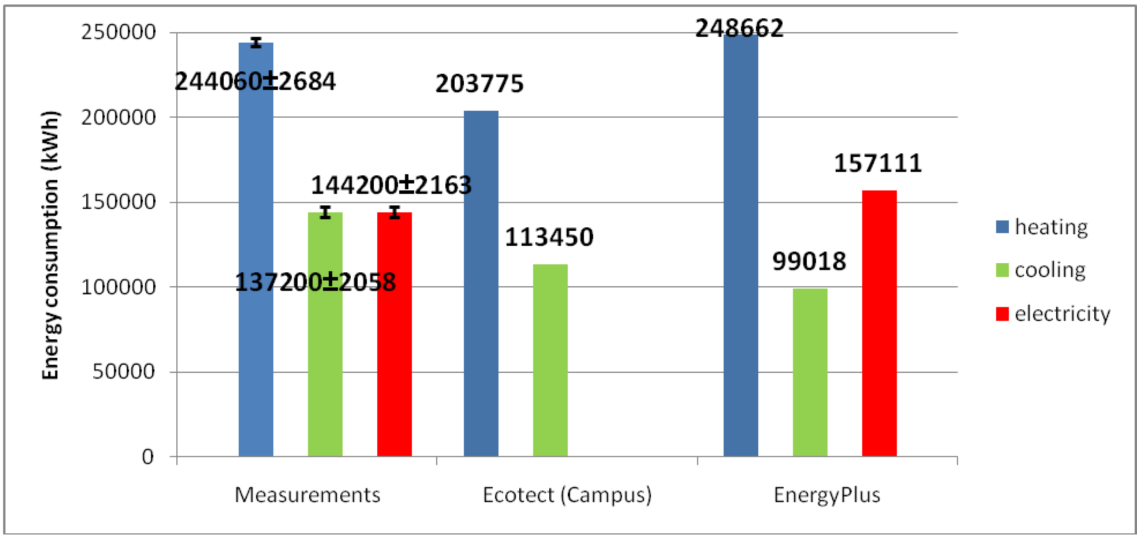


Figure 5.23. Measurements and simulation results in 2007.

The same trend can be also observed in 2008 (Figure 5.24). EnergyPlus and Ecotect under-estimate heating energy consumption by 5.6+0.1% and 22.10±0.25%, respectively. Although cooling energy consumption is over-estimated by Ecotect (30±0.45%) , it is under-estimated by EnergyPlus (7.7±0.12%).

