

**KHALID ALALOOSI**

**SELECTION OF THE BEST HVAC SYSTEM FOR INDUSTRIAL  
BUILDINGS BY USING MULTI-CRITERIA DECISION-MAKING TOOLS**

**THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES  
OF  
ATILIM UNIVERSITY**

**KHALID ALALOOSI**

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BY USING MULTI-CRITERIA DECISION-MAKING TOOLS

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

---

Prof. Dr. Ali Kara  
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Industrial engineering, Atilim University.

---

Assoc.Prof.Dr. T. Erman ERKAN  
Head of Department

This is to certify that we have read the thesis SELECTION OF THE BEST HVAC SYSTEM FOR INDUSTRIAL BUILDINGS BY USING MULTI-CRITERIA DECISION-MAKING TOOLS submitted by KHALID ALALOOSI and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

---

Asst. Prof. Dr. Cihan TURHAN  
Co-Supervisor

---

Assoc. Prof. Dr. Uğur BAÇ  
Supervisor

Examining Committee Members:

Assoc.Prof.Dr. Gülin Feryal CAN  
Industrial Eng. Department, Baskent University

Assoc. Prof.Dr. Uğur BAÇ  
Industrial Eng. Department, Baskent University

Assoc.Prof.Dr. T. Erman ERKAN  
Industrial Eng. Department, Atilim University

**Date: 6/8/2020**

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: **KHALID ALALOOSI**

Signature:

## **ABSTRACT**

### **SELECTION OF THE BEST HVAC SYSTEM FOR INDUSTRIAL BUILDINGS BY USING MULTI-CRITERIA DECISION-MAKING TOOLS**

**KHALID ALALOOSI**

M.S., Department of Industrial Engineering

Supervisor: Assoc. Prof. Dr. Uğur BAÇ

Co-Supervisor: Asst. Prof. Dr. Cihan TURHAN

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Heating Ventilating and Air Conditioning (HVAC) selection is a difficult task, especially when the selection relates to technical, economic, and environmental criteria. HVAC systems are responsible for 50% of total energy consumption in buildings and play a major role in the ability to reduce harmful emissions. The great demand for energy and the upward trend in the use of HVAC systems with the global need to impose measures on environmental hygiene underlines and focuses the importance of choosing the most appropriate HVAC system during the design process.

The case study of an industrial building in Ankara has several machines studied. The Design Builder (DB) program was used in the dynamic building energy simulation and knowledge of the total energy consumption of the building. Stepwise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum Product Assessment (WASPAS) methods has been applied for the purpose of decision making due to its ability to accurately weigh criteria and to choose the most appropriate alternative through subjective and objective assessments with great accuracy. WASPAS

is characterized by its ability to facilitate the effective data and vague information and to provide a good systematic decision-making analysis.

Eleven HVAC systems were examined based on 27 criteria, including technical, environmental, and economic criteria. The results of selecting the best HVAC system using SWARA and WASPAS showed Sensitivity analysis performed according to different lambda values. The (Water-source Heat Pumps) is preferred at the first rank in all cases and it was identified as the best alternative for industrial buildings. It has been determined that the choice of alternative is economically, technically and environmentally most logical.

Keywords: HVAC system, SWARA, WASPAS, MCDM

## ÖZ

### ÇOK KRİTERLİ KARAR VERME ARAÇLARI KULLANILARAK ENDÜSTRİYEL BİNALAR İÇİN EN İYİ HVAC SİSTEMİNİN SEÇİLMESİ

KHALID ALALOOSI

Endütri Mühendisliği Bölümü Yüksek Lisans/ Master

Danışman: Doç. Dr. Uğur BAÇ

Eş Danışman: Dr. Öğr.Cihan TURHAN

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Isıtma Havalandırma ve Klima (HVAC) seçiminde özellikle seçim teknik, ekonomik ve çevresel kriterlerle ilgili olduğunda zordur. HVAC sistemleri, binalardaki toplam enerji tüketiminin %50'sini oluşturur. Ayrıca sistem, zararlı emisyonların azaltılmasında önemli bir rol oynar. Tasarım sürecinde en uygun HVAC sisteminin seçilmesinde, enerjiye olan büyük talep, HVAC sistemlerinin kullanım oranının artışı ve çevresel hijyene yönelik önlemlerin uygulanmasına yönelik küresel ihtiyaçlar belirleyici oluyor.

Ankara'daki bir endüstriyel binanın vaka analizinde birkaç makinenin üzerinde çalışılmıştır. Bu analizde Design Builder (DB) programı kullanılarak, dinamik bina enerji simülasyonu yapılmış ve binanın toplam enerji tüketimi hesaplanmıştır. Analizdeki karar verme sürecinde kriterleri doğru tartma, sübjektif ve objektif değerlendirmelerde yüksek doğruluk sağlayarak en uygun alternatifi seçebilmek adına Kademeli Ağırlık Değerlendirme Oranı Analizi (SWARA) ve Ağırlıklı Toplu Toplam Ürün Değerlendirme (WASPAS) yaklaşımları uygulanmıştır. WASPAS, etkili verileri ve belirsiz bilgileri kolaylaştırma ve iyi bir sistematik karar verme analizi sağlama yeteneği ile bilinmektedir.

Teknik, çevresel ve ekonomik kriterler dahil 27 kritere göre 11 HVAC farklı sistemi incelenmiştir. SWARA ve WASPAS yöntemleri kullanarak seçilen en iyi HVAC sisteminin analiz sonuçları, farklı lamda değerlerine göre gerçekleştirilen hassasiyet analize gösterilmiştir. Su kaynaklı Isı Pompaları, her durumda endüstriyel binalar için en iyi alternatif olarak belirlenmiştir. Bu seçiminin ekonomik, teknik ve çevresel olarak en uygun olduğu tespit edilmiştir.

Anahtar Kelimeler: HVAC sistemi, SWARA, WASPAS, MCDM

## **DEDICATION**

TO THE CANDLE THAT HIGHLIGHTED MY WAY, MY GREAT ... FATHER

TO THE SPRING OF KINDNESS, MY DEAREST ... MOTHER

TO MY WIFE, BROTHERS AND SISTERS, WITH LOVE AND GRATITUDE

TO THE BEST FRIENDS (OTHMAN, IBRAHIM, AHMED)

AND FOR EVERY PERSON WHOSE HEART THROBBED FOR ME

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## LIST OF SYMBOLS/ABBREVIATIONS

MCDM	Multi Criteria Decision-Making
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
CAV	Constant Air Volume
VAV	Variable Air Volume
COP	Coefficient of Performance
PID	Proportional Integral Derivative
IEA	International Energy Agency
LCC	Life Cycle Cost
KBCD	knowledge-Based Conceptual Design
AHP	Analytic Hierarchical Process
ANP	Analytic Network Process
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
DOE	Department of Energy
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
CBA	Choosing by Advantages
ELECTRE	Elimination Et Choice Translating Reality
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
DCLG	Department for Communities and Local Government

DEMATEL	Decision Making Trial and Evaluation Laboratory
WASPAS	Weighted Aggregated Sum Product Assessment
VIKOR	VIšekriterijumsko KOmpromisno Rangiranje
WSM	Weighted Sum Model
WPM	Weighted Product Model
SWARA	Stepwise Weight Assessment Ratio Analysis
FAD	Fuzziness in Axiomatic Design
COPRAS	Complex Proportional Assessment
FMOO	Fuzzy Multi-Objective Optimization
MABAC	The Multi-Attributive Border Approximation area Comparison
ARAS	Additive Ratio Assessment
MOORA	Multi-Objective Optimization Method by Ratio Analysis
C1	Ergonomics
C11	Ventilation
C12	Relative Humidity
C13	Visual Impact
C14	Noise Level
C15	Thermal Comfort
C2	Economic Cost
C21	Capital Cost
C22	Maintenance Cost
C3	Technical Properties
C31	Water Consumption

C32	Energy Consumption
C33	CO <sub>2</sub> Emission
C34	COP Heating
C35	COP Cooling
C36	Single Control Zone
C37	Multi Control Zone
C4	Physical Properties
C41	Indoor Area Requirement
C42	Outdoor area requirement
C43	Indoor Appearance
C44	Outdoor Appearance
C5	Flexibility
C51	Installation Flexibility
C52	Integration Flexibility
C53	Energy Source Flexibility
C54	Ease of Maintenance
C6	Reliability
C61	Lifetime
C62	Lead Time
C63	Repair Time
C64	Fewer Components
C65	Vendor Availability
A1	All-Air System Single Zone (CAV)
A2	All-Air System Multi Zone (CAV)

A3	All Air System Terminal Reheat (CAV)
A4	All-Air System Dual Duct
A5	All-Air System Variable Air Volume
A6	Air-water system Fan-Coil Unit
A7	All water system Fan-Coil Unit
A8	Air-Water System Induction Unit
A9	Water-Source Heat Pumps
A10	Heating and Cooling Panels
A11	Split System

# CHAPTER 1

## 1. INTRODUCTION

### 1.1 Background of Study

The HVAC system is a widespread tool that creates clean air conditioning, changes the indoor air quality, and improves thermal comfort for people. In 1902, Willis invented the first electric air conditioning unit. The main work of the HVAC system is to decrease temperature in summer and increase it in winter. Moreover, HVAC system adjusts the air and its quality through cooling, heating, ventilation, and dehumidification. Free evaporation and cooling are one of the most popular cycles which are also considered as a group of dynamic cycles [1]. Air conditioning systems are one of the essential devices that should be available in every building to keep the interior environment clean. Depending on the location, multiple regions, and distribution, air conditioning systems can be customized in local and central systems. HVAC systems consist of refrigeration equipment, ventilation equipment, heating equipment and air distribution equipment. The main air generator is located away from the building in a dedicated room for equipment, then the clean air conditioning is delivered to the location specified by the ducts. Central HVAC systems consist of air-powered systems, water-powered systems and both water-air systems. HVAC systems are used in more of different buildings such as commercial, industrial, residential, and institutional buildings [2].

Air cycle work can be summarized by drawing air from the outside environment then cooling or heating the air and redistributing it to the required places. The choice of a suitable HVAC system depends on the amount of energy consumption and the thermal demand of the building. Climate, age of the building and individual preferences are other important factors in defining the appropriate system [3]. Individual choice preferences

depend on the criteria provided in each HVAC system which are the critical issue for the most appropriate choice. Suitable and appropriate criteria are most important in choosing an appropriate HVAC system [4].

## 1.2 Major HVAC System Components

The HVAC system consists of several devices and equipment that combine to form an integrated HVAC system to provide a comfortable indoor environment [5]. Figure 1.1 illustrates the main parts of the HVAC system.

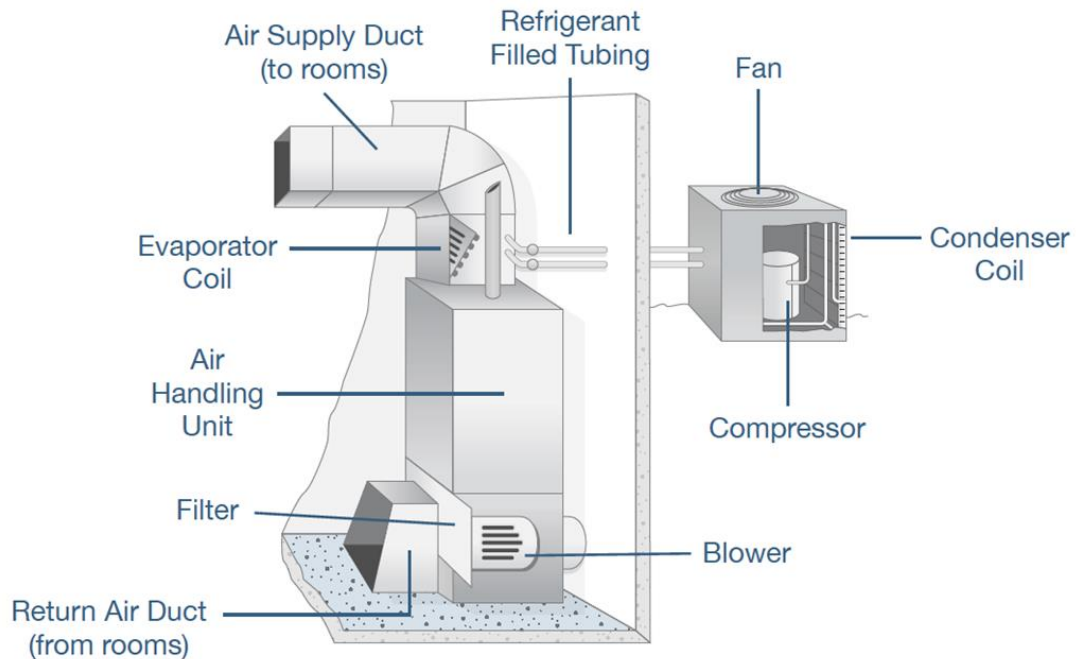


Figure 1.1 The main parts of the HVAC system [6].

The components can be specified as listed below:

- All mixed air and outdoor control
- Air filter
- Display fan
- Exhaust or relief fans and air outlet

- The amount of outdoor air
- Conveyor channels
- Peripheral devices
- Return air system
- Heating and cooling coil
- Free standing heating or cooling unit
- Cooling tower
- Boiler
- Control
- Water cooler
- Moisturizing and dehumidification equipment

There are four main requirements for each HVAC system [7]. Figure 1.2 illustrates these requirements.

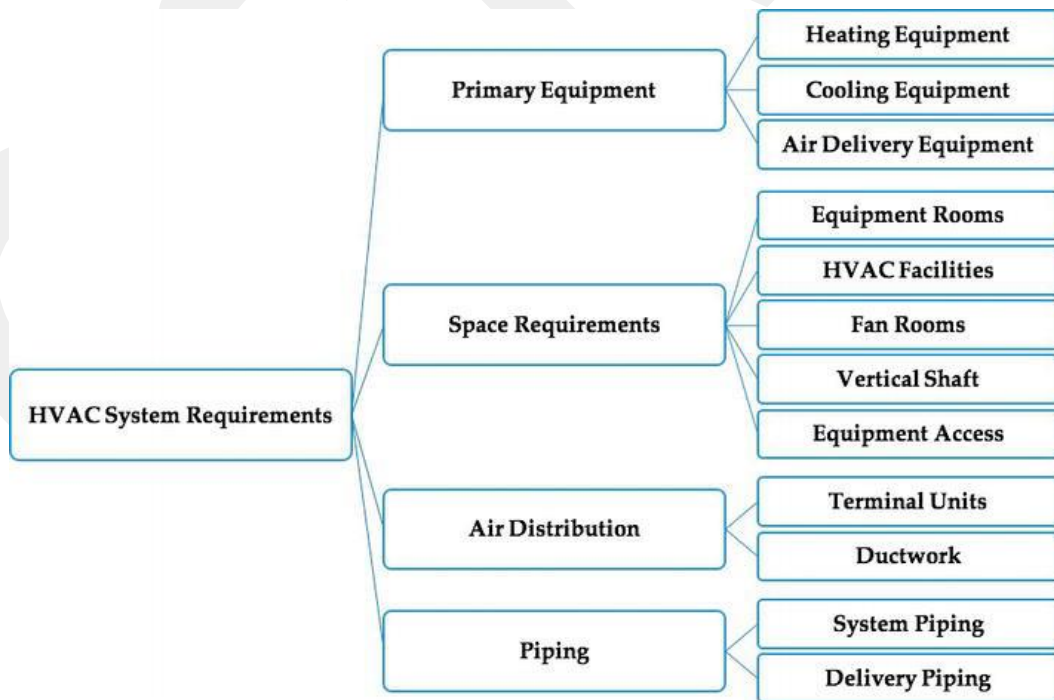


Figure 1.2 Requirement of HVAC systems [5].

### 1.3 Types of HVAC System

HVAC systems are classified into centralized and decentralized system. The HVAC system is either localized for a specific area of the building or centrally located outside the building [8]. Therefore, depending on the location of the primary equipment and the basis for classification of the system, an air distribution system for the building is designed [9].

#### 1.3.1 Central HVAC System

Central HVAC system equipment and devices are located outside the building on the top or side of the building in a suitable central area outside the area to be ventilated his reason called centralization [10]. Air conditioners are divided into several types, and these types differ in terms of control, method of air distribution and ventilation cycles. Figure 1.3 shows the classification of central HVAC systems.

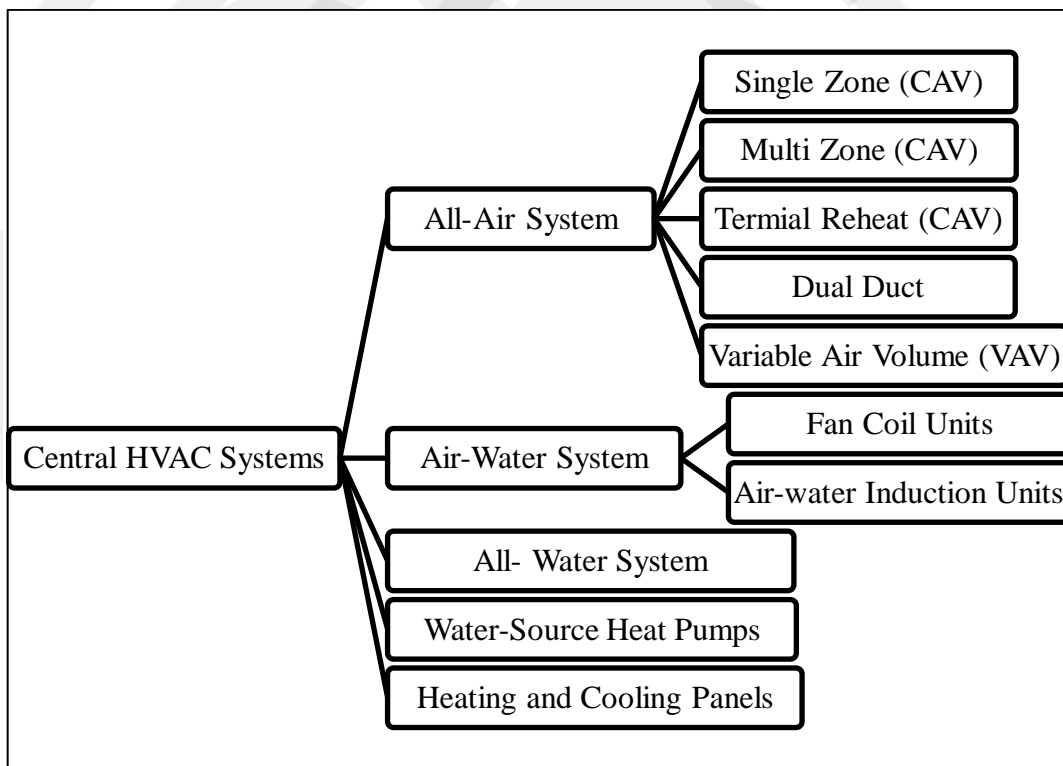


Figure 1.3 The classification of central HVAC systems [5].

### a. All-Air System

Heat or cool is transferred to the designated building by air. Air systems can be classified into single zone (CAV), multi-zone (CAV), dual duct, terminal heating (CAV), and variable air volume [11,12].

#### i. Single Zone (CAV)

The operation of the system is controlled by one controller. This type of system is characterized by ease of maintenance and design. The cost of this system is lower than other systems. The only disadvantage of these systems is that the needs of only one region are met. The components of this system are heat generation, refrigeration, ducting and airflow handling unit. Usually buildings are multi-zone thermal, however there are some buildings and applications with one temperature zone. This system can be used in many family homes as a single thermal zone [13].

#### ii. Multi Zone (CAV)

In a multi-zone HVAC system, several regions have different thermal requirements, which leads to the demand for separate supply channels. The system consists of internal mixing dampers, cooling and heating coils and air handling unit. It is recommended that a maximum of 12 areas be provided. If there are more than 12 areas, more air handling is recommended. This system is characterized by the ability to meet the needs of more than one region without wasting energy. The only additional need in this system is multiple air channels to supply multiple areas [14].

#### iii. Terminal Reheat (CAV)

This system is multi-zoned which considers the adaptation of one region. The heating coil is placed below the air supply estuary near each area below the air handling unit. To satisfy thermal comfort, a thermostat is controlled in each temperature control zone. Air is cooled according to comfort by an air handling unit and the terminal heating adds the required heat. Terminal reheating features control several areas to keep it under good thermal conditions. It can be installed and removed easily so it is flexible. One disadvantage of peripheral heating is that it consumes a large amount of energy [15].

#### iv. Dual Duct

This system is important as it reduces the disadvantages of previous systems by using terminal control. It is both controlled and correct terminal system for multiple zone concepts. The air handling unit provides hot and cold surface. These tables are distributed in all parts of the region by separate and parallel streams. There is a mixing box for hot and cold air which is controlled by a precise thermostat to set the required temperature [16].