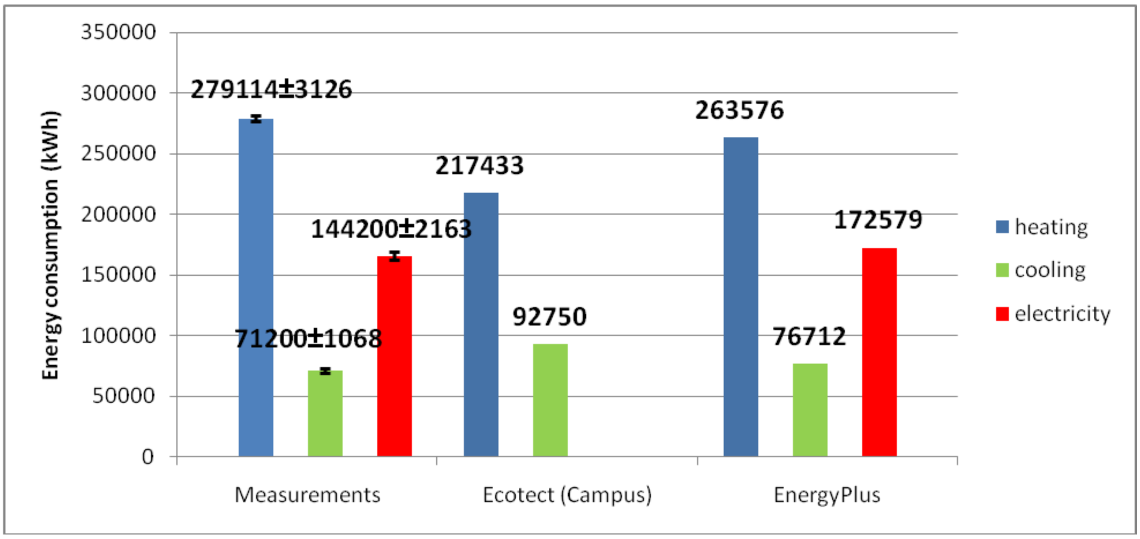


Figure 5.24. Measurements and simulation results in 2008.

5.2.3. Comfort Simulations

Simulations are performed with EnergyPlus to obtain Fanger PMV value to have an idea about the total comfort of the building for 24 hours between 2006 and 2008. PMV value is an statistical index regarding comfort level of the selected space and ASHRAE 55 (2004) classify comfort as given in Table 5.5.

Table 5.5. Comfort level according to PMV values
(Source: ASHRAE 55 2004).

PMV	Comfort	PMV
-3	< Cold <	-2
-2	< Cool <	-1
-1	< Slightly cold <	0
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 xx). In this study, -1 <PMV<+1 range is used to compare comfort conditions of different scenarios.

Fanger PMV indexes for whole building are calculated by years with the changes in occupation, heating set point temperature and operation profile. As seen in Figure 5.25, operation profile of 2007 (45 °C at non-office hours, adjusted manually depending on outdoor temperature) and 2008 (adjusted automatically depending on outdoor temperature) resulted better PMV values in heating season. This result is proved by the fact that number of discomfortable days decreased from 164 to 155 in 2007 and from 155 to 92 in 2008. Although heating season averages of 2008 show a better PMV index, the difference between weekdays and weekends are significant. This phenomena may be occurred by sharp changes in operation profile between weekend and weekdays, probably a computational error.