#### v. Variable Air Volume (VAV)

The HVAC system with (VAV) is one of the appropriate systems to achieve thermal comfort for some areas that require different air quantities due to the change in thermal loads of the building. Previous systems have fixed air volume [17]. The variable air volume system consists of a terminal control box which is available in all of the building to adjust the air volume. Air conditioning is supplied to the control box through the central air handling unit. By controlling the airflow rate the region temperature is controlled. The airflow rate can adversely affect the surrounding areas with similar or different airflow rate and temperature. Some buildings may require a relatively low flow rate which reduces fan strength. This reduces airflow and affects air quality in the building [18].

#### b. All-Water System-Fan Coil Unit

This system transports and distributes hot and cold water to the designated place by pumping water from a central system. This system is characterized by its small size because water has higher density compared to air, where a large amount of heat can be transferred at a lower size [19]. There are many connection devices used, such as heaters, plate radiators and floor radiators. The fan coil unit is the primary type used to cool and adapt the required area [20].

Fan coil unit can be installed vertically or horizontally and be very small. It can be used in circulating fans and appropriate control systems. The shape and design of this system should be appropriate because it is located indoors. Heat and cool are transferred from the central system to the fan coil. There is a precise thermostat that controls the rate of

water flow in the building to the fan coil unit. The main defect in this system is noise and ventilation which can only be obtained by connecting to the outside air [21].

c. Air-Water System

It is a hybrid system that combines the advantages of both water and air systems, where the water is responsible for transferring heat or cool to the building by 90%, while the air is responsible for maintaining air circulation and maintaining the temperature [22].

i. Fan-Coil Unit

This system is supplied with water from central water systems, while it is supplied with air from central air handling units. The units of the fan coil in this system are similar to the air conditioning units [23]. Air is delivered to the building either separately or through fan coils. They are found in several types, such as the dual-channel system and the four-channel system [24].

ii. Air-water Induction Unit

Induction units differ internally from fan units but are similar externally. Induction units stimulate airflow through the cabinet through the air handling units which generate high airflow. This process can be done by mixing the air from the room with the main air of the central unit to produce air conditioning for the room [25].

d. Water-Source Heat Pumps

Water source heat pumps act as a source of cooling and heating. They are used in very cold weather to provide a large amount of heat inside the building. An entire building can be equipped with several individual heat pumps and can be controlled depending on the thermal demand of each region [26]. The disadvantage of this system is the lack of ventilation as in the fan coil unit. In the case of heat and solar energy, boilers are used to supply the water with the necessary heat. In the event of cooling, water cooling tower is used to get rid of heat. The pump redistributes the heat from one part to another in the building in the case of demand for heating for the area and cooling for another area at the same time [27].

#### e. Heating and Cooling Panels

The panels should be installed on the walls, floors, and ceilings, where the latter shall be a source of thermal comfort. These panels are called the radiant plate [28]. These systems are in the form of tubes inside the roofs of buildings for the purpose of providing thermal comfort from heating or cooling. It is recommended to limit the ceiling temperature to 140 degrees Fahrenheit for a ceiling level of 15 feet high for the purpose of thermal comfort and not to affect the heads of the people. It is also recommended to limit the floor temperature from 66 to 84 degrees for the purpose of resting and not affecting the feet of the people. This system is very expensive compared to other systems due to the high installation cost. The advantage of this system is a few inches of space is required to install the panels [29].

#### **1.3.2 Local HVAC System-Split System**

The building can consist of one large area or several areas that require central heating, cooling, and ventilation to provide thermal comfort [30]. This system is widely used in residential homes and apartments where the house needs equipment located inside the building. Every local agency serves the designated area without crossing into other regions. In each region there is a specific local system and thermostat to control the temperature. Local HVAC systems serve specific individual areas in many buildings where each region is individually controlled [31].

The systems consist of two devices: Evaporator inside the building and condenser outside. The two devices are connected by cables and cooling channels. The system can consist of one high capacitor and several evaporators to meet the needs of several regions at the same time. This system is able to solve the problems of all small buildings that need little cooling. The only drawback is that its installation clearly affects the building's architectural design and its beauty [32].

## 1.4 Selection of HVAC System

Heating and cooling are essential components as they are essential in factories, companies, and apartment buildings. The demand for heating and cooling is very high as it dominates the industry sectors. Factory selection decisions for HVAC have increased recently due to increased fuel prices. Companies and factories are looking for the best alternatives that can provide thermal comfort at low cost [3]. Recently, the complexity of decision-making has increased around choosing the best HVAC system in industrial buildings for cooling, heating, or plant ventilation due to the availability of many technological alternatives and many electronic standards. Some experts focus on the minimum cost, which leads to their failure to choose the optimal system as they ignore other criteria [33]. The information used in the decision-making procedure has a crucial role especially in industrial buildings [34]. Providing high indoor air quality, thermal comfort with least energy consumption and little impact on the environment have a major impact and are among the basic criteria in choosing the best HVAC system. The main factors that affect energy efficiency are the direction of the building, its design, shading, natural ventilation, use of insulators, etc. These factors are important, but they are not sufficient to reduce the energy consumption and CO<sub>2</sub> emissions. Due to the great development in HVAC systems, it is potential to reduce many harmful emissions and energy consumption [35]. On the other hand, building ventilation is essential and important for providing a clean and acceptable atmosphere. In modern years, indoor air quality has become an important and major goal in factories. Inappropriate ventilation and high humidity are directly related to a person's mood, leading to a series of diseases that may affect a person. The use and design of the HVAC system in the factories is necessary because natural ventilation cannot meet the complete thermal comfort of people, especially in dense urban environment [36]. Industrial buildings are a big energy consumer, so reducing energy consumption can benefit the economy regionally and internationally. Ventilation is a major energy consumer, while cooling operations show a significant increase in industrial buildings due to the high temperature produced by appliances and machines. HVAC systems design is important as it plays a significant role in improving the productivity and work of plant employees. The operational cost is a very important matter especially in factories and the estimation of the capital cost has a

big role. The cost greatly affects decision-making as cost has a significant role in terms of choosing the best decision [37].

### **1.5 Statement of Problem**

The HVAC system is responsible for the largest amount of energy use in buildings as it consumes 55% of the building's energy. HVAC systems affect the environment greatly due to CO<sub>2</sub> emissions as they cause major changes in climate and global warming. Chinese, Nardin and Saro, (2011) stressed the need to define an alternative for HVAC systems for the factories [38]. It was emphasized that all factories and companies are looking for alternatives at a low initial and operational cost. The focus was on the problem of user satisfaction, technical standards, economic standards, environmental and energy standards during the study conducted by Avgelis and Papadopoulos in 2009 [39]. The possibility of applying decision-making processes to choose alternatives in the concept of sustainability to reduce energy consumption was emphasized. The study conducted by Tian, Si, Shi and Fang, (2019) focused on the problem of reliability, initial cost, maintenance cost, and user comfort by selecting the best alternative HVAC Time [40].

In the modern environment, the demand for energy consumption and the low environmental impact have increased. The demand for thermal comfort has also increased. These demands cannot be achieved through architectural building design, orientation, good natural ventilation, appropriate interior planning, passive cooling and use of insulators to maintain heat, and other influencing factors [3]. These demands are difficult to achieve due to the high internal loads, the dense urban environment, the escalation of gases and soils, and climate changes in different seasons. HVAC systems play an important role to reach these requirements, including thermal comfort, reducing environmental pollution, and maintaining energy consumption at an acceptable level. HVAC systems have a major impact on the fulfillment of these requests. Moreover, it is necessary to choose the most suitable HVAC system for industrial buildings. Therefore,

when building a factory or building, one should consider choosing the best HVAC system because of its effect on the following [41]:

- The problem of high energy consumption
- CO<sub>2</sub> emissions
- Level of noise
- Maintenance costs
- The required space inside the building
- Aesthetic design
- Level of temperature control
- Efficient cooling and heating
- (IAQ) and thermal comfort

### **1.6 Research Objectives**

This research aims to select the best HVAC system in industrial buildings by applying a decision-making technique, based on the preferences and choices of decision makers, and depending on the performance of available alternatives. The choice of the HVAC system is based on performance criteria including economic performance, environmental performance, and technical performance. These criteria are combined and arranged into one comparison and applied by the decision maker.

On the other hand, choosing the best HVAC system can achieve the following:

- Choosing the HVAC system that is suitable for the building with high specifications and low energy consumption can bring profits to the building economically.
- Choosing a highly efficient HVAC system can improve indoor air quality (IAQ) and thermal comfort for people.
- Choosing the HVAC system with more advantages, such as humidity control, ventilation level, and temperature control, can provides adequate comfort conditions.

- The choice of HVAC system with lower CO<sub>2</sub> emissions has a major impact on the environment.
- Choosing an HVAC system with easier installation and less complex maintenance can save profits and time.
- The choice of HVAC system with fewer spatial requirements inside or outside of the building gives an additional advantage to the system.

### **1.7 Justification of Study**

This study was conducted to overcome several gaps Related to the best HVAC selection. This study emphasizes the importance of:

- a) Consider a large group of alternative HVAC systems
- b) Assist experts, decision makers, and designers in the decision-making process
- c) Analysing alternatives and standards based on documented sources
- d) Consider the revolutionary changes to systems in the future

The lack of sufficient academic studies on HVAC system selection for industrial buildings and the importance of choosing the appropriate air conditioning system in the initial stages of planning, justify the motivation behind using decision-making methodology to choose the best system. Increasing demand for thermal comfort, improving IAQ while reducing environmental impact, lower energy consumption and lowering economic costs are important factors. These demands cannot be fully met by a dynamic climate design approach that improves building orientation and interior planning and adopts passive cooling and natural ventilation. HVAC systems contribute significantly and meet the requirements of a comfortable indoor environment. Therefore, to meet these demands, while maintaining building energy consumption and associated CO<sub>2</sub> emissions at acceptable good levels, it is important to choose the most suitable HVAC system.

## 1.8 Methodology Overview

The aim of the study is determined by choosing the best alternative based on a set of criteria. Alternatives for HVAC systems and appropriate criteria were defined by a group of experts. The objective, criteria and alternatives were defined and clarified as in the usual methods of decision-making.

Design builder software is used to perform simulations in order to get the required data for several alternatives. Several data are obtained for each alternative with specific criteria through simulation within the program. Values for other criteria for alternatives were collected from reliable sources with the assistance of a group of experts.

Design builder is one of the academic programs used by engineers, architects, and energy engineers to calculate heat load and cooling load for industrial, commercial, residential and office buildings. Through the program, it is possible to schedule working times and know the amount of consumption of the building throughout the year. The program contains all alternatives for HVAC, where it is possible to choose the specific alternative and know the convenience, energy consumption and emissions of harmful gases and other important criteria. The program is used as part of the research plan to obtain accurate data [42].

After collecting all data through the program and reliable sources, decision-making techniques were used to choose the appropriate alternative. WASPAS and SWARA approaches were applied in decision-making processes for accuracy, priority, and demonstration of their decision-making ability in various fields. Criteria and alternatives were weighed through expert evaluations using marital comparison and estimated weight.

Multi-criteria decision-making is an instrument or major concerned with studying and selecting decisions related to choosing the best alternative from several candidate alternatives, taking into account many alternatives or options that have an ambiguous or tangible effect. This specialty focuses not only on choosing the best alternative, but rather gives priority to other alternatives with high accuracy [43]. Decision makers often try to choose the best alternative without focusing on priority. This tool is applied when

multiple paths to work are available and the decision maker focuses on choosing one of these paths without knowing the best alternative in advance [44].

The decision-making process consists of three stages:

- a) The first stage: deals with realizing the problem and determining the criteria for judgment. Where the problem is diagnosed, the reason related to the status of the decision, and the purpose of the decision.
- b) The second stage: deals with developing goals, values, and preferences to compare alternatives with each other in a fair and transparent manner.
- c) The third stage: means allocating work plans to the results obtained from the previous analyses and procedures.

The decision-making process consists of setting a goal, identifying criteria and available alternatives [45]. These alternatives are weighed according to the available criteria and obtain the highest weight for the alternatives, which will be the best alternative as in figure 1.4.

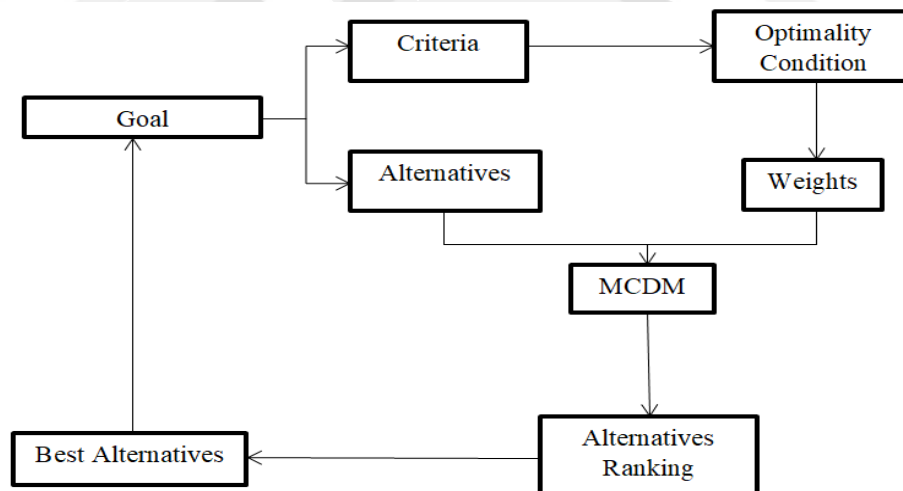


Figure 1.4 Structure of MCDM [46].

## 1.9 Structure of Study

The study consists of five chapters which includes:

Chapter one: dealing with the overview, problems, goals and justifications for the study

Chapter two: dealing with previous studies and literature review. In the literature review, research related to the selection of HVAC systems is studied and analysed. Studies on preferences and alternatives that decision makers focus on are also reviewed

Chapter three: dealing with applying the MCDM methodology to the specific alternatives for the HVAC system where preferences are mathematically analysed and calculated to obtain the best alternative

Chapter four: dealing with result and discussion. The results obtained are analysed, discussed, clarified, and interpreted in addition to the results obtained from this research.

Chapter five: dealing with conclusion.

## **CHAPTER 2**

### **2. LITERATURE REVIEW**

To achieve an accurate and satisfactory conclusion about the results and the best options reached by this research, it is important to review previous studies that present issues related to HVAC systems such as how to choose the best system and the methods used to reach it. It is also important to review the available alternatives and the advantages of these alternatives. Furthermore, this chapter discusses the criteria that are relied upon in decision-making, where a brief explanation is provided on each criterion, its real importance and clear impact on choosing the best system. The literature is also reviewed for the methods used in decision-making to identify the advantages of each methods and the results that can be obtained from each method.

#### **2.1 Choosing of HVAC System**

The design and direction of the building plays a main role in reducing energy consumption and providing a large amount of comfort, but it is not possible to provide the appropriate thermal demand and the quality of indoor air through them only. HVAC systems play a big role in providing high air quality and reducing environmental impact and energy consumption [47]. The provision of high-efficiency HVAC systems is very necessary in an urban environment as it is directly related to the comfort of people and high humidity and low air quality lead to many diseases. HVAC systems play a necessary vital role in ridding the air of high humidity and low air quality. The demand for heating and cooling in industrial buildings is very large and is one of the main general components of energy requirements [48].

Capital cost is an economically important role in purchasing HVAC systems. The decisions to purchase HVAC depend not only on the capital cost, but also on the operating cost. The cost in choosing the best HVAC system is very important as it is divided into capital, operating and maintenance costs [3].

One of the primary tasks in the selection process is choosing an air conditioning system that protects the environment from harmful emissions. The climate suffers from harmful emissions from factories, factories, cars, and airplanes, in addition to some HVAC systems. Choosing a suitable system with little or no emission contributes significantly to improving climate and global warming [49].

Companies and factories are interested in finding better low-cost HVAC alternatives for heating and cooling. The capabilities of improvement and selection of the best system are clear and available. Due to the large number of alternatives and standards related to them, the decisions have become more and more complex. The complexity involved is not related to alternatives, but rather to complex, conflicting standards [50,65].

All the conditions mentioned above can be achieved by promoting informed choice and dealing with complex issues by identifying the needs of decision makers and using MCDM methods.

A decision-making process is a tool, or a selection process aimed at finding the best alternative to achieve the best option [51]. People can make many daily decisions based on personal intuition due to the lack of many criteria and options. When the selection process, environment and surrounding conditions are complex and many alternatives and criteria are available, careful, and transparent decision-making is of great importance [52]. Decision-making in a complex environment should be capable of obtaining [52] [53].

- a) Clear and transparent results in addition to decisions and documented decision-making criteria.
- b) Rational decisions that are easy to understand can be repeated a lot.

The Department of energy (DOE) recommends that, despite the many circumstances in which decisions, the decision must have some characteristics, including [53]:

- a) It provides many equal alternatives
- b) It has an impressive future
- c) A set of reviews and studies are required at many levels of management
- d) Requires approval to existing facilities

These conditions can be applied at different management levels for selecting the HVAC system [54]. HVAC systems in buildings require several levels of investment [55,56]. During the design period, a specialized team must be available in the system selection process to ensure the availability of access requirements and the availability of space for the design [57]. Several primary and secondary HVAC systems are provided, and the best system is chosen based on available criteria. [58,59,39]. CO<sub>2</sub> emissions from HVAC systems cause a dangerous rate of pollution to the environment, causing climate change and global warming [60]. This underscores the urgent need to choose an appropriate system. From previous studies, it was found that the major gap is the lack of an air conditioning system selection tool [61,62]:

- a) Help the decision makers, not just the researchers
- b) Consider a set of alternatives
- c) Use confirmed sources of information
- d) Consider climate change and future change

This gap emphasizes the fundamental importance of choosing an approach that helps in the accurate selection of Different HVAC systems. The following literature explains the methods, approaches, techniques, and problems that have been studied and confirmed their importance by the group of researchers.

The researchers Shahrestani, Yao and K.Cook (2018), explained that HVAC systems consume nearly 55% of the total energy consumption in buildings. This high demand demonstrates the importance of choosing a suitable system during design. Choosing a suitable energy-saving HVAC system achieves high demand, especially in modern buildings. The cost of the investment has great importance to estimate the cost of each system in order to obtain the best non-consumed system at an appropriate cost [63]. Energy consumption in addition to cost estimation faces an escalating demand to reduce consumption and high cost. MCDM methods and its techniques are chosen to deal with

uncertainty and obtain more accurate results [64]. Determining the cost of the system design and the amount of energy consumption is important to choose the best alternative by using a decision-making approach because random evaluation is much less accurate and reduces confidence in selection [34,65].

Ali (2013) explained that controlling HVAC systems have a significant impact throughout the year in the internal environment in order to obtain a clean environment in offices and facilities. HVAC systems have a major impact on maintaining human health and increasing productivity, but there are alternatives that differ in terms of available standards, including reliability, economic, noise, etc. An appropriate environment must be provided for every office and plant with the appropriate standards in developed countries [66].

McQuiston, Parker and Spitler (2000), confirmed that there is an increasing demand for (IAQ) and thermal comfort for health [67]. The increased demand for the best air conditioning system in hospitals, laboratories, factories, and offices has increased the demand for energy. Each manufacturer searches for a suitable working environment at appropriate temperatures that provide comfort to the workers. Therefore, there are challenges and difficulties for HVAC officials to choose the appropriate and efficient system.

Some important details were emphasized that should be taken into account in the MCDM for choosing the most appropriate air conditioning system. This process depends on the designer's experience, capabilities and time directly affecting him. Decision-making standards and appropriate design recommendations are the factors facing clients. During this study, to make an appropriate decision, the criteria and scope of the study were determined. Moreover, the defects and advantages of each system were provided. Several HVAC systems and challenges were examined. Some buildings have a water heating pump, while others may have a gas source. Consideration has been given to user satisfaction, air quality and noise. System alternatives were considered to make an appropriate decision at a particular time [61].

The HVAC system can perform in all conditions, as the quality of HVAC components, maintenance and energy saving plays a major role in its reliability [68]. CBA enables to

use different perspectives and provides a good discussion environment as well as to understand the advantages of each alternative to make an appropriate decision. The advantages of each of the alternatives are presented and discussed. The cell system and natural gas cooler with the cooling tower replacement are easy to maintain and very reliable than other alternatives. It was suggested that using the CBA approach in other projects would make documentation easier. The possibility of using CBA in the future to make better decisions was also mentioned [35].

The need to reduce gas emissions and reduce energy consumption was emphasized through a reassessment of air conditioning systems [69]. Weather conditions and geographical location have been shown to have a major impact on energy efficiency. Precise indicators must be used for evaluation. Several different methods such as technology, geographic region and weights were used to operate. More sophisticated methods were used in addition to traditional methods. The most suitable HVAC can be used in the most appropriate place, which reduces gas emissions and consumption [70].

Decision-makers aim to reduce the economic cost and make the best decision to improve buildings. Information on the criteria was gathered from decision-makers and available alternatives were discussed. The focus of the study was on investment costs which are the most important for factories while operating costs are very important for residential homes. The comparison and deduction method are a robust AHP methodology as there are different approaches to the decision-making method. The results indicated that operating costs are less important in industrial heating than capital costs. AHP methodology still exists and contributes to the selection of the best energy plans for countries [38].

During the study conducted by Avgelis and Papadopoulos (2009) several criteria were evaluated: economic aspects, environmental impacts, (IAQ) and thermal comfort. The dynamic performance was applied to select the most suitable AC systems. To assess the best performance of HVAC systems, system simulation was used by Klein, Beckman, Mitchell and Duffie in 2009 [71]. During the study conducted by Avgelis and Papadopoulos (2009), annual price changes including electricity, oil, and natural gas were considered and the appropriate decision was made based on economic changes.

The main areas contributing to the selection of the most appropriate HVAC systems were identified during this study:

- a) According to the European Commission [72], there are international obligations to reduce the carbon ratio that affects decision-making based on carbon intensity and then assess carbon emissions from HVAC systems.
- b) Climatic conditions differ from one region to another where this study was applied in Greece and the results may differ in another region under different conditions.
- c) Climate change forecasts affecting future systems testing have not been considered.
- d) Several alternatives to available (HVAC) systems have been studied, including air conditioners in the partition room, gas boilers, hot water radiators, and an air distribution system. These sub-sections are presented to show available studies to overcome deficiencies when testing the HVAC system.

A system called Knowledge-Based Knowledge Design (KBCD) was introduced by Maor, Panjapornpon, and Reddy in 2004 to define HVAC systems by automatically defining and tuning a wide range of systems [59]. The power simulation program was used to evaluate alternatives provided by Panteli, Raphael and Tham in 2012 [73]. To assess the basic and operating costs of the HVAC systems, the Maintenance and Ownership Cost Unit has been developed. By simulating energy consumption, the LCC of systems was evaluated. Subsequently, according to the criteria the alternatives were classified [74]. There are several areas for choosing the most appropriate HVAC though the KBCD model and its power are used in criteria analysis using simulations. According to a study by Elovitz in 2002 [75], the time has a major impact on the choice of HVAC systems, as designers are forced to underestimate the evaluation of alternatives. Although it has been assumed that the method reduces time in choosing alternative systems, it is time consuming by evaluating alternatives. Although the simulation program is used to evaluate alternatives, evaluation of alternatives, especially in the early stages, takes a long time [75]. LCC is the only standard used to evaluate HVAC. There could be concerns about not taking into account the environmental impact of adaptation and climate change.

The concerns that designers face in choosing HVAC are the climatic conditions that influence decision-making. A comprehensive model was developed to cope with changes in climatic conditions when testing the HVAC. A framework was established by Shin and S.Haberl in 2019 to analyse mechanical and electrical services through design decision in buildings [76]. Early assumptions and suggestions were made about the decision-making process. Some steps have been taken for possible improvement:

- a) Each feature was evaluated in each alternative system where the advantage was considered the most important part in decision making [76].
- b) Energy consumption and CO<sub>2</sub> emissions are not considered during decision making.

An expert system of five HVAC software packages was introduced by Jung and Jazizadeh in 2019. Depending on the type and form of building and geographical location, the first group attempted to identify many HVAC systems. Some information related to virtual systems was estimated. Operational and structural costs, required space, required power and system life were estimated depend on the base of the thumb, although it is not very precise. The second sub-group was created to identify defects in the project design. This group has the property of determining the physical properties of the elements used in the construction, so it is used to determine the value of insulation based on the information obtained from the work profiles.

The third subgroup is based on knowing where the factors identified in the first subgroup were assessed more accurately. To determine the HVAC components and system control methods two and four sets were used. These two groups contain information about how to control HVAC and its components. Despite the quality and modernity of the system, the shortcomings of the expert system were identified [77]:

- a) The wrong decisions may be generated due to the reliance on simple rules of guiding knowledge by the expert system. These wrong decisions cannot be controlled and corrected during construction [78].
- b) The possibility of applying this tool in different buildings under other climatic conditions is not clearly defined [78].

- c) It was not clear the use of criteria in how to choose the HVAC system in the first group [78].
- d) Environmental impacts and indoor air quality of HVAC were not considered [79].

## 2.2 HVAC System Performance Evaluation Criteria

As part of the research plan and to choose the appropriate alternative it is necessary to define key criteria to complete the decision-making process. The main need for criteria lies in giving each alternative its appropriate evaluation based on the criteria values and using decision-making techniques. The main criteria are subdivided into sub-categories in order to ensure better and reliable results by looking at the precise topics. A set of criteria must be defined in the process of choosing the best alternative in order to ensure the effectiveness of the decision-making process. Criteria help in achieving the goals set more efficiently and in identifying areas that can be improved. Through the criteria, important scientific, technical, and environmental aspects can be identified.

Numerous research and studies have emphasized the importance of each of the criteria in assessing the performance of HVAC systems. The Table 2.1 shows each criterion with references that confirm its importance.

Table 2.1 Criteria with References.

Main criteria	Sub-criteria	Reference
Ergonomics	Ventilation	Fisk, W. J. (2017)[80], Sundell, et al. (2011)[81], Batterman, et al. (2017)[83], Mendell, et al.(2013)[84], Wargocki, P., & Wyon, D. P. (2013)[85], Zomorodian, Z. S., Tahsildoost, M., & Hafezi, M. (2016)[86].
	Relative humidity	Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Soyguder, S., Karakose, M.,

		<p>&amp; Alli, H. (2009)[88], Altun, H., &amp; Yalcinoz, T. (2008)[89], Chen, W. C., Fu, G. L., Tai, P. H., &amp; Deng, W. J. (2009)[90], Yeh, J. S., &amp; Cheng, C. H. (2005)[91], Frias-Martinez, E., Magoulas, G., Chen, S., &amp; Macredie, R. (2005)[92].</p>
	Visual impact	<p>Wang, J. J., Jing, Y. Y., &amp; Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Chowdhury, A. A., Rasul, M. G., &amp; Khan, M. M. K. (2008)[93], Korkas, C. D., Baldi, S., Michailidis, I., &amp; Kosmatopoulos, E. B. (2016)[94], Korkas, C. D., Baldi, S., Michailidis, I., &amp; Kosmatopoulos, E. B. (2015)[95], Yang, L., Yan, H., &amp; Lam, J. C. (2014)[96], Becker, R., &amp; Paciuk, M. (2009)[97].</p>
	Noise level	<p>Wang, J. J., Jing, Y. Y., &amp; Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Arroyo, P., Tommelein, I. D., Ballard, G., &amp; Rumsey, P. (2016)[35], Jennings, P. A., Dunne, G., Williams, R., &amp; Giudice, S. (2010)[98], Singh, S., Payne, S. R., &amp; Jennings, P. A. (2014)[99], Leite, R. P., Paul, S., &amp; Gerges, S. N. (2009)[100].</p>
	Thermal comfort	<p>Heinzerling, D., Schiavon, S., Webster, T., &amp; Arens, E. (2013)[101], Sarbu, I., &amp; Sebarchievici, C. (2013)[102], Corgnati, S. P., Ansalidi, R., &amp; Filippi, M. (2009)[103], Pei, Z., Lin, B., Liu, Y., &amp; Zhu, Y. (2015)[104], Wang, W., Wang, J., Chen, J., Huang, G., &amp; Guo, X. (2018)[105].</p>
Economic cost	Capital cost	<p>Chinese, D., Nardin, G., &amp; Saro, O. (2011)[38], Avgelis, A., &amp; Papadopoulos, A. M. (2009)[39], Shahrestani, M., Yao, R., &amp; Cook, G. K. (2012)[106], Wang, J. J., Jing, Y. Y., &amp; Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Alanne, K., Salo, A., Saari, A., &amp; Gustafsson, S. I. (2007)[107], Cho, J., Kim, Y., Koo, J., &amp; Park, W.</p>

		(2018)[49].
	Maintenance cost	Chinese, D., Nardin, G., & Saro, O. (2011)[38], Avgelis, A., & Papadopoulos, A. M. (2009)[39], Shahrestani, M., Yao, R., & Cook, G. K. (2012)[106], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Alanne, K., Salo, A., Saari, A., & Gustafsson, S. I. (2007)[107], Au-Yong, C. P., Ali, A. S., & Ahmad, F. (2014)[108], Bouvard, K., Artus, S., Bérénguer, C., & Cocquempot, V. (2011)[109].
Technical properties	Water consumption	Alipour, V., Mahvi, A. H., & Rezaei, L. (2015)[110], Chakrabarti, S. S., & Das, P. K. (2015)[111], (Chan and Ng, 2015), El-Morsi, M., Klein, S. A., & Reindl, D. T. (2003)[112], Elmer, T. H., & Hyde, J. F. (1986)[113].
	Energy consumption	Avgelis, A., & Papadopoulos, A. M. (2009)[39], Shahrestani, M., Yao, R., & Cook, G. K. (2012)[106], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Arroyo, P., Tommelein, I. D., Ballard, G., & Rumsey, P. (2016)[35].
	CO <sub>2</sub> emission	Avgelis, A., & Papadopoulos, A. M. (2009)[39], Shahrestani, M., Yao, R., & Cook, G. K. (2012)[106], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Alanne, K., Salo, A., Saari, A., & Gustafsson, S. I. (2007)[107].
	COP heating	Yu, F. W., & Chan, K. T. (2005)[114], Aprea, C., Mastrullo, R., Renno, C., & Vanoli, G. P. (2004)[115], Koury, R. N. N., Machado, L., & Ismail, K. A. R. (2001)[116], Shelton, S. V., & Weber, E. D. (1991)[117], Manske, K. A., Reindl, D. T., & Klein, S. A. (2001)[118].

	COP cooling	Yu, F. W., & Chan, K. T. (2005)[114], Aprea, C., Mastrullo, R., Renno, C., & Vanoli, G. P. (2004)[115], Koury, R. N. N., Machado, L., & Ismail, K. A. R. (2001)[116], Shelton, S. V., & Weber, E. D. (1991)[117], Manske, K. A., Reindl, D. T., & Klein, S. A. (2001)[118].
	Single control zone	Mirinejad, H., Sadati, S. H., Ghasemian, M., & Torab, H. (2008)[119], Afram, A., & Janabi-Sharifi, F. (2014), Lei, J., Hongli, L., & Cai, W. (2006)[121], Wen, J. T., & Mishra, S. (2018)[123], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Perera, D. W. U., Pfeiffer, C. F., & Skeie, N. O. (2014)[122].
	Multi control zone	Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Geng, G., & Geary, G. M. (1993)[124], Dounis, A. I., Bruant, M., Santamouris, M., Guarracino, G., & Michel, P. (1996)[125].
Physical properties	Indoor area requirement	Arroyo, P., Tommelein, I. D., Ballard, G., & Rumsey, P. (2016)[35], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Wang, W., Rivard, H., & Zmeureanu, R. (2006)[126], Ouarghi, R., & Krarti, M. (2006)[127], Caldas, L. G., & Norford, L. K. (2003)[128], Ferdyn-Grygierek, J., & Grygierek, K. (2017)[129].
	Outdoor area requirement	Arroyo, P., Tommelein, I. D., Ballard, G., & Rumsey, P. (2016)[35], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Wang, W., Rivard, H., & Zmeureanu, R. (2006)[126], Ouarghi, R., & Krarti, M. (2006)[127], Caldas, L. G., & Norford, L. K. (2003)[128], Ferdyn-Grygierek, J., & Grygierek, K. (2017)[129].
	Indoor appearance	Yang, Z., M. Peng, and L. Wang, (2006)[130], Saïd, M.N.A., R.A. MacDonald, and G.C. Durrant, (1996)[131],

		Yi, L., et al., (2005)[132], Tan, G. and L.R. Glicksman, (2005)[133], Huang, C. and X. Wang, (2009)[134], Helmis, C.G., et al., (2007)[135], Stamou, A. and I. Katsiris, (2006)[136].
	Outdoor appearance	Yang, Z., M. Peng, and L. Wang, (2006)[130], Saïd, M.N.A., R.A. MacDonald, and G.C. Durrant, (1996)[131], Yi, L., et al., (2005)[132], Tan, G. and L.R. Glicksman, (2005)[133], Huang, C. and X. Wang, (2009)[134], Helmis, C.G., et al., (2007)[135], Stamou, A. and I. Katsiris, (2006)[136].
flexibility	Installation flexibility	Chinese, D., Nardin, G., & Saro, O. (2011)[38], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani,et al. (2018)[61], K.M. Patel, P.K. Jain, D.K. Koli, (2015)[137], S.S. Wane, M.B. Nagdeve, (2012)[138], K. Mukesh, R.M. Sarviya, J.L. Bhagoria, (2011)[139], M.K.A. Saeedi, (2012)[140], K.S. Meenakshi, E.P.J. Sudhan, (2011)[141]
	Integration flexibility	Chinese, D., Nardin, G., & Saro, O. (2011)[38], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani,et al. (2018)[61], K.M. Patel, P.K. Jain, D.K. Koli, (2015)[137], S.S. Wane, M.B. Nagdeve, (2012)[138], K. Mukesh, R.M. Sarviya, J.L. Bhagoria, (2011)[139], M.K.A. Saeedi, (2012)[140], K.S. Meenakshi, E.P.J. Sudhan, (2011)[141], ] C.B. Pawar, K.R. Aharwal, Alok Chaube, (2009)[142], Trane, (2011)[143], J. Braun, S. Klein, W. Beckman, J. Mitchell, (1989)[144], V.M. Zavala, (2012)[145].
	Energy source	P.D. Lund, J. Lindgren, J. Mikkola, J. Salpakari, (2015)[146], R. Aazami, K. Aflaki, M.R. Haghifam, (2011)[147], A. Arteconi, F. Polonara, (2017)[148], M.

	flexibility	Stadler, W. Krause, M. Sonnenschein, U. Vogel, (2009)[149], G. Niro, D. Salles, M.V. Alcântara, L.C. da Silva, (2013)[150], E. Kremers, J. Mari, O. Barambones, et al., (2013)[151], F. Sossan, V. Lakshmanan, G.T. Costanzo, M. Marinelli, P.J. Douglass, H. Bindner, (2016)[152], T.G. Hovgaard, L.F. Larsen, K. Edlund, J.B. Jørgensen, (2012)[153].
	Ease of maintenance	A. Kusiak, M. Li, F. Tang, (2010)[154], M. Mossolly, K. Ghali, N. Ghaddar, (2009)[155], S. Yoon, C. Park, G. Augenbroe, (2011)[156], M. Zaheer-uddin, G.R. Zheng, (2000)[157], J. Braun, S. Klein, W. Beckman, J. Mitchell, (1989)[158], L. Lu, W. Cai, Y.S. Chai, L. Xie, (2005)[159], V.M. Zavala, (2012)[160], Q. Liu, Z. Wang, X. He, D. Zhou, (2014)[161].
Reliability	Lifetime	Arroyo, P., Tommelein, I. D., Ballard, G., & Rumsey, P. (2016)[35], Chinese, D., Nardin, G., & Saro, O. (2011)[38], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], Wang, W., Rivard, H., & Zmeureanu, R. (2006)[126], Q. Tu, D. Zou, C. Deng, J. Zhang, L. Hou, M. Yang, G. Nong and Y. Feng, (2016)[162], T. N. Aynur, (2010)[163], J.-L. Lin and T.-J. Yeh, (2007)[164], S. Atas, M. Aktas, I. Ceylan and H. Dogan, (2017)[165].

	Lead time	Chinese, D., Nardin, G., & Saro, O. (2011)[38], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], B Stephens, A. Novoselac, J.A. Siegel, (2010)[166], J.A. Siegel, (2016)[167], D.B. Shirey, H.I. Henderson, (2004)[168], K.S. Cetin, P.C. Tabares-Velasco, A. Novoselac, (2014)[169], B Stephens, J.A. Siegel, A. Novoselac, (2011)[170], M. Touchie, J.A. Siegel, (2018)[171], J.W. Thornburg, C.E. Rodes, P.A. Lawless, C.D. Stevens, R.W. Williams, (2004)[172].
	Repair time	Chinese, D., Nardin, G., & Saro, O. (2011)[38], Wang, J. J., Jing, Y. Y., & Zhang, C. F. (2009) [87], Shahrestani, et al. (2018)[61], B Stephens, A. Novoselac, J.A. Siegel, (2010)[166], J.A. Siegel, (2016)[167], D.B. Shirey, H.I. Henderson, (2004)[168], K.S. Cetin, P.C. Tabares-Velasco, A. Novoselac, (2014)[169], B Stephens, J.A. Siegel, A. Novoselac, (2011)[170].
	Fewer component	M. Zaheer-uddin, G.R. Zheng, (2000)[157], J. Braun, S. Klein, W. Beckman, J. Mitchell, (1989)[158], L. Lu, W. Cai, Y.S. Chai, L. Xie, (2005)[159], V.M. Zavala, (2012)[160], Q. Liu, Z. Wang, X. He, D. Zhou, (2014)[161], T. N. Aynur, (2010)[163].
	Vendor availability	P.D. Lund, J. Lindgren, J. Mikkola, J. Salpakari, (2015)[173], R. Aazami, K. Aflaki, M.R. Haghifam, (2011)[174], A. Arteconi, F. Polonara, (2017)[175], M. Stadler, W. Krause, M. Sonnenschein, U. Vogel, (2009)[176], G. Niro, D. Salles, M.V. Alcântara, L.C. da Silva, (2013)[177].

To reach the best alternative, criteria must be classified in order to be relied upon MCDM. The criteria were compiled based on several previous studies and with the assistance of a group of experts. The criteria are carefully classified to include technical, environmental, and economic fields. For sufficient information, each criterion is detailed and detailed in the next section.

### **2.2.1 Ergonomics**

The focus is on unhealthy problems that result from HVAC systems and cause many diseases for people inside the building. Getting thermal comfort and high air quality has become the focus of attention of this period as it has become a new focus for study owners because of its great importance. Not only does the temperature greatly affects people's health, but also the movement of air and high humidity throughout the building [80].

#### **2.2.1.1 Ventilation**

There is an increasing interest at present in the rates of ventilation inside buildings and factories where associations and technical organizations focus on ventilation along with air quality and thermal comfort. They consider them to be the main topics, especially in factories. Technical societies are concerned with health issues as they have issued standards related to IAQ and determine the ventilation rates. The ASHRAE 62-1689 standard explained that ventilation is necessary to accept indoor air quality. The standard states that: to provide indoor air quality directly to a specific area, high levels of air and air quality must be provided. high air quality is provided through higher rates of outdoor air. There are many pollutants in factories that cause a decrease in air quality and the outside air itself may be polluted due to the dust [80]. It requires providing adequate ventilation to rid the air inside the factory of dust, pollutants, and smoke harmful to human health. It is necessary to choose a highly ventilated HVAC system to fulfil these demands. The choice is very important especially in factories where large quantities of harmful gases are rising [81].

### **2.2.1.2 Relative Humidity**

HVAC systems have temperature controls and humidity control units known as humidifiers, as all the details of the building's internal environment are controlled to make it comfortable for residents. Thermostats are available as temperature controllers, in addition to humidity regulators, to provide a comfortable environment [82]. Humidifiers are used as part of central HVAC systems to reduce winter dehydration and maintain internal relative humidity in closed buildings. During high temperatures, the humidity inside the building increases as the hot air contains a high percentage of humidity that is controlled by humidifiers. Once the building's humidity level is low, the humidifier will self-serve to provide the required humidity. This feature is available in some HVAC systems, which is a very important feature because of the diseases and humidity that affect the walls of the building [91]. It is necessary to determine which HVAC system possesses this very important property by the decision-maker. Precise control of humidity, temperature, and ventilation level is required, especially in factories that are highly affected by IAQ. Sometimes the quality of the product is affected by the high humidity, which causes great losses [92].

### **2.2.1.3 Visual Impact**

The HVAC system is available nowadays in all workplaces for ventilation and providing the required comfort for workers and employees. Sometimes HVAC systems cause harm to health, especially the eyes. Despite the great benefit that these systems provide, some systems have a clear impact on health. During prolonged periods of work, employees can have dry eyes due to prolonged sitting in an air-conditioned environment [94]. The eye is the most sensitive part of the human body, so it is more susceptible to diseases caused by conditioning systems. Many systems reduce humidity, causing eye dryness and inflammation. For this reason, the air distribution system has a major impact on choosing a suitable and suitable air conditioning [95].

#### **2.2.1.4 Noise Level**

At present, there is a clear increase in working hours due to the development and intensity of globalization. Because of the intense competition in the markets at the international and individual levels, employers stress the need to increase production by forcing employees to work overtime and for a higher effort [2]. The employees try to do their best to get the job done. For this, it is important to have a refreshing working environment free of noise as possible. The comfortable environment plays a positive role, no matter how, it helps workers present everything they have and passively in the event of noise and discomfort, causing discomfort, anxiety, and stress. Acoustic comfort, lighting and thermal comfort are essential elements in a modern work environment [99]. Noise is a very important problem, especially in the current era due to the increase in devices in the workplace. The machines in the factories cause loud noise that annoys the workers, in addition to the HVAC systems, some of which also cause noise. Choosing a suitable HVAC system with fewer voices and noiseless noise has a major role in reducing staff stress and discomfort and plays an important role in increasing productivity. Noise is an important environmental standard on which to choose an appropriate HVAC system [100].