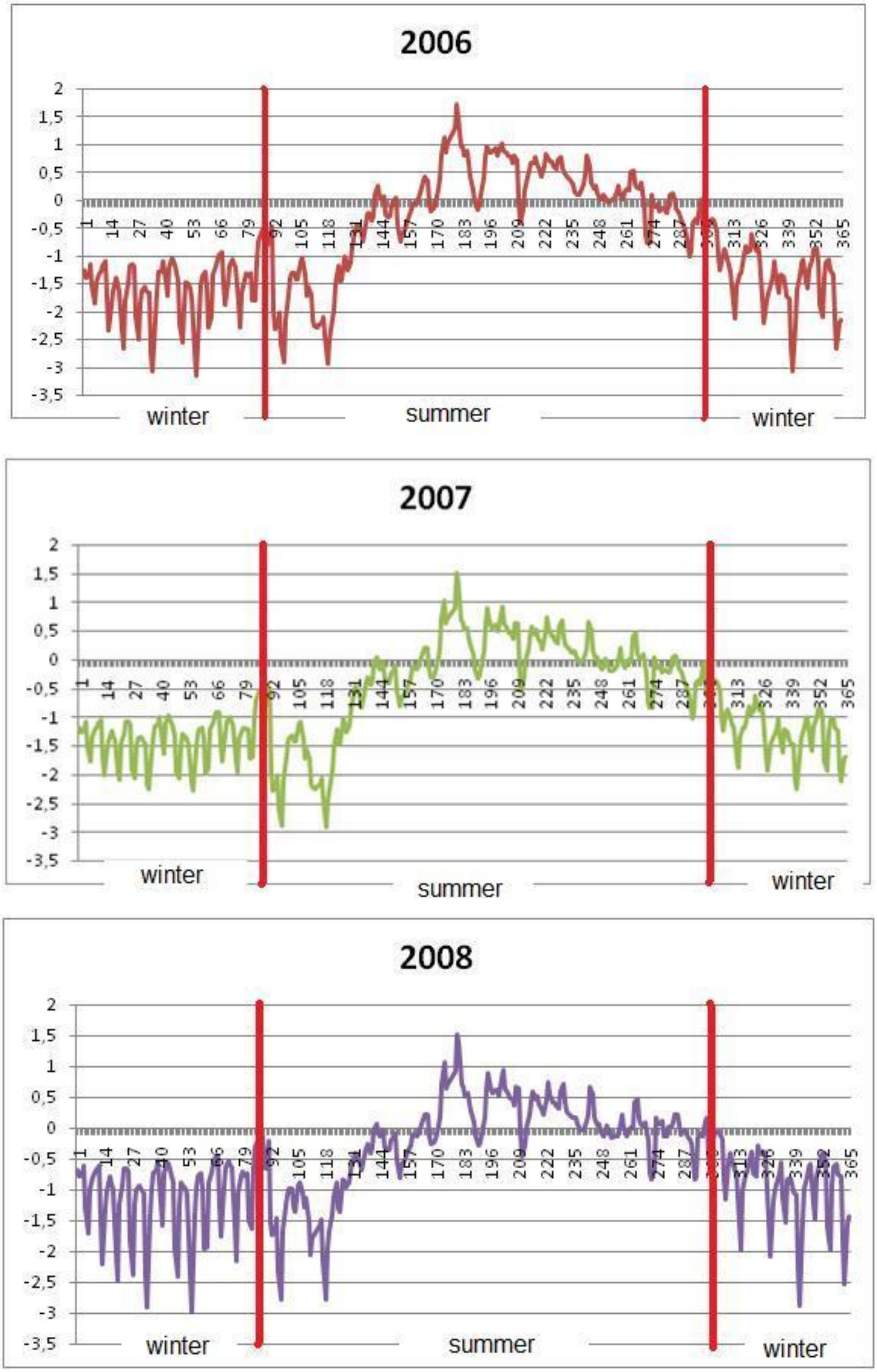


Figure 5.25**.** PMV values of the Administrative Building between 2006 and 2008.

5.2.4. No-HVAC Case

A hypothetical case, where there is no heating and cooling system operated in the building (non-conditioned environment) is simulated by EnergyPlus. Objective of this simulation is to estimate the building's behavior in lack of energy. Figure 5.26 shows the daily averages of indoor and outdoor temperatures during simulated year.

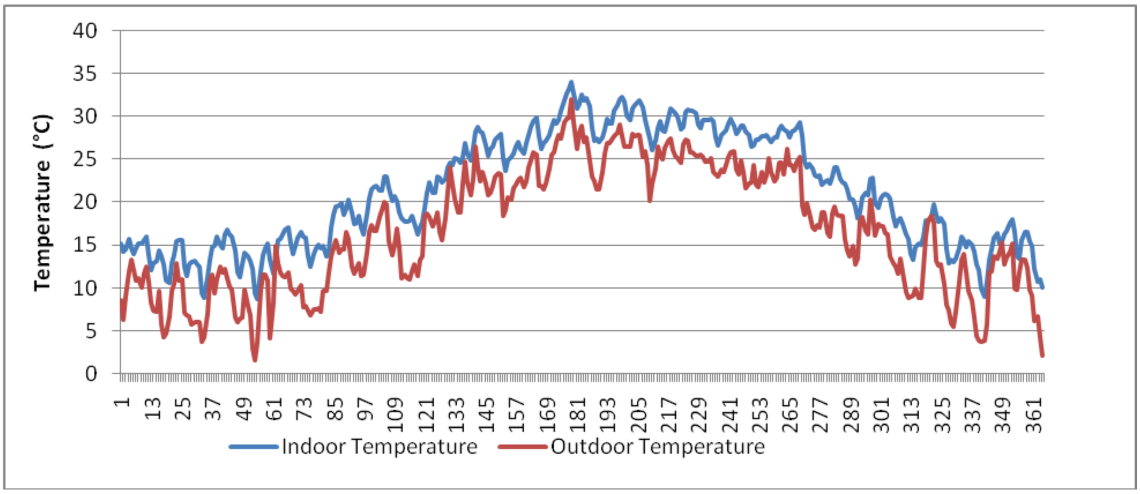


Figure 5.26. Indoor and outdoor temperatures for no-HVAC case.