#### **2.2.1.5 Thermal Comfort**

The internal climate in the building depends on temperature level and that it is at an acceptable and comfortable level for the people regardless of the condition of the climate outside the building. Indoor air should be comfortable, acceptable, and clean [103]. Thermal comfort can be described as the person expressing his acceptance and satisfaction with the surrounding environment through his self-response (ASHRAE). Hygiene, noise, and acoustics express physical and mental comfort. Ventilation, humidity, and temperature levels express the thermal comfort of the body. As a result of heat exchange of the environment with the body, the feeling of heat comfort for people is the most important element [104]. The thermal environment is affected by air temperature, air speed and humidity as well as by the activity rate and clothing. The primary purpose of the HVAC system is to generate acceptable levels of internal

building thermal conditions. The HVAC system has a primary mission to provide thermal comfort by adding or removing heat. The system also removes or adds moisture to the building. HVAC systems differ in terms of providing the required thermal comfort, and this depends on several factors that combine to provide acceptable comfort. Thermal comfort and (IAQ) are fundamental to the HVAC system, which decision makers focus on choosing the appropriate system [105].

### **2.2.2 Economic Cost**

Buildings with high energy performance are relatively expensive, but they are technically applicable in some countries. Investment cost and energy performance are always the important factors that are often differentiated between during choosing HVAC systems. Many factors affect the cost of a building, as the relative cost of HVAC systems is very high. Therefore, it is necessary to consider and focus carefully to choose the most appropriate and least expensive system [38]. Quality, cost, and time are among the main factors that are interconnected. Customers are searching for highly efficient buildings with a specific period at a lower cost. Due to the changes that occur in the properties of the building, investment costs arise and constitute 15% of the capital costs and represent mechanical and electrical costs. The HVAC system consumes about 50% of the total power in a small office building. Therefore, choosing an appropriate system with the lowest cost and consumption in the early stages of design has a major impact on the decision-maker [107]. Cost is a critical component of choosing a HVAC system, so this standard has been taken among the most important criteria. Most studies are limited to the total cost of a building, but there are rare studies on cost in HVAC systems [61].

#### **2.2.2.1 Capital Cost**

The initial cost of HVAC systems is one of the most important expenditures during the system life cycle as it is a key factor during the building economic analysis process. In the long run, the initial cost for HVAC systems contributes 20-50% of the total life cycle cost. Many system design savings can be achieved. Cost estimation methods are very

important as the methods with many cost details have good results. The initial cost can also be estimated from previous experiences, with the addition of detailed specifications [39]. Despite these methods used, there must be a difference in the bids. HVAC systems differ from each other in terms of the initial cost. The systems consist of major components: air ducts, control devices, cooling towers, air handling unit and refrigeration station. Lowest systems are often less expensive devices and equipment. It is important to know the costs of the equipment and then the costs of the design. 85% of the estimated costs of the design goes to equipment and labour, while 15% goes to the contractor as profits and overheads. It is important to estimate the initial cost of HVAC systems and to choose the appropriate cost system that can provide a financial value that can be used in other areas [105,106].

#### **2.2.2.2 Maintenance Cost**

HVAC systems are designed inside factories, buildings, and offices to ensure thermal comfort, ventilation, and humidity levels. To avoid the spread of pollutants, bacteria and viruses, buildings require high air quality and ventilation. The level of humidity and ventilation control should be very high and always check proper operation [108]. To reduce failure and errors exposure to HVAC systems that lead to an additional cost, it is necessary to carry out regular maintenance of these systems. The cost of these errors is complicated and sometimes high. The maintenance cost for HVAC systems varies depending on the type of system, equipment condition and conditions of use. When the system equipment increases, the maintenance cost increases. Maintenance is essential for HVAC systems to avoid faults. Therefore, it is necessary to consider the cost of maintenance when choosing the best HVAC system [109].

#### **2.2.3 Technical Properties**

Technical properties include the amount of energy and water consumption, system efficiency, temperature control and gas emissions.

### **2.2.3.1 Water Consumption**

HVAC water systems work by pumping cooled water after lowering the temperature in it to the (AHU). The water inside the (AHU) continues to transfer through the heat transfer coil. The air handling unit pumps the air and forces it out from certain openings in the room. The hotter air moves in the room until it comes into contact with the low-temperature cooling coil and is returned to the cooling tower [110]. A large amount of water is lost during this process through evaporation and erosion in the form of droplets carried by the airflow. Factories and commercial buildings consume a large amount of water. Water consumption depends on the type of building, climate, and the quality of the HVAC system. HVAC systems consume 48% of the building's water consumption. This is a very large percentage and calls for choosing an HVAC system that can reduce consumption [111].

### **2.2.3.2 Energy Consumption**

The population growth rate is constantly increasing, which confirms the increase in the number of buildings and factories, which leads to an increase in energy consumption. According to studies carried out by the International Energy Agency (IEA), half of the energy consumption in buildings and factories is due to HVAC systems for ventilation and thermal comfort purposes. According to studies, energy consumption in the building is determined by several factors: the selection of an appropriate HVAC system, building design and maintenance, and a change in the standards of comfort for people [69].

Factories consume a large amount of energy in all countries of the world. Energy consumption in factories is estimated globally at 52% in 2008, as shown in figure 2.1.

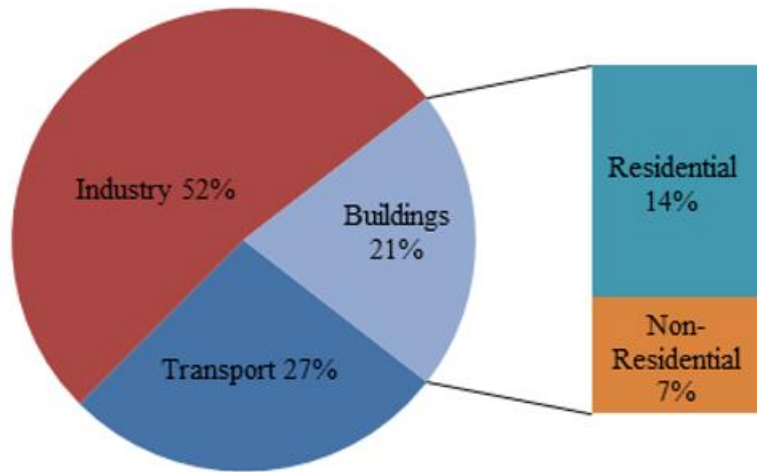


Figure 2.1 General energy consumption [66].

In the United States in 2010, energy consumption was about 30% in factories as shown in figure 2.2.

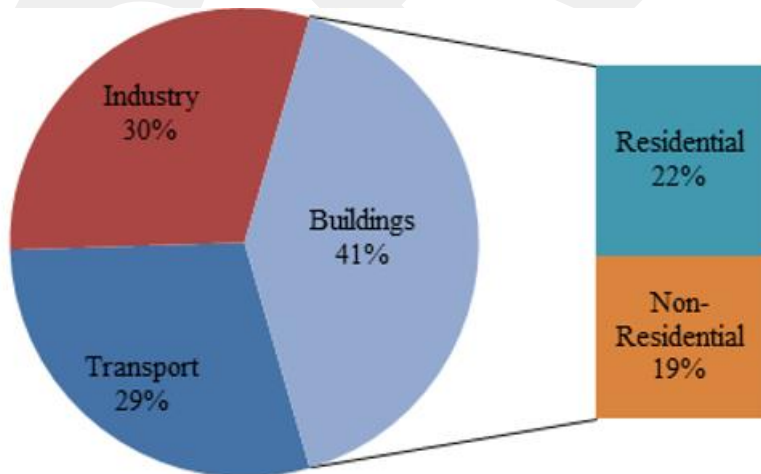


Figure 2.2 Energy consumption in United States [66].

HVAC systems consume 43% of total energy consumption in factories as shown in figure 2.3. This percentage is high compared to other sources of consumption.

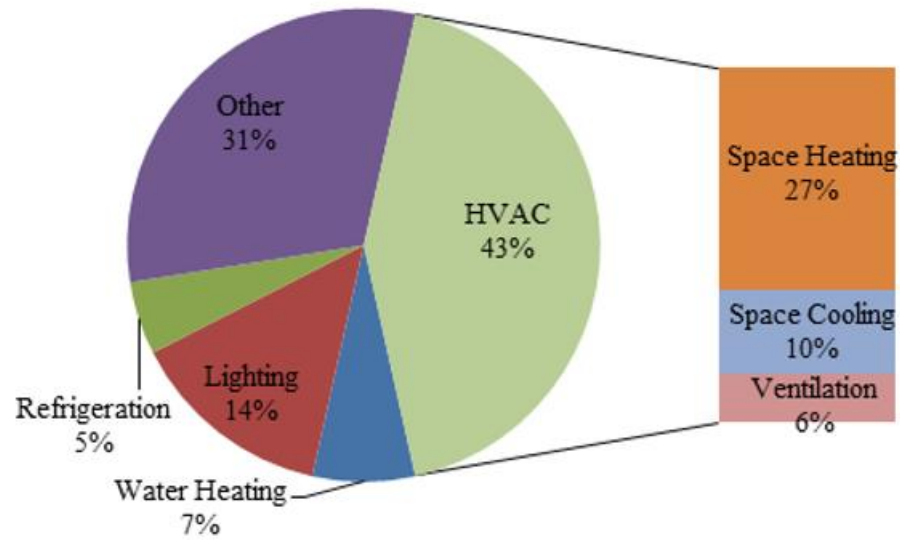


Figure 2.3 HVAC systems energy consumption [66].

Therefore, choosing the HVAC system with less consumption can reduce the total energy consumption in the world. Consumption is a very important topic and it is the most important criterion to choose the best HVAC system [61].

### 2.2.3.3 CO<sub>2</sub> Emission

Global developed countries are looking for increased efforts to transform global cities into sustainable, more liveable cities. These efforts are being made to raise the level of buildings in terms of emissions and concern for the environment to rid cities of CO<sub>2</sub> damage and other emissions. It is found great interest in city planning and building design to maintain the balance of the modern ecosystem. Studies have shown that the operating capacity that is consumed in daily life is much greater than the energy used in building and designing the building [48]. That is why today attention is focused on reducing CO<sub>2</sub> emissions from buildings, especially industrial buildings, to maintain the ecosystem. Choosing a HVAC system with a lower emission rate is a great opportunity for decision-makers and engineers. The HVAC system is responsible for a large proportion of the CO<sub>2</sub> emissions from fuel combustion. This criterion is one of the most important criteria by which the best HVAC system is chosen in addition to energy consumption [105].

#### **2.2.3.4 Coefficient of Performance (COP) Heating & Cooling**

It is an evaluation of the cooling and heating performance of HVAC systems. On the other hand, it is a tool to evaluate the effectiveness of the HVAC system in transferring an amount of heat or cooling versus the amount of electrical energy consumption. COP is the amount of heat that can be transferred at a certain temperature from the air conditioner at a certain amount of energy. The primary use of this tool is in performance evaluation of geothermal heat pumps. It is also used in the evaluation of the cooling and heating performance of HVAC systems. COP shows the amount between the input power (electricity) and the output power generated by the system [114].

$$\text{COP} = \text{power output}/\text{power input}$$

When choosing the best HVAC system, it is preferable to choose the system that generates a large amount of energy with less electricity. COP is a key criterion for rating the efficiency of HVAC systems [115].

#### **2.2.3.5 Single Control Zone**

The concept of single-zone control means the ability to control every part of the building. When one temperature controller is available and one of the rooms requires an increase in temperature due to the location or thermal load, this leads to an increase in the temperature of the other rooms where the building is hotter. In the case of other rooms getting hot without being needed, people are forced to open windows, which causes a significant decrease in temperature and a significant loss of energy used for heating. This is due to the difference in the appropriate and comfortable temperature from one person to another [120]. Adding a controller in each room will give the person the freedom to change the temperature according to personal comfort. The multi-zone control system provides a lot of energy as there are many rooms where there is no need for heating or ventilation for that and through the thermostat the system is isolated and the energy used is saved. There are some negatives in this system that can affect the positives available in the system, as this system needs many equipment and devices, as well as electronic barriers to direct air to different areas [121].

### **2.2.3.6 Multi Control Zone**

One of the goals of decision-makers is to choose an HVAC system with an efficient controller to meet convenience requirements and reduce energy consumption. This is due to the high demand for HVAC systems, as it is one of the major devices that consume a large amount of energy in the building [123].

A multi-zone system consists of an outdoor unit connected to several indoor units via connecting tubes [121]. It is possible to install from 2 to 8 connecting tubes, both external and internal units. The multi-zone system differs from the one-region system in that it requires a high cost, complex installation, and many additional requirements. The multi-zone system does not provide on-demand comfort as it cools or warms the entire building with the same temperature [119].

### **2.2.4 Physical Properties**

The physical properties of HVAC systems include the requirements of the interior and exterior space, the shape and appearance of the interior and exterior of the system.

#### **2.2.4.1 Indoor Area Requirement**

The area of electrical and mechanical requirements ranges between 4%-9% of the total building area. Buildings generally fall within a range of 6% to 9% as mentioned in ASHRAE. The distribution system and connection ducts occupy the largest part of the total area of the building concerning the central HVAC system. As for the local systems, the internal distribution device and the internal piece occupy more space and the ducts do not occupy the large area inside the building [126]. The required horizontal and vertical space within the building must be taken into account. Indoor ventilation requires fans and other equipment that requires adequate space. Conduits for systems that heat water require large places inside each room where they require electrical and mechanical distribution [127].

#### **2.2.4.2 Outdoor Area Requirement**

The outdoor space is very important for HVAC systems as it requires sufficient air. The central system requires a large area on the side or top of the building and this is controlled by space restrictions. The equipment room is located outside the building where it does not require air conditioning and it is best to choose a suitable central location for it to facilitate maintenance and operation and reduce and simplify the connection ducts and column layouts [126]. The size of the equipment room should be taken into account to facilitate the installation and removal of equipment and for ventilation and maintenance as it contains refrigeration equipment including cooling towers, pumps, boilers, heat exchangers and other equipment. The local HVAC system takes up less space compared to the central system because it is limited to one or more rooms where its size is small [132].

#### **2.2.4.3 Indoor Appearance**

HVAC systems and their design play a big role in modern buildings. The choice of a highly efficient system is closely related to the energy efficiency of the building. The choice of a system with aesthetic is closely related to the architecture and design of the building. The central system greatly affects the shape of the building from the inside because of the large number of connection ducts, which requires packaging and concealment tools [133]. As for the local system, it does not significantly affect the aesthetic of the building from the inside. The water systems clearly affect the interior of the building due to the large number of radiators, connecting tubes, and mechanical equipment. The choice of HVAC system with an external and internal aesthetic is very popular with people as well as efficiency [136].

#### **2.2.4.4 Outdoor Appearance**

When every person thinks about building a beautiful building or factory and designing its structure in a nice-looking way, HVAC system design comes to mind, which is

necessary and clearly affects the exterior design of the building. The design and selection of the HVAC system is important in the early stages of planning as well as in building design. Many engineers do not consider this, and at the end of the building design they suffer from many problems that affect the aesthetic of the building [136]. Engineers usually realize the importance of choosing an HVAC system in the final stages of work, which causes many problems affecting the architectural design of the building. There are many types of high-performance HVAC systems, but the aesthetic of the system reflects another image that clearly influences system selection. The building owner can achieve a balance that reflects a better image by choosing the system with the highest performance and the most aesthetic [137].

### **2.2.5 Flexibility**

Flexibility includes installation flexibility, system integration, easy maintenance, and power supplies.

#### **2.2.5.1 Installation Flexibility**

HVAC systems vary in installation and design. Often the outdoor unit is easy to configure and only takes up space. As for the indoor unit, it represents the biggest problem in HVAC systems as they differ in terms of flexibility of installation. Some systems are formed as a network of pipes inside the wall, ceilings or floors and are difficult to install. Others are in the form of fans in the ceilings connected by pipes and others in the form of heat pipes for heating purposes [139]. When a HVAC system is required to be replaced or installed in a building, decision-makers and engineers face a difficult decision to choose between systems. Systems differ when installed in terms of speed and ease. Some systems are complex and require more time and costs [140]. When the customer requests the design of the HVAC system for a particular building, the flexibility of the installation plays an important role in terms of equipment consumption and influence the architectural form of the building and the time required. Ducting is the most important and difficult task when installing HVAC systems. The

systems differ in terms of flexibility, and after the decision-maker who makes the critical decision in choosing the system [141].

#### **2.2.5.2 Integration Flexibility**

The integration flexibility indicates the potential for future improvement, addition and integration of the HVAC system. Modern buildings require a comfortable, noise-free work environment with a good level of humidity and ventilation. The improvement in worker comfort required by reducing noise and providing thermal comfort cannot be made in many HVAC systems because they are statically designed and cannot be changed. [154].

Due to future climate and economic standards and criteria, the demand for HVAC systems will increase and remain in vogue. The increasing demand for HVAC systems in the future underlines the importance of various improvements to reduce energy consumption, technical failures, installations, noise, cost and harmful gas emissions [155]. Air conditioning systems differ from each other, and each type has characteristics that differ from the others. Future flexibility and the ability to integrate, change and install HVAC systems is an important issue focused on future work to facilitate technical change processes [156].

#### **2.2.5.3 Energy Source Flexibility**

The process for selecting a HVAC system in a building depends on several criteria that can be considered and determined important by the decision-maker. One of these criteria is the availability of energy sources and easy access to them, in addition to their low cost. The main energy sources are gas, oil, and electricity [173]. The choice of energy source depends on the inhabited area because some types of energy are not available in other regions. When choosing a HVAC system that runs on specific fuel energy, the environmental impact remains an important factor in choosing a power source [174]. When choosing a specific HVAC system that operates on a specific fuel, it is necessary to pay attention to energy efficiency and meet the needs of thermal comfort. Decision-making if all sources of energy are available are very difficult because they are linked to other factors that affect one another [175].

#### **2.2.5.4 Ease of Maintenance**

The HVAC system consumes about two-thirds of the energy in the building, so it is necessary to carry out regular maintenance to improve efficiency and obtain thermal comfort in the least possible time. Maintenance is an important way to ensure that the system is free of problems and errors and to extend the life of the system [155]. HVAC systems differ among themselves in terms of ease of maintenance and how to access all system equipment for the purpose of maintenance. Systems with complicated maintenance and difficult access to equipment can cause neglected maintenance by the building owner. Ease of maintenance is a secondary criterion that is not often emphasized [154].

The main tasks that can be performed include changing the air filter, removing dirt, tightening electrical connections, and lubricating moving parts. These processes help the system prevent sudden breakdowns. Easy maintenance helps choose the right building HVAC system. Decision-makers always focus on choosing a simple and inexpensive system to avoid breakdown and prohibitive costs, and to increase reliability [156].

#### **2.2.6 Reliability**

Reliability includes system lifetime, lead time, repair time, lowest components, and vendor availability.

##### **2.2.6.1 Lifetime**

The shelf life of HVAC systems is from 15 to 25 years with maintenance available. The life of the system depends on the proximity of the pollutants that cause corrosion, maintenance, operating hours, and the type of device used. Some engineers have indicated that the system life ranges between 15 to 30 and an average lifetime of 20 years. There are multiple classifications for the age of HVAC systems. Where the average lifetime of air systems is 16 years, the average life of the boilers is 25 years and that of the heat pumps is 15 years [38]. The life of the system in each type depends on

several different internal factors related to electrical and mechanical equipment. System life is an important factor for the decision-making as a system with a long life can provide more investment. It is necessary to choose a long-life HVAC system as it has a major influence on decision making [126].

#### **2.2.6.2 Lead Time**

In each HVAC system, there are three basic parts for fixation: the outdoor unit, the indoor unit, and the connection ducts. The indoor unit is installed on a wall or ceiling, according to the appropriate location. The outdoor unit shall be fixed on a concrete base to the side or top of the building, provided that the base of the outdoor unit does not come into contact with water. The connection between these two units is carried out with electrical wires, connecting tubes and operating keys [167]. Installation time varies depending on the type, make, and model of the system. Installing the system does not require a long time in all cases; however, at present, users tend to complete all the needs of the building as quickly as possible. Due to the rapid needs of customers, it is imperative to choose an HVAC system that is easy to install and does not take much time [171].

#### **2.2.6.3 Repair Time**

Repair time is the time required to maintain and repair system errors. All buildings feature an HVAC system to maintain a safe and comfortable temperature for employees, customers, goods and equipment important to the business. The HVAC system is robust and is designed to last for many years, but like all mechanical equipment, it begins to wear or requires cleaning over time. This is why it is important to service the various parts of your HVAC system based on the recommended schedule. Different HVAC systems require different maintenance times, the air system may require 1 hour or 30 minutes, and the water system may require 15 minutes [38]. Neglecting necessary maintenance ensures a steady decline in air conditioning performance while energy use steadily increases. Maintenance of HVAC systems should be done twice a year to

maintain the system and the air quality from it. Operations require unlimited time depending on the type of system. The time required for the maintenance process is very important to the decision maker because it influences the decision making process and sometimes it prioritizes a specific system [105].

#### **2.2.6.4 Fewer Components**

HVAC systems consist of major parts including outdoor unit, indoor unit and delivery ducts. Each of these parts contains electrical and mechanical equipment. These equipment differ according to the type of system used. [163]

Systems with less space and less equipment greatly affect the decision-making process. Systems with less equipment provide a great deal of reliability. Some systems contain a large number of components, which makes them vulnerable to various errors. The decision maker relies on the criterion of the least components in choosing the best HVAC system. The system with the fewest components is often the most reliable and has the fewest errors. The decision maker relies on the lowest component criterion to select a suitable HVAC system. Maintenance cost is small with few errors. A system with smaller equipment often does not require much space [164].

#### **2.2.6.5 Vendor Availability**

HVAC systems are available in all countries of the world as they are of great importance and one of the main devices in buildings. Sellers of these systems are available in many countries, and many companies that export these systems are available with reliable and high-quality standards [147]. The local HVAC system is widely available in all countries of the world because it is a system which is easy to transport and install even after the completion of the building in addition to its low cost. The purchase of the system depends on the available references, social references, and the license [148]. The appropriate system can be classified and selected depending on its availability in the market. If the HVAC system is requested from another country or region, the transport fares are high, in addition to the possibility of crashes and errors due to transportation.

The vendor availability of the system is very important, and the decision maker focuses on this standard as part of the secondary criteria that influence decision making [146].

The above criteria are used in the decision-making process to choose the best HVAC system. The objective, criteria and alternatives are determined first and then the decision-making methodology is determined to arrive at the appropriate alternative. The methodologies used in decision-making differ according to accuracy, characteristics, and clarity. The following literature on decision-making techniques is presented to learn about the differences, methods, processes, features, priorities, and plans for each technology.

### 2.3 Decision Making Methods and Techniques

MCDM method is a widespread process and tool that basically requires work to choose one alternative from among several alternatives. The decision-making process evolved and included new and mysterious approaches to improvement. This tool helps the decision maker to solve problems that meet many criteria and many alternatives to choose the best and appropriate alternative [178]. Decision-making is widely used in energy and HVAC systems to choose the appropriate system according to the type of building, climate, and surrounding conditions. Decision-making is used as an effective tool in the problems of choosing the appropriate HVAC system because it depends on evaluating alternatives with different perspectives with many criteria available. Several decision-making approaches are available that are widely used in HVAC systems: AHP, ANP, TOPSIS, and others [179].

Decision-making methods are applied in different scientific fields. In recent years, the application of decision-making methods has increased due to the diversity and increase of products and projects. Table 2.2 shows methods, problems, and reference applied

Table 2.2 Methods, problems, and reference applied

Method	Application	Reference
SWARA and ARAS hybrid method	The enhancement of engine operating	Balki, M. K., Erdoğan, S., Aydın, S., & Sayin, C.

	parameters	(2020)[180]
SWARA&COPRAS methods	Renewable energy production	Yücenur, G. N., Çaylak, Ş., Gönül, G., & Postalcioglu, M. (2020)[181]
SWARA/ARAS hybrid method	Sustainability indicators for renewable energy systems	Ghenai, C., Albawab, M., & Bettayeb, M. (2020)[182]
Bayesian Network approach	Selecting energy efficient HVAC systems	Tian, Z., Si, B., Shi, X., & Fang, Z. (2019)[183]
SWARA—CODAS approach	Dam construction material selection	Ijadi Maghsoodi, A., Ijadi Maghsoodi, A., Poursoltan, P., Antucheviciene, J., & Turskis, Z. (2019)[184]
SWARA and WASPAS approach	Prioritizing the solutions of reverse logistics implementation to mitigate its barriers	Prajapati, H., Kant, R., & Shankar, R. (2019)[185]
WASPAS Method	risk qualitative analysis	Mohammadreza Badalpur & Ehsan Nurbakhsh. (2019)[186]
TOPSIS method	Choosing of the best flotation machine	Štirbanović, Stanujkić, Miljanović and Milanović (2019)[187]
A hybrid method (AHP-EW) and (MABAC)	Consider matching inverse logistics demands	Wang, Jiang, Zhang, Wang, Yang and Lid (2019)[188]
A hybrid (MCDM) method called (BWM-ARAS)	Futuristic copper mapping in the Abhar region, northwestern Iran	Bahrami, Hassani and Maghsoudi (2019)[189]
D-FAD method	Applications in safety maintenance planning	Seiti, Hafezalkotob, Najafi and Khalaj (2019)[190]
TOPSIS and WASPAS	Human risk assessment of Panchet dam in India	Bid, S., & Siddique, G. (2019)[191]
A hybrid MCDM-FMOO approach	Choose a sustainable resource and customize the request	Mohammed, Harris and Govindand (2019)[192]
AHP-TOPSIS method	Selection of composite materials suitable for	Patnaik, P. K., Swain, P. T. R., & Purohit, A.

	structurally complex applications	(2019)[193]
Fuzzy TOPSIS	Evaluating heat and installed power systems	Wibowo and Grandhi (2018)[194]
Choosing by advantages (CBA)	Choosing the best solution among a large number of design alternatives for HVAC systems	Arroyo, Mourgues, Flager and Correa (2018)[135]
SWARA	Improving criteria prioritization process	Zolfani, S. H., Yazdani, M., & Zavadskas, E. K. (2018)[195]
fuzzy SWARA and fuzzy COPRAS	The presence of risk criteria	Zarbakshnia, N., Soleimani, H., & Ghaderi, H. (2018)[196]
WASPAS and TOPSIS method	Selection of a car sharing station	Deveci, M., Canitez, F., & Gökaşar, I. (2018)[197]
WASPAS	Website evaluation	Stanujkić, D., & Karabašević, D. (2018)[198]
DEMATEL-based analytic network process (DANP) and (VIKOR)	Improve the airline's financial and operating performance	Pineda, Liou, Hsu and Chuang (2018)[199]
DEMATEL, VIKOR and DEMATEL based on (DANP)	Create a sustainable performance appraisal for important international airports	Lu, Hsu, Liou and Lo (2018)[200]
(DEMATEL), (DANP), (ANP), interval uncertainty and (VIKOR)	Optimization of reliability-based products	Feng, Hong, Tian, Li, Tan and Hu (2018)[201]
analytic hierarchy process (AHP)	Choose the right PCM to meet the specific requirements	Yang, Zhu, Chang, Wang, Yang and Ma (2018)[202]
WSM, TOPSIS, VIKOR and ELECTRE	Prioritizing renewable energy sources in Taiwan buildings	Lee and Chang (2018)[203]
Delphi method, (GAHP) and (PROMETHEE)	assessment of common transportation systems in Tehran City	M. Nassereddine and H. Eskandari (2017)[204]
(MCDM) techniques and combining Building	Evaluating the possibilities of	Pavlovskis, Antucheviciene and

Information Modeling (BIM)	redeveloping buildings	Migilinskas (2017)[205]
(IFAHP) method	The problem of choosing a supplier	Gülçin Büyüközka, Fethullah Göçer (2017)[206]
(MCDM) methods with geographical information system (GIS)	Convenient location for wind farms	Villacreses, Gaona, Gómez and Jijóna (2017)[207]
TOPSIS, DEA and COPRAS and	The problem of selecting materials	Nasab and Anvari (2017)[208]
(CBA)	Choosing a HVAC system for a non-energy museum	Arroyo, Tommelein, Ballard and Rumsey (2016)[35]
Analytical Hierarchy Process (AHP)	Integrated green building evaluation	Si, Halburd, Nasiri and Bell (2016)[209]
ANN techniques	Develop a site suitability index for wind energy production	Ghosh, Chakraborty, Saha, Majumder and Pal (2016)[210]
(FAHP) and (VIKOR)	Evaluate and select a third-party logistics provider selection.	Boakai, S. (2016)[211]
(WPM), (COPRAS), (AHP), (TOPSIS) and (WSM)	Affordability assessment of sustainable housing	Mulliner, Malys and Maliene (2016)[212]
(AHP), (ELECTRE) and (PROMETHEE)	HVAC system design with anticipated uncertainty of consumption	Huang and Wang (2015)[213]
SWARA	Regional landslide hazard assessment in Iran	Dehnavi, A., Aghdam, I. N., Pradhan, B., & Varzandeh, M. H. M. (2015)[214]
(TOPSIS), (DEA) and (VIKOR)	Evaluating aggregation algorithms for analyzing financial risks	Kou, Peng, Wang (2014)[215]
Bayesian Markov chain Monte Carlo method	Decision making of HVAC system	Kim, Y. J., Ahn, K. U., & Park, C. S. (2014)[34]
WASPAS Method	Manufacturing Decision Making	Shankar CHAKRABORTY, Edmundas Kazimieras ZAVADSKAS.

		(2013)[216]
RR-PARETO2	HVAC design and operation	Pantelic, J., Raphael, B., & Tham, K. W. (2012)[217]
SWARA	Selection of rational dispute resolution method	Keršuliene, V., Zavadskas, E. K., & Turskis, Z. (2010)[218]
(AHP)	Choosing the best heating system in an industrial building	Chinese, Nardin and Saro (2011)[38]
(MCDM) Electre III	Designing suitable HVAC systems for buildings	Avgelis and Papadopoulos (2009)[39]
Fuzzy technique similarity to ideal solution (TOPSIS)	Evaluation of six HVAC schemes	Wang, Jing and Zhang (2009)[87]

## **CHAPTER 3**

### **3. METHODOLOGY**

In this chapter, the methods, applications, and processes used to complete the research are explained. Chapter three explains the state of the building that was being worked on, simulation software and decision-making techniques that were applied to reach the results. The overall structure of the research, goal, criteria, and alternatives are clarified to get the best option.

The problem that the study is looking to solve lies in the high amount of energy consumed by HVAC systems and the harmful emissions they generate, causing climate pollution. The study looks to find the best alternative with high standards acceptable technically, economically, environmentally, and healthily.

The problem of choosing the best HVAC system was chosen due to the benefits and results that can be obtained from improving energy consumption, reducing damage to environment and climate, and improving thermal comfort conditions that play a big role in improving production processes in factories. These requirements and the likely results obtained from them confirm the importance of choosing a suitable alternative that has the ability to achieve the needs required, especially at the present time with the development of HVAC devices.

For solving the problem of choosing the best HVAC system, research and methodologies and methods have been discussed. It was concluded that MCDM is able to solve and find the appropriate alternative by applying it to a different set of alternatives. MCDM technology is applied in many fields related to the problem and cases of choosing the best alternative. MCDM methods was found to be a vital technology in the process of identifying an appropriate alternative. Several studies show

that MCDM methods is applicable to the problem of selecting the best HVAC system and that it has yielded good results in previous studies.

The factory building and the knowledge of the cooling and heating load are determined by the Design builder program and the building materials for the walls, ceilings, floors, and windows are specified. Work steps consist of defining the goal, criteria and alternatives first, and then defining the data for each standard through objective assessments and using the Design builder program. The standards are weighed by a group of experts. The WASPAS and SWARA methodologies are applied to reach the final results.

### **3.1 Structure of MCDM model**

Decision-making techniques are structural and general analysis of the complex problems involved in choosing the best alternatives. Decision-making techniques help find the best alternative to HVAC systems. Decision-making techniques were used in many scientific, industrial, and economic fields. Technologies are a comprehensive framework based on choosing the best alternative. SWARA and WASPAS methods are used to select the best HVAC system because of its accuracy and clarity in all applied processes, and it has proven its effectiveness and worth in many industrial and scientific fields.

The business structure of decision-making consists of several layers and includes the goal, criteria, sub-criteria, and alternatives. The standards are divided into multiple sub-criteria. Each criterion is weighed using marital comparison methods and objective weighting methods by a group of experts. In the marital comparison method, each criterion is weighed by comparing its importance with the other criterion while respecting the other alternatives. A score is obtained for each alternative, and the best alternative is to have a higher score compared to the other alternatives. In other processes and methods, a group of experts weighs each criterion through objective assessments and obtaining the best alternative.

The target layer indicates the selection of the most suitable HVAC system. The standards layer consists of 11 standards and each standard contains a number of sub-criteria. The alternatives layer refers to a group of 11 alternatives.

### **3.1.1 Goal Layer**

The goal is to choose the best HVAC system for industrial buildings by using decision-making techniques. Choosing the best HVAC system in buildings is able to reduce environmental pollution and energy consumption. A vital and futuristic system is chosen to address air quality and thermal comfort issues through efficiency, humidity reduction, noise level, and ventilation. A system with an initial economic cost and a low maintenance cost is chosen. A system with a high reliability is selected related to the life of the system, availability of energy sources, ease of installation, ease of maintenance, and vendor availability. The appropriate alternative is obtained by applying decision-making methodologies.

### **3.1.2 Criteria Layer**

The criteria layer consists of several criteria that have been evaluated and selected on the basis of importance by a group of experts who emphasized their importance. Several sub criteria are branched from the basic criteria in order to conduct accurate evaluation and analysis of the research. Criteria are weighed accurately by experts, using pairwise comparison methods and objective assessments. Some of criteria are qualitative and some of them are quantitative. Qualitative criteria (Ergonomics, Visual impact, Noise level, Economic Cost, Capital cost, Maintenance cost, Technical Properties, Water Consumption, Single control zone, Multi control zone, Physical properties, Indoor area requirement, Outdoor area requirement, Indoor appearance, Outdoor appearance, Flexibility, Installation flexibility, Integration flexibility, Energy source flexibility, Ease of maintenance, Reliability, Lifetime, Lead time, Repair time, Fewer components, Vendor availability) are evaluated by expert opinions with SWARA. Quantitative criteria (Ventilation, Relative Humidity, Thermal comfort, Energy consumption,  $CO_2$  emission, COP heating, COP cooling) are evaluated and determined by Design Builder simulation. Figure 3.1 indicates the criteria and sub criteria.

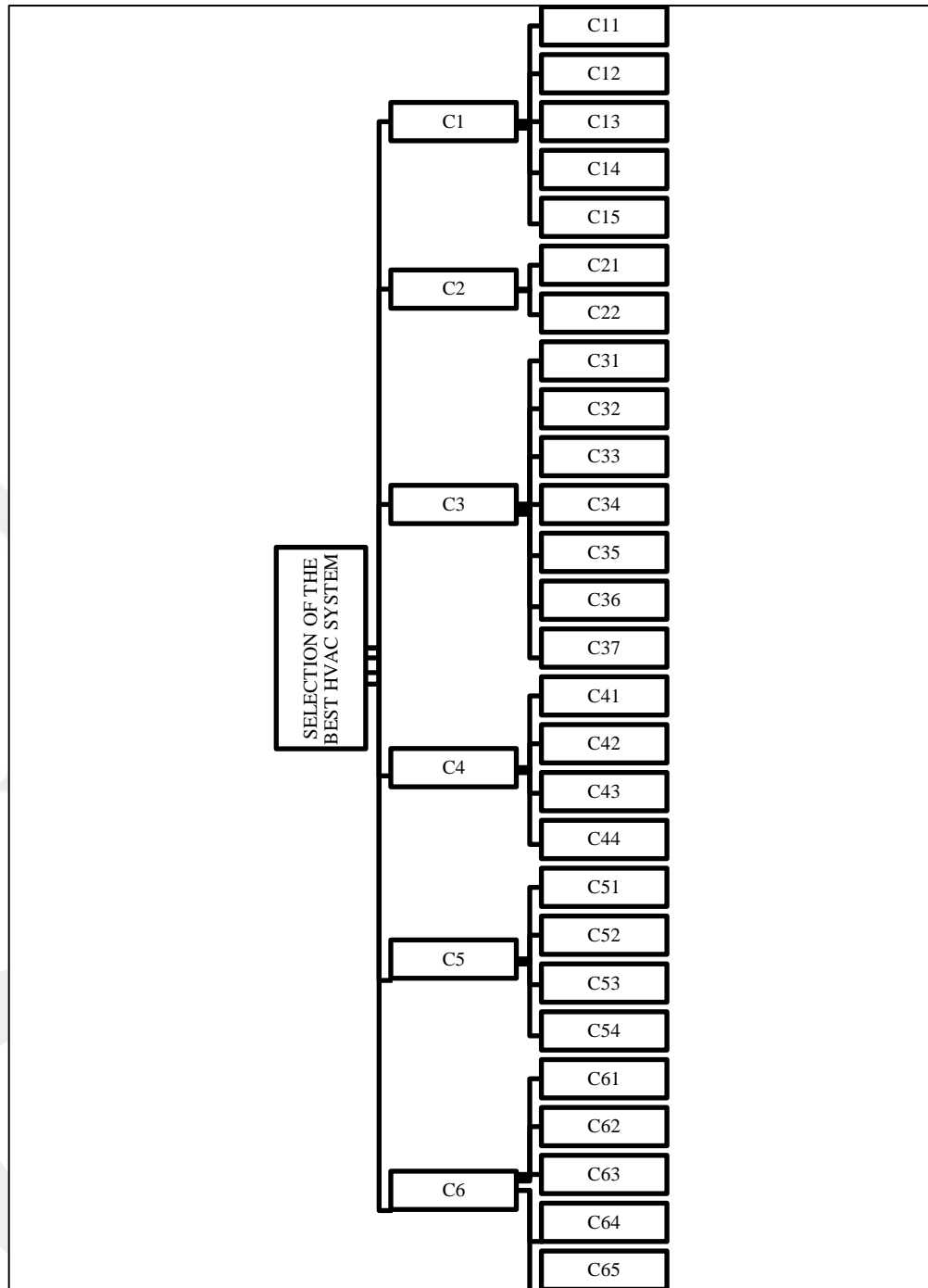


Figure 3.1 Criteria and sub criteria.

### 3.1.3 Alternative Layer

The alternatives layer consists of a set of alternatives to HVAC systems that have been identified through the available systems and experts. Through decision-making

processes, preference is gained for each alternative by weighing the criteria, and priority is given to the appropriate alternative. The alternatives were selected and identified by the experts depending on the alternatives available in the market. The alternatives used in factories, factories, companies, and residential buildings were identified for their availability and the possibility of using them in the process of choosing the best alternative. Alternatives consist of:

- All air system single Zone (CAV)
- All air system multi Zone (CAV)
- All air system terminal Reheat (CAV)
- All air system dual Duct
- All air system (VAV)
- Air-water system fan-Coil Unit
- All water system fan-Coil Unit
- Air-water system induction Unit
- Water-source heat Pumps
- Heating and cooling Panels
- Split system

Figure 2.3 indicates the structure of decision-making consisting of the objective, criteria and alternatives.

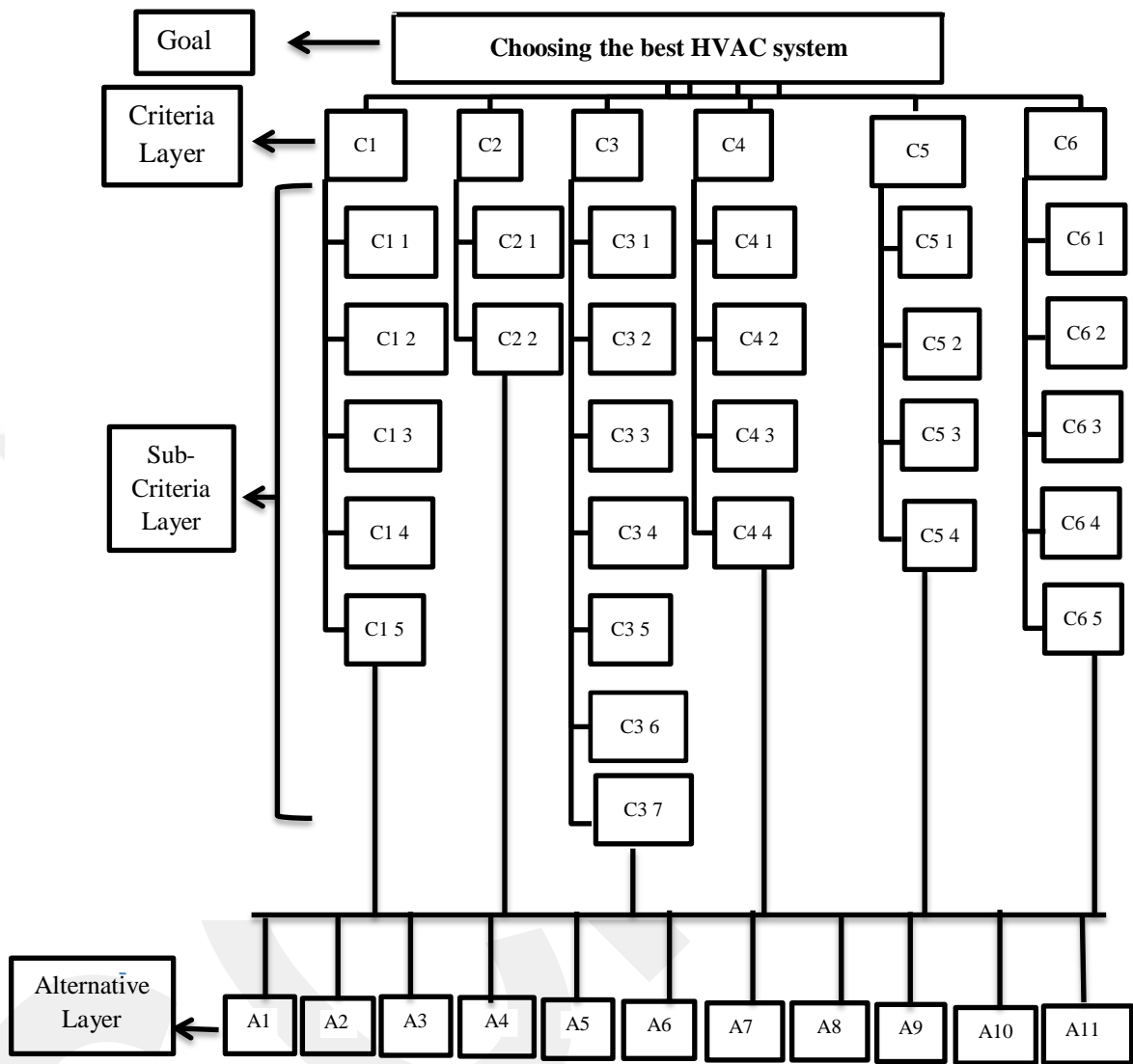


Figure 3.2 General structure of decision-making

### 3.2 Case Building

The factory consists of two parts, one of which contains machines and equipment, and the other is an office that contains a computer to conduct operations. The factory is located in Ankara, with an area of 1862 and a size of 9310.4. Figure 3.3 and figure 3.4 indicate the building's shape.