Indoor temperature fluctuates from 8.68 to 34.05°C while outdoor temperature fluctuates from 2.11 to 32.56°C in non-conditioned environment. Comfort in the building can be illustrated as PMV index in Figure 5.25. PMV index fluctuates from -3.3 to 2.92, leading 279 days outside -1 <PMV<+1 comfort range from slightly cold to slightly warm.

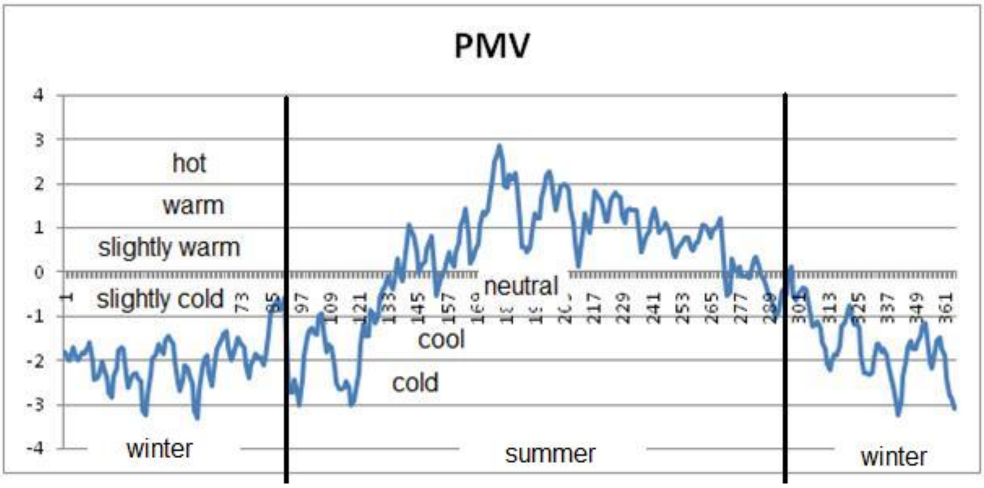


Figure 5.27. PMV index of the building for no-HVAC case.

5.3. Performance Improvement Measures

Primary energy consumption and greenhouse gas emission of the Administrative Building in 2008 are calculated as 193.85 kWh/m^2 and 45.92 kgCO_2/m^2. Regarding with these values, the Building can be classified as class "C" in terms of primary energy consumption and class "D" in terms of greenhouse gas emission according to Building Energy Performance Regulation (2008).

To increase energy performance of the building which does not meet the requirements of TS 825, the obligatory standard, following measured are proposed:

1- External insulation application for building envelope including roof and external walls. For practical reasons floor insulation is not included.
2- Replacing window frames with new types of frame and glass.
3- Modifying fuel burners to achieve 85% boiler efficiency.

Measures are taken by 3 different improvement scenarios:

1- Application of 8 cm XPS external insulation to the building envelope + Modifying fuel burners to achieve 85% boiler efficiency,

2- Replacement of old windows with aluminum frame to PVC frame with low-e properties + Modifying fuel burners to achieve 85% boiler efficiency,
3- Combination of 1st and 2nd scenarios.

Table 5.6. Improvement measures and U values.