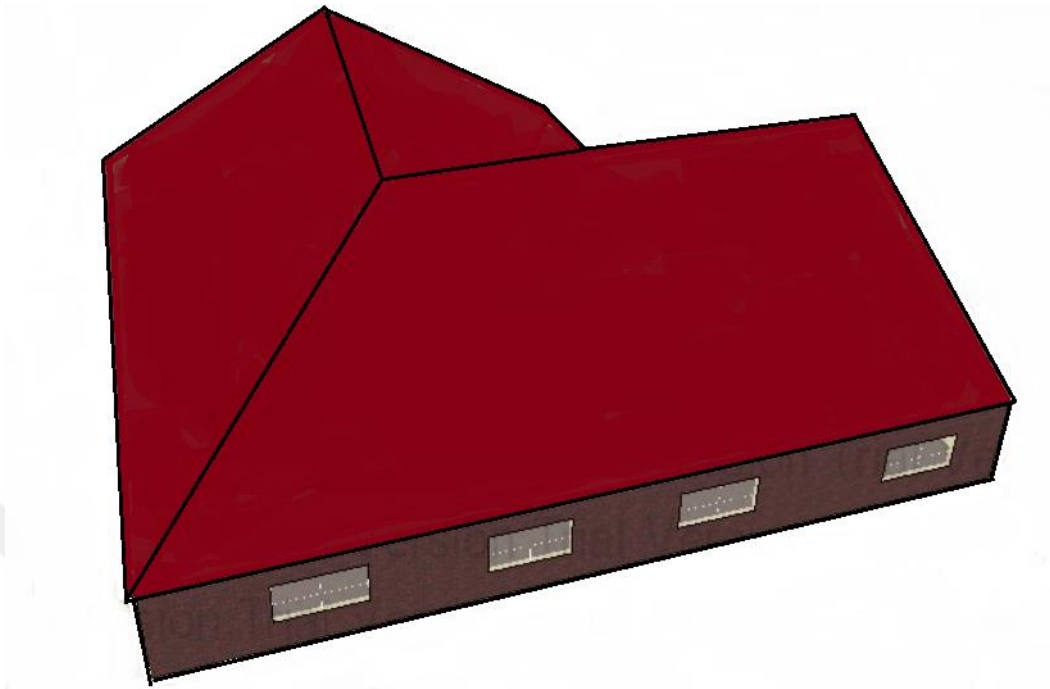


Figure 3.3 Building diagram

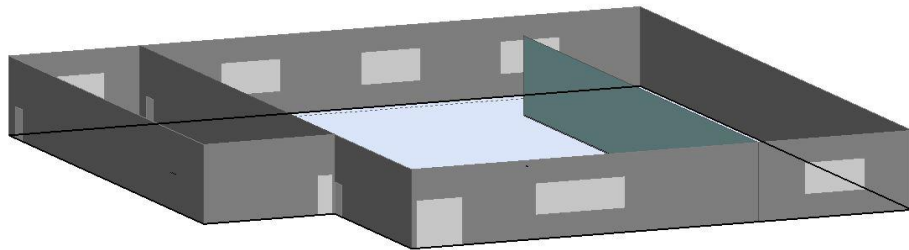


Figure 3.4 Building shape

The factory consists of walls, ceilings and floors with measurements that suit the standards of the factories. Each part of the factory consists of several layers with different conductivity factor and density. The values of construction material have been calculated with Design Builder as seen in Appendix-A. The Appendix-A shows building materials and layers used for walls, ceilings, and floors.

Table 3.1 indicates the building's standards metrics obtained from Appendix-A. The following table shows the conductivity coefficient for each material, thickness, specific temperature, and density.

Table 3.1 Building's standards metrics

<b>Construction materials</b>				
	Thickness (cm)	Conductivity (W/m. K)	Specific heat (J/kg. K)	Density (kg/m <sup>3</sup> )
<b>Walls</b>				
Plaster	2	0.5	1000	1300
Brick	15	0.72	840	1920
Plaster	3	0.5	1000	1300
<b>Floor</b>				
Plasterboard	1.3	0.25	896	2800
Air gap	20	Thermal resistance (m <sup>2</sup> .k/W) 0.18		
MW glass wool	14.45	0.04	840	12
Asphalt	1	0.7	1000	2100
<b>Ground</b>				
Timber	3	0.14	1200	650

flooring				
Floor/roof screed	7	0.41	840	1200
Cast concrete	10	1.13	1000	2000
Urea formaldehyde foam	13.27	0.04	1400	10
<b>Partitions</b>				
plaster	1.2	0.5	1000	1300
Brick cavity	11.5	0.72	840	1920
plaster	1.2	0.5	1000	1300
Windows $A = 8 \text{ m}^2$ Single blue 6 mm $U = 5.778 \text{ W/m}^2.\text{K}$				
External doors $A = 9 \text{ m}^2$ , Thickness = 3.5 cm Aluminum				

The information in the table was used as input for Design Builder. The building was drawn up, energy simulations were performed, and the demand for cooling and heating load was calculated by Design Builder. These processes are essential for obtaining heat and cooling loads and for selecting suitable alternatives for carrying cooling and heating in the building. After entering the alternatives, special data are obtained for each alternative related to the specified criteria.

Design Builder is used to measure energy and control the thermal comfort of a building. The program uses a software tool to control lighting, energy, carbon, and shading. The program uses a lot in the energy simulation process to know the total consumption of the building and the amount of demand for heating and cooling. The program was used in many economic and scientific analysis of various buildings and designs. It is considered one of the widespread programs among engineers and architects for the purposes of thermal simulation of the building. The program allows the use of various types of HVAC systems, selecting the specific system, simulating, and identifying the amount of moisture, thermal comfort, the amount of consumption, and other characteristics.

Design Builder was used as a simulation research plan for different HVAC systems. The program is considered one of the accurate and clear programs because of its characteristics and accurate aspects related to working hours, shading, and the choice of building materials and the direction and size of the building.

The factory contains several machines and equipment for production, welding, cutting, and drilling purposes. Figure 3.5 shows the machines and the consumption amount for each machine.

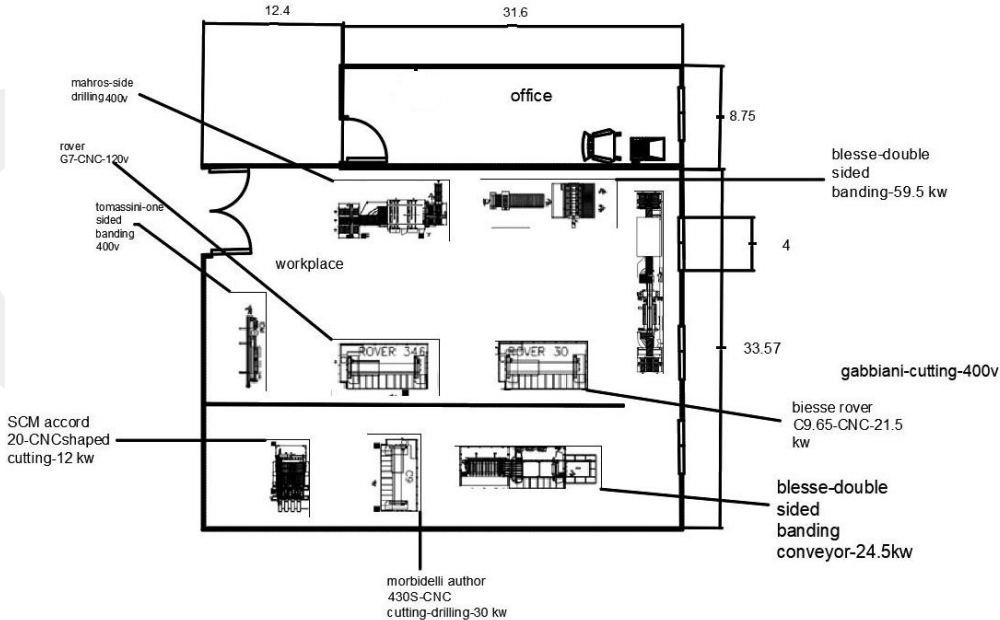


Figure 3.5 Machines and consumption amount for each machine.

The factory consists of building materials for factories, and materials for walls, ceilings, floors, doors, and windows have been identified. All construction information was acquired by Design Builder. The following illustrations indicate the information available on construction, materials, measurements, and type of materials used.

- i. The walls consist of three layers and the U value is  $0.470 \text{ W/m}^2\text{-K}$
- ii. The roofs consist of four layers and U values is  $0.250 \text{ W/m}^2\text{-K}$
- iii. The ground consist of four layers and U values is  $0.250 \text{ W/m}^2\text{-K}$
- iv. Windows is a blue 6 mm and U value is  $5.778 \text{ W/m}^2\text{-K}$

### **3.2.1 Alternatives and Data Obtained from Design Builder**

After completing the construction, entering the available information about the building materials, and entering the required data for thermal comfort and working times, the simulation process was done for the building.

Cooling load was obtained at 236.44 kW and heating load at 189.460 kW. The values of cooling load and heating load have been calculated with Design Builder as seen in Appendix-B.

The simulation procedure is pressed after selecting one of the alternatives, and the available information and criteria are obtained. The values of every alternative have been calculated with Design Builder as seen in Appendix-C, D, E, F, G, H, I, J, K, L, M.

Every Appendix have 4 images for each alternative through the DB program:

- The first picture shows the sensible and radiant temperatures and heat gain.
- The second picture shows the relative humidity and thermal comfort
- The third picture shows the level of ventilation
- The fourth picture shows the coefficient of performance

The following appendices Shows the alternative simulation with value of criteria:

APPENDIX-C: Shows simulation of All air system single Zone (CAV) and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-D: Shows simulation of All air system multi zone (CAV) and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-E: Shows simulation of All air system terminal reheat (CAV) and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-F: Shows simulation of All air system dual duct and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-G: Shows simulation of All air system (VAV) and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-H: Shows simulation of Air-water system fan-Coil Unit and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-I: Shows simulation of All water system fan-Coil Unit and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-J: Shows simulation of Air-water system Induction Unit and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-K: Shows simulation of Water source heat pump and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-L: Shows simulation of Heating and Cooling panels and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

APPENDIX-M: Shows simulation of Split system and Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling.

After simulating and obtaining criteria values for all alternatives, the values are combined into one table to facilitate decision-making processes.

CO2 emissions for each alternative are obtained by applying the carbon dioxide emissions equation:

$$Q_{\text{prim}} = [Q_h - Q_{h\text{-res}}] * F_{\text{seg}} + [Q_{\text{dhw}} - Q_{\text{dhw-res}}] * F_{\text{dhw-seg}} + [Q_p + Q_f + Q_{\text{lighting}}] * F_{e\text{-seg}}$$

For first alternative:

$$F_{\text{seg}} \text{ for electricity} = 0.617$$

$$\text{SEG} = 660.62 * 0.617 = 407.6 \text{ kgCO}_2$$

The table 3.2 indicates the values obtained from Design builder and carbon dioxide emissions equation that will be used in decision making.

Table 3.2 Values of criteria obtained from Design builder and carbon dioxide emissions equation.

<b>C</b> <b>A</b>	<b>Time not comfortable /hours</b>	<b>Energy Consumption kWh/m<sup>2</sup></b>	<b>Ventilation Ac/h</b>	<b>Relative Humidity %</b>	<b>CO<sub>2</sub> kg/m<sup>2</sup>.y</b>	<b>COP Heating</b>	<b>COP cooling</b>
A1	938	660.62	0.283	42	407.6	2	2.5
A2	729.50	340.25	2.84	30.27	209.94	2	4
A3	518	233.58	5.207	28.02	144.12	1.2	1.80
A4	938	660.63	0.28	41.73	407.6	1.3	1.80

A5	938	660.65	0.28	41.74	407.6	1.3	1.80
A6	2230.5	487.32	0.76	29.52	300.68	1.3	1.80
A7	2314	131.98	6.1	28.90	81.434	1.5	2.00
A8	1782	159.4	5.28	27.40	98.360	1.2	1.80
A9	2610	30.37	3.53	22.91	18.73	1.1	1.2
A10	1904	364.64	1.35	28.17	224.98	1.3	2.5
A11	2323.5	244.4	3.137	28.96	150.82	2.250	1.80

### 3.3 Application of SWARA and WASPAS Method

A questionnaire for different HVAC systems and criteria was filled in by a group of experts. The following table 3.3 shows information related to decision makers as years of experience and field of specialization.

Table 3.3 Information of decision makers.

DM	Years of Experience	Department
DM1	15	Energy systems engineering department, expertise area: building energy efficiency, thermal comfort
DM2	11	Electrical and electronics engineering department, expertise area: HVAC system control
DM3	14	Energy systems engineering department, expertise area: smart HVAC systems, building energy efficiency, thermal comfort

The criteria were evaluated according to their effect on the decision to choose the best HVAC system by three experts specializing in air conditioning. The scale (1: most important, ..... 0: least important) was used to evaluate the criteria. SWARA technology is used to weigh criteria of HVAC systems through objective and subjective assessments.

The alternatives to HVAC systems were evaluated by comparing criteria one-by-one by using the scale given between (1-7).

Ratings for evaluating alternatives

<b>Ratings</b>	<b>Meaning</b>
1	Very Bad
2	Bad
3	Fairly Bad
4	Neutral
5	Fairly Good
6	Good
7	Very Good

After obtaining the weight of the criteria and the values of alternatives, WASPAS technology is applied to choose the appropriate alternative through the decision-making process.

### **3.3.1 SWARA Method**

SWARA is a new technology used in decision making and weighting of standards, and was developed by Keršulienė et al. This method was used to solve many problems in various scientific fields. The SWARA method consists of several steps [218].

- i. Determine the criteria and arrange them based on their importance in descending order.
- ii. The standard is expressed in  $j$ , while the previous criterion is in  $j-1$ , and the second criterion is started to express importance.
- iii. Determine the weight of criteria

The SWARA and AHP method uses even comparisons and consists of the similar number of criteria, but the AHP method requires a large comparison compared to the SWARA method that requires fewer comparisons. In AHP technology, if a large number of criteria are used, the number of comparisons increases, which causes a negative impact on the consistency of the standards and the implemented comparisons. The SWARA method is more attractive because it contains a few comparisons. Through SWARA method, respondents can express their positions very freely, because they are not defined by fixed measures [195].

SWARA is one of the methods used to resolve disputes and determine rational decision by assessing weight step by step based on the opinion of experts and decision makers. The SWARA method can be used in a virtual environment to solve the practical and scientific dispute of decision support systems [196].

Each decision-making system should contain four sets of procedures:

- i. Identify rational alternatives
- ii. Formation of feature systems for identifying, describing, and determining their importance
- iii. Determine priorities, the value of alternatives and the degree of interest
- iv. Providing the best alternatives and submitting proposals to the conflicting parties

Experts have a major and important role in the SWARA method, where experts and decision-makers are initially identified to prioritize standards. The SWARA method can be used in many energy and sustainability technologies and many of the issues used in decision making. The SWARA methods was used by the [184] to select and prioritize

building materials for dams. The SWARA method was used to give and prioritize solutions to mitigate logistical implementation barriers by [185]. The SWARA technique was used by [182] to determine the sustainability indicators used in the evaluation of renewable energy systems. The SWARA method has been used to improve engine start-up settings by [180]. The SWARA method was used by [181] to evaluate renewable energy production.

The SWARA method is characterized by the possibility of removing the criterion with little or ineffective effect, as it can be said that this standard is ineffective and does not have an important role in the research model [214].

SWARA method's steps are as follows:

Step 1: Each DM determines the most important criterion by its own priority. The most important criterion is given 1.00 points. Decision makers assign the points to another criterion by considering the most important criterion. The points are assigned between 0.1 and 1. The points assigned to the criteria are

$$p_j^k; J=1, \dots, n, k=1, \dots, l, l=3; 0 \leq p_j^k \leq 1$$

Step 2: geometric mean of importance scores are calculated for all criteria. Eq. (1) is used by the decision makers to find the geometric mean of the relative importance scores assigned to the criteria for each criterion.

$$\bar{p}_j = \frac{\sum_{k=1}^l p_j^k}{l}, \quad j = 1, 2, \dots, n, k=1, \dots, l, l=3 \quad (1)$$

Step 3: All criteria are ranking to small one to big one in order to their relative geometric mean scores and compared. As a result of this comparison, the comparative significance  $s_j$  values of the geometric mean value are calculated. The values of  $c_j$  indicate how important the  $j + 1$  criterion is according to the  $j$  criterion. These values are obtained by binary comparison.

Step 4: For all criteria, the coefficient value  $c_j$  is calculated using Eq. (2). The coefficient of the criterion with the greatest  $s_j$  value is  $c_j=1$ .

$$c_j = s_j + 1; j = 1, 2, \dots, n \quad (2)$$

Step 5: Corrected weights ( $s'_j$ ) for all criteria are calculated with the help of Eq. (3). The corrected weight of the criterion which is in the first rank is  $s'_j = 1$ .

$$s'_j = \frac{s_j^{j-1}}{c_j} \quad j = 1, 2, \dots, n \quad (3)$$

Step 6: Final criteria weights ( $w_j$ ) are calculated for all criteria with Eq. (4)

$$w_j = \frac{s'_j}{\sum_{j=1}^n s'_j}, j = 1, 2, \dots, n \quad (4)$$

Firstly, the questionnaires were collected from the decision makers and the geometric mean was found among them. The following tables show the questionnaires with the calculations to find the final weight.

After collecting data and assessments from decision makers, geometric mean of Importance scores is calculated. Table 3.4 shows geometric mean calculation.

Table 3.4 Scores of main criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$ .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C1	0.8000	0.9500	0.9000	0.8811
C2	0.5000	0.6000	0.9000	0.6463
C3	0.9000	0.9000	0.9500	0.9164
C4	0.6000	0.8500	1.0000	0.7990
C5	0.7000	0.2500	0.8000	0.5192
C6	0.5000	0.5000	0.3000	0.4217

Through SWARA calculation, the comparative importance of Geometric mean is found. Table 3.5 shows calculation of comparative importance of Geometric mean.

Table 3.5 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C3	0.9164	
C1	0.8811	0.0353
C4	0.7990	0.0821
C2	0.6463	0.1526
C5	0.5192	0.1271
C6	0.4217	0.0975

By using SWARA steps Coefficient values, corrected weight values and final weight values is obtained. Table 6.3 shows the calculation for finding final weights.

Table 3.6 Values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$
C3	1.0000	1.0000	0.2022
C1	1.0353	0.9659	0.1953
C4	1.0821	0.8926	0.1805
C2	1.1526	0.7744	0.1566
C5	1.1271	0.6871	0.1389
C6	1.0975	0.6260	0.1266

The same steps of SWARA apply to all sub-criteria to obtain final weights.

Table 3.7 Scores of ergonomics criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$  .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C11	0.8500	0.5000	0.9500	0.7391
C12	0.8500	0.4500	0.9500	0.7136
C13	0.4500	0.1000	0.1000	0.1651
C14	0.8000	0.8000	0.5500	0.7061
C15	1.0000	1.0000	1.0000	1.0000

Table 3.8 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C15	1.0000	
C11	0.7391	0.2609
C12	0.7136	0.0255
C14	0.7061	0.0075
C13	0.1651	0.5410

Table 3.9 The values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C15	1.0000	1.0000	0.2610	0.0510
C11	1.2609	0.7931	0.2070	0.0404
C12	1.0255	0.7734	0.2018	0.0394
C14	1.0075	0.7676	0.2003	0.0391
C13	1.5410	0.4981	0.1300	0.0254

Table 3.10 Scores of economic cost criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$ .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C21	0.8000	0.9500	0.6000	0.7697
C22	0.2000	0.5000	0.4000	0.3420

Table 3.11 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C21	0.7697	
C22	0.3420	0.4277

Table 3.12 The values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C21	1.0000	1.0000	0.5881	0.0921
C22	1.4277	0.7004	0.4119	0.0645

Table 3.13 Scores of technical properties  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$ .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C31	0.2500	0.1500	0.5000	0.2657
C32	0.9500	0.9500	1.0000	0.9664
C33	0.9000	0.8000	1.0000	0.8963
C34	0.9000	0.9000	0.9000	0.9000
C35	0.8500	0.8500	0.9000	0.8664
C36	0.7000	0.2500	0.5000	0.4440
C37	0.8000	0.7000	0.6000	0.6952

Table 3.14 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C32	0.9664	
C34	0.9000	0.0664
C33	0.8963	0.0037
C35	0.8664	0.0299
C37	0.6952	0.1711
C36	0.4440	0.2513
C31	0.2657	0.1783

Table 3.15 Values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C32	1.0000	1.0000	0.1755	0.0355
C34	1.0664	0.9377	0.1646	0.0333
C33	1.0037	0.9343	0.1640	0.0331
C35	1.0299	0.9071	0.1592	0.0322
C37	1.1711	0.7746	0.1359	0.0275
C36	1.2513	0.6190	0.1086	0.0220
C31	1.1783	0.5254	0.0922	0.0186

Table 3.16 Scores of physical properties criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$ .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C41	0.9500	0.9500	1.0000	0.9664
C42	0.8000	0.1000	0.2000	0.2520
C43	0.4500	0.8000	1.0000	0.7114
C44	0.2500	0.1500	0.2000	0.1957

Table 3.17 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C41	0.9664	
C43	0.7114	0.2550
C42	0.2520	0.4594
C44	0.1957	0.0562

Table 3.18 Values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C41	1.0000	1.0000	0.3497	0.0631
C43	1.2550	0.7968	0.2786	0.0503
C42	1.4594	0.5460	0.1909	0.0345
C44	1.0562	0.5169	0.1808	0.0326

Table 3.19 Scores of flexibility criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$  .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C51	0.8000	0.8500	0.5000	0.6980
C52	0.7000	0.7000	0.6000	0.6649
C53	0.8000	0.9000	0.8000	0.8320
C54	0.5500	0.2500	0.5000	0.4097

Table 3.20 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C53	0.8320	
C51	0.6980	0.1341
C52	0.6649	0.0330
C54	0.4097	0.2553

Table 3.21 The values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C53	1.0000	1.0000	0.2928	0.0407
C51	1.1341	0.8818	0.2582	0.0359
C52	1.0330	0.8536	0.2499	0.0347
C54	1.2553	0.6800	0.1991	0.0277

Table 3.22 Scores of reliability criteria  $P_j^k$  according to decision makers and the Geometric mean of Importance scores  $\bar{P}_j$  .

Criteria	Decision makers/DM			Geometric mean of Importance scores $\bar{P}_j$
	DM1	DM2	DM3	
C61	0.7000	0.9500	0.9000	0.8427
C62	0.5500	0.1000	0.5000	0.3018
C63	0.5000	0.5500	0.4000	0.4791
C64	0.2500	0.1500	0.1000	0.1554
C65	0.5000	0.5000	0.5000	0.5000

Table 3.23 Comparison of Geometric mean of Importance scores.

Criteria	Geometric mean of Importance scores $\bar{P}_j$	comparative importance of Geometric mean $s_j$
C61	0.8427	
C65	0.5000	0.3427
C63	0.4791	0.0209
C62	0.3018	0.1773
C64	0.1554	0.1465

Table 3.24 The values of  $c_j, s'_j$  and  $w_j$  of the criteria.

Criteria	coefficient values $c_j$	corrected weight values $s'_j$	Final weight values $w_j$	Global weight
C61	1.0000	1.0000	0.2751	0.0348
C65	1.3427	0.7448	0.2049	0.0259
C63	1.0209	0.7295	0.2007	0.0254
C62	1.1773	0.6197	0.1705	0.0216
C64	1.1465	0.5405	0.1487	0.0188

Through the previous tables, the final weight of each criterion was obtained. Table (3.25) shows the weights of the criteria obtained from the previous methods.

Table 3.25 Final weights

Weights			
Capital cost $C_{21}$	0.0921	COP heating $C_{34}$	0.0332
Maintenance cost $C_{22}$	0.0645	CO <sub>2</sub> emission $C_{33}$	0.0331
Indoor area requirement $C_{41}$	0.0631	Outdoor appearance $C_{44}$	0.0326
Thermal comfort $C_{15}$	0.0510	COP cooling $C_{35}$	0.0321
Indoor appearance $C_{43}$	0.0502	Ease of maintenance $C_{54}$	0.0276
Energy source flexibility $C_{53}$	0.0406	Multi control zone $C_{37}$	0.0274
Ventilation $C_{11}$	0.0404	Vendor availability $C_{65}$	0.0259
Relative humidity $C_{12}$	0.0394	Repair time $C_{63}$	0.0254
Noise level $C_{14}$	0.0391	Visual impact $C_{13}$	0.0254
Installation flexibility $C_{51}$	0.0358	Single control zone $C_{36}$	0.0219
Energy consumption $C_{32}$	0.0354	Lead time $C_{62}$	0.0215
Lifetime $C_{61}$	0.0348	Fewer components $C_{64}$	0.0188
Integration flexibility $C_{52}$	0.0347	Water Consumption $C_{31}$	0.0186
Outdoor area requirement $C_{42}$	0.0344		

### 3.3.2 WASPAS Method

WASPAS is a methodology used in decision making that was developed in 2012 by Zavadskas et al. WASPAS is a newly used MCDM method that is used to solve various problems in different fields [216]. The WASPAS methodology is a mixture of a weighted product model (WPM) and a weighted sum model (WSM), but it is more accurate and characterized by simple mathematical operations. Therefore, this tool has become widespread, acceptable, and effective in decision-making. WASPAS methodology is characterized by several advantages compared to other methodologies when compared to Gray theory, it is able to facilitate the effective representation of inaccurate data and vague information and provides a good systematic decision-making analysis and is able to describe visualizations in the evaluation process for designers. The WASPAS methodology is characterized by its ability to express ambiguity for a specific group rather than an organic function through the border region [210]. WASPAS is also distinguished by avoiding assumptions and exploring unclear and subjective assessment of experts by including approximate figures in decision-making

methods. Several experts emphasized the importance of the WASPAS methodology because it gives highly reliable results. Deveci, Muhammet, Canitez, and Gökaşar in 2018 emphasized the need to use the WASPAS methodology to verify the strength and durability of the approach in assessing alternative solutions [197]. Sumanta, and Siddique in 2019 also pointed out that WASPAS methods is a useful tool developed to solve mysterious problems and accurate decision-making [191]. Deveci, Muhammet, Canitez, and Gökaşar in 2018 explained that WASPAS technology can be used to solve the problem of choosing a car sharing station [197]. WASPAS methods was used by Sumanta, and Siddique in 2019 to assess the human risks of a dam in India [191]. The WASPAS methods was used to evaluate the green resource problem [219].

The methodology can be applied in decision making for conflicting daily situations. The WASPAS methodology is based on the degree of certainty of decision making and defines the approximate group based on actual values. Deal systematically WASPAS with operational data and does not rely on other assumptions [187].

The criteria weights can provide by experts. For this research, criteria weights are the results obtained from the SWARA method. By doing the sensitive analysis within its own function, WASPAS can check the consistency of alternative rankings. Considering the accuracy or the verification of the accuracy of using those two methods, WASPAS is actually referred as the best appropriate MCDM method. Zavadskas et al. (2012) proposed the following steps for WASPAS method [218]:

Step 1: Structure the initial decision matrix

Step 2: Normalize the decision matrix

$$X_{ij} = \frac{x_{ij}}{\max(x_{ij})} \quad (5)$$

$$X_{ij} = \frac{\min(x_{ij})}{x_{ij}} \quad (6)$$

Step 3: Calculate the total relative importance based on WSM method with eq.7

$$Q_i^{(1)} = \sum_{j=1}^n X_{ij} \cdot W_j \quad (7)$$

Step 4: Calculate the total relative importance based on WPM method with eq.8

$$Q_i^{(2)} = \prod_{j=1}^n X_{ij}^{w_j} \quad (8)$$

Step 5: In order to have improved ranking accuracy and helpfulness of decision-making process, in the WASPAS method, a more general equation for formative the total relative significance of alternatives is given by eq.9

$$Q_i = \lambda \cdot Q_i^{(1)} + (1 - \lambda) \cdot Q_i^{(2)} \quad (9)$$

Firstly, alternatives are evaluated using a scale (1-7) by experts. Then the arithmetic mean is found among the various decision makers. The following tables describe the processes and values extracted from WASPAS implementation.

Evaluations obtained from the expert1 and Design Builder program.

Table (3.26-a) initial decision matrix for DM1

		DM1													
C	A	C <sub>11</sub>	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>15</sub>	C <sub>21</sub>	C <sub>22</sub>	C <sub>31</sub>	C <sub>32</sub>	C <sub>33</sub>	C <sub>34</sub>	C <sub>35</sub>	C <sub>36</sub>	C <sub>37</sub>
	A1	0.283	42.00	6.0	6.0	938.0	5.0	5.0	7.0	660.620	407.600	2.0	2.5	6.0	3.0
	A2	2.840	30.27	6.0	5.0	729.5	4.0	4.0	7.0	340.250	209.940	2.0	4.0	7.0	7.0
	A3	5.207	28.02	6.0	5.0	518.0	3.0	5.0	7.0	233.580	144.120	1.2	1.8	5.0	6.0
	A4	0.280	41.73	6.0	6.0	938.0	4.0	5.0	7.0	660.630	407.600	1.3	1.8	5.0	6.0
	A5	0.280	41.74	6.0	4.0	938.0	4.0	5.0	6.0	660.650	407.600	1.3	1.8	7.0	7.0
	A6	0.760	29.52	5.0	5.0	2230.5	6.0	6.0	4.0	487.320	300.680	1.3	1.8	3.0	1.0
	A7	6.100	28.90	5.0	4.0	2314.0	5.0	6.0	1.0	131.980	81.434	1.5	2.0	3.0	1.0
	A8	5.280	27.40	5.0	5.0	1782.0	4.0	5.0	1.0	159.400	98.360	1.2	1.8	3.0	4.0
	A9	3.530	22.91	7.0	6.0	2610.0	4.0	4.0	1.0	30.370	18.730	1.1	1.3	6.0	6.0
	A10	1.350	28.17	6.0	7.0	1904.0	3.0	3.0	4.0	364.640	224.980	1.3	2.5	5.0	6.0
	A11	3.137	28.96	4.0	5.0	2323.5	6.0	6.0	3.0	244.400	150.823	2.25	1.8	5.0	1.0

Table (3.26-b) initial decision matrix for DM1

DM1													
C	C <sub>11</sub>	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>15</sub>	C <sub>16</sub>	C <sub>17</sub>	C <sub>18</sub>	C <sub>19</sub>	C <sub>20</sub>	C <sub>21</sub>	C <sub>22</sub>	C <sub>23</sub>
A													
A1	2.00	4.00	6.00	3.00	4.00	4.00	5.00	4.00	6.00	5.00	3.00	2.00	7.00
A2	2.00	4.00	6.00	3.00	4.00	4.00	5.00	4.00	6.00	5.00	2.00	1.00	6.00
A3	1.00	4.00	6.00	3.00	3.00	4.00	5.00	3.00	5.00	5.00	1.00	1.00	5.00
A4	2.00	4.00	5.00	3.00	3.00	4.00	5.00	4.00	6.00	5.00	3.00	2.00	6.00
A5	2.00	4.00	6.00	3.00	4.00	4.00	5.00	4.00	6.00	4.00	2.00	1.00	6.00
A6	5.00	5.00	5.00	4.00	6.00	1.00	1.00	6.00	7.00	6.00	5.00	6.00	7.00
A7	5.00	5.00	5.00	4.00	7.00	1.00	1.00	6.00	7.00	6.00	5.00	6.00	7.00
A8	3.00	5.00	4.00	4.00	6.00	1.00	1.00	5.00	5.00	5.00	4.00	5.00	5.00
A9	6.00	6.00	7.00	6.00	4.00	4.00	6.00	4.00	5.00	4.00	3.00	4.00	5.00
A10	5.00	6.00	4.00	6.00	3.00	5.00	6.00	5.00	5.00	4.00	3.00	6.00	4.00
A11	4.00	5.00	6.00	4.00	6.00	1.00	1.00	6.00	6.00	6.00	5.00	7.00	7.00

Evaluations obtained from the expert2 and Design Builder program.

Table (3.27-a) initial decision matrix for DM2

DM2														
C	C <sub>11</sub>	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>15</sub>	C <sub>21</sub>	C <sub>22</sub>	C <sub>31</sub>	C <sub>32</sub>	C <sub>33</sub>	C <sub>34</sub>	C <sub>35</sub>	C <sub>36</sub>	C <sub>37</sub>
A														
A1	0.28	42.00	3.00	1.00	938.00	4.00	5.00	7.00	660.62	407.60	2.00	2.50	7.00	1.0000
A2	2.84	30.27	4.00	1.00	729.50	4.00	5.00	7.00	340.25	209.94	2.00	4.00	4.00	7.0000
A3	5.20	28.02	5.00	2.00	518.00	4.00	4.00	7.00	233.58	144.12	1.2	1.80	4.00	5.00
A4	0.28	41.73	4.00	2.00	938.00	4.00	3.00	7.00	660.63	407.60	1.3	1.80	5.00	7.00
A5	0.28	41.74	4.00	3.00	938.00	4.00	3.00	7.00	660.65	407.60	1.3	1.80	4.00	7.00
A6	0.76	29.52	2.00	2.00	2230.50	2.00	4.00	5.00	487.32	300.68	1.3	1.80	4.00	2.00
A7	6.10	28.90	2.00	2.00	2314.00	2.00	4.00	1.00	131.98	81.43	1.5	2.00	4.00	2.00
A8	5.28	27.40	3.00	3.00	1782.00	2.00	5.00	3.00	159.40	98.36	1.2	1.80	6.00	4.00
A9	3.53	22.91	4.00	4.00	2610.00	3.00	2.00	1.00	30.37	18.73	1.1	1.2	4.00	7.00
A10	1.35	28.17	6.00	6.00	1904.00	1.00	1.00	4.00	364.64	224.98	1.3	2.50	3.00	6.00
A11	3.13	28.96	1.00	2.00	2323.50	7.00	6.00	4.00	244.40	150.82	2.25	1.80	7.00	1.00

Table (3.27-b) initial decision matrix for DM2

		DM2												
C	A	C <sub>41</sub>	C <sub>42</sub>	C <sub>43</sub>	C <sub>44</sub>	C <sub>51</sub>	C <sub>52</sub>	C <sub>53</sub>	C <sub>54</sub>	C <sub>61</sub>	C <sub>62</sub>	C <sub>63</sub>	C <sub>64</sub>	C <sub>65</sub>
A1		4.00	4.00	7.00	2.00	4.00	1.00	4.00	2.00	5.00	2.00	2.00	4.00	6.00
A2		3.00	4.00	7.00	2.00	2.00	4.00	4.00	2.00	4.00	2.00	2.00	3.00	6.00
A3		4.00	3.00	7.00	2.00	3.00	4.00	4.00	2.00	4.00	2.00	2.00	4.00	6.00
A4		3.00	4.00	7.00	2.00	3.00	4.00	3.00	2.00	3.00	2.00	2.00	4.00	6.00
A5		4.00	4.00	7.00	2.00	3.00	3.00	2.00	2.00	4.00	3.00	3.00	4.00	6.00
A6		3.00	6.00	1.00	6.00	4.00	5.00	2.00	6.00	6.00	6.00	6.00	4.00	7.00
A7		2.00	6.00	1.00	6.00	4.00	5.00	2.00	6.00	6.00	6.00	6.00	5.00	7.00
A8		5.00	5.00	5.00	5.00	4.00	5.00	4.00	6.00	5.00	5.00	5.00	5.00	5.00
A9		6.00	6.00	7.00	7.00	1.00	6.00	4.00	4.00	5.00	4.00	4.00	2.00	5.00
A10		5.00	6.00	4.00	4.00	1.00	5.00	5.00	5.00	6.00	4.00	4.00	4.00	3.00
A11		4.00	4.00	1.00	2.00	5.00	1.00	1.00	6.00	3.00	6.00	6.00	7.00	7.00

Evaluations obtained from the expert3 and Design Builder program.

Table (3.28-a) initial decision matrix for DM3

		DM3													
C	A	C <sub>11</sub>	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>15</sub>	C <sub>21</sub>	C <sub>22</sub>	C <sub>31</sub>	C <sub>32</sub>	C <sub>33</sub>	C <sub>34</sub>	C <sub>35</sub>	C <sub>36</sub>	C <sub>37</sub>
A1		0.28	42.00	7.00	3.00	938.00	4.00	2.00	7.00	660.62	407.60	2.00	2.50	7.00	1.00
A2		2.84	30.27	7.00	2.00	729.50	3.00	2.00	7.00	340.25	209.94	2.00	4.00	7.00	7.00
A3		5.20	28.02	7.00	4.00	518.00	3.00	2.00	7.00	233.58	144.12	1.2	1.80	5.00	6.00
A4		0.28	41.73	7.00	2.00	938.00	3.00	2.00	7.00	660.63	407.60	1.3	1.80	7.00	6.00
A5		0.28	41.74	7.00	3.00	938.00	3.00	2.00	6.00	660.65	407.60	1.3	1.80	7.00	6.00
A6		0.76	29.52	4.00	4.00	2230.50	6.00	6.00	3.00	487.32	300.68	1.3	1.80	6.00	1.00
A7		6.10	28.90	4.00	4.00	2314.00	6.00	6.00	2.00	131.98	81.43	1.5	2.00	6.00	1.00
A8		5.28	27.40	6.00	5.00	1782.00	2.00	3.00	5.00	159.40	98.36	1.2	1.80	7.00	6.00
A9		3.53	22.91	7.00	6.00	2610.00	2.00	2.00	1.00	30.37	18.73	1.1	1.2	4.00	6.00
A10		1.35	28.17	7.00	7.00	1904.00	4.00	3.00	2.00	364.64	224.98	1.3	2.50	4.00	6.00
A11		3.13	28.96	2.00	5.00	2323.50	7.00	6.00	6.00	244.40	150.82	2.25	1.80	7.00	1.00

Table (3.28-b) initial decision matrix for DM3

		DM3												
C	A	C <sub>41</sub>	C <sub>42</sub>	C <sub>43</sub>	C <sub>44</sub>	C <sub>51</sub>	C <sub>52</sub>	C <sub>53</sub>	C <sub>54</sub>	C <sub>61</sub>	C <sub>62</sub>	C <sub>63</sub>	C <sub>64</sub>	C <sub>65</sub>
A1		7.00	3.00	7.00	3.00	1.00	4.00	4.00	4.00	5.00	3.00	4.00	2.00	5.00
A2		7.00	3.00	7.00	3.00	1.00	7.00	4.00	4.00	5.00	3.00	5.00	2.00	5.00
A3		7.00	3.00	7.00	3.00	1.00	4.00	4.00	4.00	4.00	3.00	2.00	2.00	4.00
A4		7.00	3.00	7.00	3.00	1.00	4.00	4.00	4.00	4.00	3.00	2.00	2.00	3.00
A5		7.00	3.00	7.00	3.00	1.00	4.00	4.00	4.00	4.00	3.00	2.00	2.00	5.00
A6		4.00	4.00	5.00	4.00	3.00	6.00	1.00	7.00	6.00	3.00	6.00	7.00	6.00
A7		4.00	4.00	5.00	4.00	3.00	6.00	1.00	7.00	6.00	3.00	7.00	7.00	6.00
A8		3.00	5.00	6.00	3.00	4.00	5.00	2.00	4.00	4.00	3.00	5.00	4.00	5.00
A9		7.00	7.00	7.00	7.00	6.00	6.00	7.00	3.00	3.00	3.00	4.00	1.00	5.00
A10		3.00	6.00	4.00	7.00	5.00	6.00	5.00	3.00	4.00	3.00	2.00	4.00	4.00
A11		4.00	4.00	1.00	3.00	7.00	1.00	1.00	7.00	6.00	3.00	7.00	6.00	7.00

By applying the first step of WASPAS technology, the first matrix is found.

Table (3.29-a) Structure of the initial decision matrix.

		Step1							
C	A	C11	C12	C13	C14	C15	C21	C22	
A1		0.2830	42.0000	5.0133	2.6207	938.00	4.3089	3.6840	
A2		2.8400	30.2700	5.5178	2.1544	729.50	3.6342	3.4200	
A3		5.2070	28.0200	5.9439	3.4200	518.00	3.3019	3.4200	
A4		0.2800	41.7300	5.5178	2.8845	938.00	3.6342	3.1072	
A5		0.2800	41.7400	5.5178	3.3019	938.00	3.6342	3.1072	
A6		0.7600	29.5200	3.4200	3.4200	2230.50	4.1602	5.2415	
A7		6.1000	28.9000	3.4200	3.1748	2314.00	3.9149	5.2415	
A8		5.2800	27.4000	4.4814	4.2172	1782.00	2.5198	4.2172	
A9		3.5300	22.9100	5.8088	5.2415	2610.00	2.8845	2.5198	
A10		1.3500	28.1700	6.3164	6.6494	1904.00	2.2894	2.0801	
A11		3.1370	28.9600	2.0000	3.6840	2323.50	6.6494	6.0000	
		Max	Max	Max	max	Min	Max	Max	
		6.1000	42.0000	6.3164	6.6494	518.0000	6.6494	6.0000	

Table (3.29-b) Structure of the initial decision matrix.