Building element			**U value (W/m^2K)**	
	Current	**Improved**	**Current**	**Improved**
External wall (brick layer)	No insulation	8 cm XPS	1.93	0.4
External wall (concrete layer)	No insulation	8 cm XPS	3.29	0.44
Roof	2 cm XPS	8 cm XPS	0.92	0.44
Floor	No insulation	No insulation	2.57	2.57
Windows	Aluminum frame 9mm air gap double pane (Global solar transmission coefficient: 0.812)	PVC frame low-e 9mm air cap double pane (Global solar transmission coefficient: 0.687)	3.9	2.4

Proposed performance improvement measures are simulated by IZODER, Ecotect and EnergyPlus. Reductions achieved on heating and cooling energy consumptions are given in Table 5.7.

Table 5.7. Reductions in energy consumption achieved by 1st improvement scenario.

Scenario	Reduction	IZODER	Ecotect	EnergyPlus
1st scenario	Heating consumption (%)	46.00	21.48	23.78
	Cooling consumption (%)	-	1.61	2.11
2nd scenario	Heating consumption (%)	20.17	18.23	19.46
	Cooling consumption (%)	-	8.23	11.56
3rd scenario	Heating consumption (%)	60	38.58	36.22
	Cooling consumption (%)	-	8.61	12.17

Adding insulation to external walls and roof, changing window frames with lower U value, causes a higher decrease in heating energy consumption than cooling. This is obvious, since cooling loads are dominated by solar gains through glazing, not by transmission through building envelope.

Life cycle cost (LCC) analysis is performed to predict payback period of the investment for building envelope enhancement. With the 2008 prices of electricity and fuel-oil, inflation rate of 7%, and interest ratio of 17%; investment for the first scenario pays back in 4.4 years while investment for the second scenario pays back in 11.9 years and third scenario covering all improvements pays back in 7.2 years.

Primary energy consumption and greenhouse gas emission of the Administrative Building are calculated as 175.64 kWh/m^2 and 41.42 $kgCO_2/m^2$ for first scenario. Regarding with these values, the building can be classified as class “B” in terms of primary energy consumption and class “D” in terms of greenhouse gas emission according to Building Energy Performance Regulation (2008).

Second scenario reduces primary energy consumption to 179.39 kWh/m^2 and greenhouse gas emission to 42.69 $kgCO_2/m^2$. Regarding with these values, the building can be classified as class “B” terms of primary energy consumption and class “D” in terms of greenhouse gas emission according to Building Energy Performance Regulation (2008).

For the third scenario, primary energy consumption and greenhouse gas emissions are calculated as 164.07 kWh/m^2 and 38.48 kgCO_2/m^2. Regarding with these values, the building can be classified as class “B” in terms of primary energy consumption and class “C” in terms of greenhouse gas emission.

While first and second scenario can upgrade the primary energy consumption rate from C to B, greenhouse gas emission rate remains the same. However, they are not enough to make the building to meet the TS 825 requirements. Third scenario upgrades both primary energy consumption (C to B) and greenhouse gas emission (D to C) rates. Thus the building meets TS 825 requirements. However, comfort level of the building remains the same, a little improvement (89 days are out of 1 $<PMV<+1$ comfort range) in PMV is observed. This is because of the increase in operative temperature caused by the increase of inside wall temperatures.

CHAPTER 6

CONCLUSIONS

This study is conducted to evaluate energy performance of IZTECH Administrative Building by energy consumption measurements and simulations. Fuel consumption is measured by two flowmeters connected to the boilers. Chiller, boilers and pumps, lighting and equipment electricity consumption are measured by power analyzers. Indoor comfort measurements are taken by dataloggers located 14 different spaces in the building and local meteorological data is taken from IZTECH Meteorological Station. TS 825, CIBSE Admittance and ASHRAE Heat Balance Methods are applied to the building by IZODER, Ecotect and EnergyPlus simulation software, respectively. Effect of different heating regimes on energy consumption and comfort are simulated as well as a no-HVAC case is considered.

Meteorological data gathered from IZTECH Meteorological Station implies high wind speed between 2.5 and 6.1 m/s which increases outdoor convective heat transfer coefficient and consequently the heat loss. Temperatures measured in 2007 summer are higher than 2006 and 2008. This prevailed chiller electricity consumption increase by 57%.

53% of total energy consumption is fuel based, followed by 32% equipment and lighting, 13% chillers and 2% boilers and pumps for 2008. Fuel consumption is increasing due to continuous heating regime.

Indoor comfort measurements showed the lack of comfort due to high temperatures in summer season while thermal camera imaging identified the problematic regions of the building envelope. Measurements implies improvement in comfort due to continuous heating regime in winter season, also the difference between north and south sections of the building. According to the measurements, ratio of discomfort decreased from 37% to 22% from 2006 to 2008.

Comparing the simulation results with measurements showed that a significant difference exists in the sensitivity of the methods. It is observed that TS 825 over-estimates heating energy consumption by 66±0.7% because of the continuous heating and single building zone assumptions. CIBSE Admittance Method estimates lower heating and higher cooling energy consumption values compared with ASHRAE Heat Balance Method; which is caused by the methodology used in internal gain calculations.

Table 6.1 shows comparison of measurements and simulation results between 2006 and 2008. EN 15265 classifies simulation software comparing energy consumption estimation with a reference test room. Comparing EnergyPlus software with EN 15265 (2007) to check if EU standards are fulfilled, results have good approximation except cooling consumption in 2007 to level B validation. Taking HVAC system elements into account and physically realistic internal gain calculations are the advantages of EnergyPlus.

Table 6.1. Deviation of simulation methods compared to measurements.

	Heating consumption estimation (%)	**Cooling consumption estimation (%)**	**Electric consumption estimation (%)**
2006			
IZODER	+66±0.7	-	-
Ecotect (Izmir downtown)	-26.6±0.3	+28.7±0.43	-
Ecotect (Campus)	-21.4±0.24	+5.8±0.1	-
EnergyPlus	-1.6±0.02	-6.2±0.1	-3.3±0.1
2007			
Ecotect (Campus)	-17.3±0.26	-16.5±0.4	-
EnergyPlus	-2.2±0.01	-27.8±0.4	+9.4±0.14
2008			
Ecotect (Campus)	-22.1±0.25	+30±0.45	-
EnergyPlus	-5.6±0.06	-7.7±0.12	+4.1±0.06

In general, heating energy consumption is estimated more precisely than cooling energy consumption because of the uncertainties such as change in infiltration, natural ventilation and user intervention on cooling system. EnergyPlus estimated heating and cooling energy consumptions in 2006 by 1.6±0.02% and -6.2±0.1% deviation, respectively.

Effect of local meteorological data is observed in 2006 simulations. Ecotect simulation with IZTECH Campus data, estimates heating energy consumption 5.2% and cooling energy consumption 17.1% more precisely compared to Izmir downtown data.

No-HVAC case, where there is no heating or cooling system operated in the building, is simulated to estimate building's behavior in lack of energy. It is seen that 279 days of a year are out of -1 <PMV<+1 comfort range.

Primary energy consumption and greenhouse gas emission of the Administrative Building in 2008 are calculated as 193.85 kWh/m^2 and 45.92 $kgCO_2/m^2$. Regarding with these values, the Building can be classified as class "C" in terms of primary energy consumption and class "D" in terms of greenhouse gas emission according to Building Energy Performance Regulation (2008).Performance improvement measures (external insulation, boiler efficiency enchancement and replacing windows) are simulated with EnergyPlus using ASHRAE Heat Balance Method and reduction of 36.22% in heating and 12.17% in cooling is observed, improving energy rate of the building from C to B and greenhouse gas emission rate from D to C, making the building fulfill TS 825 standard, while investment pays back in 7.2 years without any major improvement in comfort. Comfort in no- HVAC case remains almost same as 261 days are out of -1 <PMV<+1comfortrange.

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