Step1							
C A	C31	C32	C33	C34	C35	C36	C37
A1	7.0000	660.620	407.600	2.0000	2.5000	6.6494	1.4422
A2	7.0000	340.250	209.940	2.0000	4.0000	5.8088	7.0000
A3	7.0000	233.580	144.120	1.2000	1.8000	4.6416	5.6462
A4	7.0000	660.630	407.600	1.3000	1.8000	5.5934	6.3164
A5	6.3164	660.650	407.600	1.3000	1.8000	5.8088	6.6494
A6	3.9149	487.320	300.680	1.3000	1.8000	4.1602	1.2599
A7	1.2599	131.980	81.4340	1.5000	2.0000	4.1602	1.2599
A8	2.4662	159.400	98.3600	1.2000	1.8000	5.0133	4.5789
A9	1.0000	30.370	18.7300	1.1000	1.2000	4.5789	6.3164
A10	3.1748	364.640	224.980	1.3000	2.5000	3.9149	6.0000
A11	4.1602	244.400	150.823	2.2500	1.8000	6.2573	1.0000
	Max	Min	Min	Max	Max	Max	Max
	7.0000	30.3700	18.7300	2.2500	4.0000	6.6494	7.0000

Table (3.29-c) Structure of the initial decision matrix.

Step 1						
C A	C41	C42	C43	C44	C51	C52
A1	3.8259	3.6342	6.6494	2.6207	2.5198	2.5198
A2	3.4760	3.6342	6.6494	2.6207	2.0000	4.8203
A3	3.0366	3.3019	6.6494	2.6207	2.0801	4.0000
A4	3.4760	3.6342	6.2573	2.6207	2.0801	4.0000
A5	3.8259	3.6342	6.6494	2.6207	2.2894	3.6342
A6	3.9149	4.9324	2.9240	4.5789	4.1602	3.1072
A7	3.4200	4.9324	2.9240	4.5789	4.3795	3.1072
A8	3.5569	5.0000	4.9324	3.9149	4.5789	2.9240
A9	6.3164	6.3164	7.0000	6.6494	2.8845	5.2415
A10	4.2172	6.0000	4.0000	5.5178	2.4662	5.3133
A11	4.0000	4.3089	1.8171	2.8845	5.9439	1.0000
	max	max	max	max	max	max
	6.3164	6.3164	7.0000	6.6494	5.9439	5.3133

Table (3.29-d) Structure of the initial decision matrix.

Step1							
C A	C53	C54	C61	C62	C63	C64	C65
A1	4.3089	3.1748	5.3133	3.1072	2.8845	2.5198	5.9439
A2	4.3089	3.1748	4.9324	3.1072	2.7144	1.8171	5.6462
A3	4.3089	2.8845	4.3089	3.1072	1.5874	2.0000	4.9324
A4	3.9149	3.1748	4.1602	3.1072	2.2894	2.5198	4.7622
A5	3.4200	3.1748	4.5789	3.3019	2.2894	2.0000	5.6462
A6	1.2599	6.3164	6.3164	4.7622	5.6462	5.5178	6.6494
A7	1.2599	6.3164	6.3164	4.7622	5.9439	5.9439	6.6494
A8	2.0000	4.9324	4.6416	4.2172	4.6416	4.6416	5.0000
A9	5.5178	3.6342	4.2172	3.6342	3.6342	2.0000	5.0000
A10	5.3133	4.2172	4.9324	3.6342	2.8845	4.5789	3.6342
A11	1.0000	6.3164	4.7622	4.7622	5.9439	6.6494	7.0000
	max	max	max	max	max	max	max
	5.5178	6.3164	6.3164	4.7622	5.9439	6.6494	7.0000

The decision matrix is normalized by applying the normalize equations.

Table (3.30-a) Normalized initial decision matrix.

Step2							
C A	C11	C12	C13	C14	C15	C21	C22
A1	0.0464	1.0000	0.7937	0.3941	0.5522	0.6480	0.6140
A2	0.4656	0.7207	0.8736	0.3240	0.7101	0.5466	0.5700
A3	0.8536	0.6671	0.9410	0.5143	1.0000	0.4966	0.5700
A4	0.0459	0.9936	0.8736	0.4338	0.5522	0.5466	0.5179
A5	0.0459	0.9938	0.8736	0.4966	0.5522	0.5466	0.5179
A6	0.1246	0.7029	0.5414	0.5143	0.2322	0.6256	0.8736
A7	1.0000	0.6881	0.5414	0.4775	0.2239	0.5888	0.8736
A8	0.8656	0.6524	0.7095	0.6342	0.2907	0.3790	0.7029
A9	0.5787	0.5455	0.9196	0.7883	0.1985	0.4338	0.4200

A10	0.2213	0.6707	1.0000	1.0000	0.2721	0.3443	0.3467
A11	0.5143	0.6895	0.3166	0.5540	0.2229	1.0000	1.0000

Table (3.30-b) Normalized initial decision matrix.

Step2							
C	C31	C32	C33	C34	C35	C36	C37
A1	1.0000	0.0460	0.0460	0.8889	0.6250	1.0000	0.2060
A2	1.0000	0.0893	0.0892	0.8889	1.0000	0.8736	1.0000
A3	1.0000	0.1300	0.1300	0.5333	0.4500	0.6980	0.8066
A4	1.0000	0.0460	0.0460	0.5778	0.4500	0.8412	0.9023
A5	0.9023	0.0460	0.0460	0.5778	0.4500	0.8736	0.9499
A6	0.5593	0.0623	0.0623	0.5778	0.4500	0.6256	0.1800
A7	0.1800	0.2301	0.2300	0.6667	0.5000	0.6256	0.1800
A8	0.3523	0.1905	0.1904	0.5333	0.4500	0.7539	0.6541
A9	0.1429	1.0000	1.0000	0.4889	0.3000	0.6886	0.9023
A10	0.4535	0.0833	0.0833	0.5778	0.6250	0.5888	0.8571
A11	0.5943	0.1243	0.1242	1.0000	0.4500	0.9410	0.1429

Table (3.30-c) Normalized initial decision matrix

Step 2						
C	C41	C42	C43	C44	C51	C52
A1	0.6057	0.5754	0.9499	0.3941	0.4239	0.4743
A2	0.5503	0.5754	0.9499	0.3941	0.3365	0.9072
A3	0.4807	0.5228	0.9499	0.3941	0.3500	0.7528
A4	0.5503	0.5754	0.8939	0.3941	0.3500	0.7528

A5	0.6057	0.5754	0.9499	0.3941	0.3852	0.6840
A6	0.6198	0.7809	0.4177	0.6886	0.6999	0.5848
A7	0.5414	0.7809	0.4177	0.6886	0.7368	0.5848
A8	0.5631	0.7916	0.7046	0.5888	0.7703	0.5503
A9	1.0000	1.0000	1.0000	1.0000	0.4853	0.9865
A10	0.6677	0.9499	0.5714	0.8298	0.4149	1.0000
A11	0.6333	0.6822	0.2596	0.4338	1.0000	0.1882

Table (3.30-d) Normalized initial decision matrix.

Step 2							
C	C53	C54	C61	C62	C63	C64	C65
A							
A1	0.7809	0.5026	0.8412	0.6525	0.4853	0.3790	0.8491
A2	0.7809	0.5026	0.7809	0.6525	0.4567	0.2733	0.8066
A3	0.7809	0.4567	0.6822	0.6525	0.2671	0.3008	0.7046
A4	0.7095	0.5026	0.6586	0.6525	0.3852	0.3790	0.6803
A5	0.6198	0.5026	0.7249	0.6934	0.3852	0.3008	0.8066
A6	0.2283	1.0000	1.0000	1.0000	0.9499	0.8298	0.9499
A7	0.2283	1.0000	1.0000	1.0000	1.0000	0.8939	0.9499
A8	0.3625	0.7809	0.7349	0.8855	0.7809	0.6980	0.7143
A9	1.0000	0.5754	0.6677	0.7631	0.6114	0.3008	0.7143
A10	0.9629	0.6677	0.7809	0.7631	0.4853	0.6886	0.5192
A11	0.1812	1.0000	0.7539	1.0000	1.0000	1.0000	1.0000

Weights obtained from SWARA calculation are used to find weighted product model and weighted sum model.

Table 3.31 Weights from SWARA calculation

Weights			
<i>C11</i>	0.0404	<i>C41</i>	0.0631
<i>C12</i>	0.0394	<i>C42</i>	0.0344
<i>C13</i>	0.0254	<i>C43</i>	0.0502
<i>C14</i>	0.0391	<i>C44</i>	0.0326
<i>C15</i>	0.0510	<i>C51</i>	0.0358
<i>C21</i>	0.0921	<i>C52</i>	0.0347
<i>C22</i>	0.0645	<i>C53</i>	0.0406
<i>C31</i>	0.0186	<i>C54</i>	0.0276
<i>C32</i>	0.0354	<i>C61</i>	0.0348
<i>C33</i>	0.0331	<i>C62</i>	0.0215
<i>C34</i>	0.0332	<i>C63</i>	0.0254
<i>C35</i>	0.0321	<i>C64</i>	0.0188
<i>C36</i>	0.0219	<i>C65</i>	0.0259
<i>C37</i>	0.0274		

Total relative importance based on WSM method is found by using equation 7.

Table (3.32-a) Total relative importance based on WSM method with eq 7.

Eq.7							
C	C11	C12	C13	C14	C15	C21	C22
A							
A1	0.0019	0.0394	0.0201	0.0154	0.0281	0.0597	0.0396
A2	0.0188	0.0284	0.0222	0.0127	0.0362	0.0503	0.0368
A3	0.0345	0.0263	0.0239	0.0201	0.0510	0.0457	0.0368
A4	0.0019	0.0392	0.0222	0.0170	0.0281	0.0503	0.0334
A5	0.0019	0.0392	0.0222	0.0194	0.0281	0.0503	0.0334
A6	0.0050	0.0277	0.0137	0.0201	0.0118	0.0576	0.0563
A7	0.0404	0.0271	0.0137	0.0187	0.0114	0.0542	0.0563
A8	0.0350	0.0257	0.0180	0.0248	0.0148	0.0349	0.0453
A9	0.0234	0.0215	0.0233	0.0308	0.0101	0.0399	0.0271
A10	0.0089	0.0264	0.0254	0.0391	0.0139	0.0317	0.0224
A11	0.0208	0.0272	0.0080	0.0217	0.0114	0.0921	0.0645

Table (3.32-b) Total relative importance based on WSM method with eq 7

Eq.7							
C	C31	C32	C33	C34	C35	C36	C37
A							
A1	0.0186	0.0016	0.0015	0.0295	0.0201	0.0220	0.0057
A2	0.0186	0.0032	0.0030	0.0295	0.0321	0.0192	0.0275
A3	0.0186	0.0046	0.0043	0.0177	0.0144	0.0153	0.0222
A4	0.0186	0.0016	0.0015	0.0192	0.0144	0.0185	0.0248
A5	0.0168	0.0016	0.0015	0.0192	0.0144	0.0192	0.0261
A6	0.0104	0.0022	0.0021	0.0192	0.0144	0.0137	0.0049
A7	0.0034	0.0082	0.0076	0.0221	0.0160	0.0137	0.0049
A8	0.0066	0.0068	0.0063	0.0177	0.0144	0.0166	0.0180
A9	0.0027	0.0355	0.0331	0.0162	0.0096	0.0151	0.0248
A10	0.0085	0.0030	0.0028	0.0192	0.0201	0.0129	0.0236
A11	0.0111	0.0044	0.0041	0.0332	0.0144	0.0207	0.0039

Table (3.32-c) Total relative importance based on WSM method with eq 7.

Eq.7						
C	C41	C42	C43	C44	C51	C52
A						
A1	0.0382	0.0198	0.0478	0.0129	0.0152	0.0165
A2	0.0347	0.0198	0.0478	0.0129	0.0121	0.0315
A3	0.0303	0.0180	0.0478	0.0129	0.0126	0.0261
A4	0.0347	0.0198	0.0449	0.0129	0.0126	0.0261
A5	0.0382	0.0198	0.0478	0.0129	0.0138	0.0237
A6	0.0391	0.0269	0.0210	0.0225	0.0251	0.0203
A7	0.0342	0.0269	0.0210	0.0225	0.0264	0.0203
A8	0.0355	0.0273	0.0354	0.0192	0.0276	0.0191
A9	0.0631	0.0345	0.0503	0.0326	0.0174	0.0343
A10	0.0421	0.0327	0.0287	0.0271	0.0149	0.0347

A11	0.0400	0.0235	0.0131	0.0142	0.0359	0.0065
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Table (3.32-d) Total relative importance based on WSM method with eq 7.

Eq.7								
C	C53	C54	C61	C62	C63	C64	C65	Q1
A								0.5842
A1	0.0318	0.0139	0.0293	0.0141	0.0123	0.0071	0.0220	0.6218
A2	0.0318	0.0139	0.0272	0.0141	0.0116	0.0051	0.0209	0.5961
A3	0.0318	0.0126	0.0238	0.0141	0.0068	0.0057	0.0183	0.5561
A4	0.0289	0.0139	0.0229	0.0141	0.0098	0.0071	0.0176	0.5653
A5	0.0252	0.0139	0.0252	0.0150	0.0098	0.0057	0.0209	0.5721
A6	0.0093	0.0277	0.0348	0.0216	0.0241	0.0156	0.0246	0.6095
A7	0.0093	0.0277	0.0348	0.0216	0.0254	0.0168	0.0246	0.5816
A8	0.0147	0.0216	0.0256	0.0191	0.0198	0.0131	0.0185	0.6815
A9	0.0407	0.0159	0.0233	0.0165	0.0155	0.0057	0.0185	0.5781
A10	0.0392	0.0185	0.0272	0.0165	0.0123	0.0130	0.0135	0.6236
A11	0.0074	0.0277	0.0263	0.0216	0.0254	0.0188	0.0259	

Total relative importance based on WPM method is found by applying equation 8.

Table (3.33-a) Total relative importance based on WPM method with eq 8.

Eq.8							
C	C11	C12	C13	C14	C15	C21	C22
A							
A1	0.8833	1.0000	0.9942	0.9642	0.9702	0.9608	0.9690
A2	0.9696	0.9872	0.9966	0.9569	0.9827	0.9459	0.9644
A3	0.9936	0.9842	0.9985	0.9743	1.0000	0.9376	0.9644
A4	0.8829	0.9997	0.9966	0.9679	0.9702	0.9459	0.9584
A5	0.8829	0.9998	0.9966	0.9730	0.9702	0.9459	0.9584
A6	0.9193	0.9862	0.9845	0.9743	0.9283	0.9577	0.9913

A7	1.0000	0.9854	0.9845	0.9715	0.9266	0.9524	0.9913
A8	0.9942	0.9833	0.9913	0.9823	0.9390	0.9145	0.9775
A9	0.9781	0.9764	0.9979	0.9907	0.9209	0.9260	0.9456
A10	0.9409	0.9844	1.0000	1.0000	0.9358	0.9065	0.9340
A11	0.9735	0.9855	0.9712	0.9772	0.9264	1.0000	1.0000

Table (3.33-b) Total relative importance based on WPM method with eq 8.

Eq.8							
C	C31	C32	C33	C34	C35	C36	C37
A1	1.0000	0.8965	0.9029	0.9961	0.9850	1.0000	0.9575
A2	1.0000	0.9178	0.9230	0.9961	1.0000	0.9970	1.0000
A3	1.0000	0.9302	0.9346	0.9793	0.9746	0.9921	0.9941
A4	1.0000	0.8965	0.9029	0.9819	0.9746	0.9962	0.9972
A5	0.9981	0.8965	0.9029	0.9819	0.9746	0.9970	0.9986
A6	0.9892	0.9062	0.9121	0.9819	0.9746	0.9898	0.9540
A7	0.9685	0.9492	0.9524	0.9866	0.9779	0.9898	0.9540
A8	0.9807	0.9429	0.9465	0.9793	0.9746	0.9938	0.9884
A9	0.9644	1.0000	1.0000	0.9765	0.9620	0.9918	0.9972
A10	0.9854	0.9156	0.9209	0.9819	0.9850	0.9884	0.9958
A11	0.9903	0.9287	0.9332	1.0000	0.9746	0.9987	0.9479

Table (3.33-c) Total relative importance based on WPM method with eq 8.

Eq.8						
C A	C41	C42	C43	C44	C51	C52
A1	0.9689	0.9811	0.9974	0.9701	0.9697	0.9744
A2	0.9630	0.9811	0.9974	0.9701	0.9617	0.9966
A3	0.9548	0.9779	0.9974	0.9701	0.9630	0.9902
A4	0.9630	0.9811	0.9944	0.9701	0.9630	0.9902
A5	0.9689	0.9811	0.9974	0.9701	0.9664	0.9869
A6	0.9703	0.9915	0.9571	0.9879	0.9873	0.9815
A7	0.9620	0.9915	0.9571	0.9879	0.9891	0.9815
A8	0.9644	0.9920	0.9826	0.9829	0.9907	0.9795
A9	1.0000	1.0000	1.0000	1.0000	0.9744	0.9995
A10	0.9748	0.9982	0.9723	0.9939	0.9689	1.0000
A11	0.9716	0.9869	0.9344	0.9731	1.0000	0.9437

Table (3.33-d) Total relative importance based on WPM method with eq 8.

Eq.8								
C A	C53	C54	C61	C62	C63	C64	C65	Q2
A1	0.9900	0.9812	0.9940	0.9908	0.9818	0.9819	0.9958	0.4642
A2	0.9900	0.9812	0.9914	0.9908	0.9803	0.9759	0.9944	0.5475
A3	0.9900	0.9786	0.9868	0.9908	0.9670	0.9776	0.9910	0.5381
A4	0.9861	0.9812	0.9856	0.9908	0.9761	0.9819	0.9901	0.4490
A5	0.9807	0.9812	0.9889	0.9921	0.9761	0.9776	0.9944	0.4553
A6	0.9417	1.0000	1.0000	1.0000	0.9987	0.9965	0.9987	0.4671

A7	0.9417	1.0000	1.0000	1.0000	1.0000	0.9979	0.9987	0.5404
A8	0.9596	0.9932	0.9893	0.9974	0.9937	0.9933	0.9913	0.5409
A9	1.0000	0.9848	0.9860	0.9942	0.9876	0.9776	0.9913	0.6138
A10	0.9985	0.9889	0.9914	0.9942	0.9818	0.9930	0.9831	0.4932
A11	0.9329	1.0000	0.9902	1.0000	1.0000	1.0000	1.0000	0.5076

Total relative significance of alternatives with different lambda is found by using equation 9.

Table 3.34 Total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.1)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6206	A9	1
All air system .Multi Zone	0.5550	A2	2
All water system .Fan-Coil Unit	0.5473	A7	3
Air-water system .Induction Unit	0.5450	A8	4
All air system .Terminal Reheat	0.5440	A3	5
Split system	0.5192	A11	6
Heating and Cooling Panels	0.5018	A10	7
Air-water system, Fan-Coil Unit	0.4777	A6	8
All air system .Single Zone	0.4762	A1	9
All air system .VAV	0.4664	A5	10
All air system .Dual Duct	0.4597	A4	11

Table 3.35 The total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.2)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6274	A9	1
All air system .Multi Zone	0.5624	A2	2
All water system .Fan-Coil Unit	0.5542	A7	3
All air system .Terminal Reheat	0.5498	A3	4
Air-water system .Induction Unit	0.5491	A8	5
Split system	0.5308	A11	6
Heating and Cooling Panels	0.5102	A10	7

All air system .Single Zone	0.4882	A1	8
Air-water system, Fan-Coil Unit	0.4881	A6	9
All air system .VAV	0.4774	A5	10
All air system .Dual Duct	0.4705	A4	11

Table 3.36 total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.3)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6342	A9	1
All air system .Multi Zone	0.5698	A2	2
All water system .Fan-Coil Unit	0.5611	A7	3
All air system .Terminal Reheat	0.5556	A3	4
Air-water system .Induction Unit	0.5531	A8	5
Split system	0.5424	A11	6
Heating and Cooling Panels	0.5187	A10	7
All air system .Single Zone	0.5002	A1	8
Air-water system, Fan-Coil Unit	0.4986	A6	9
All air system .VAV	0.4884	A5	10
All air system .Dual Duct	0.4812	A4	11

Table 3.37 Total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.4)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6409	A9	1
All air system .Multi Zone	0.5773	A2	2
All water system .Fan-Coil Unit	0.5680	A7	3
All air system .Terminal Reheat	0.5614	A3	4
Air-water system .Induction Unit	0.5572	A8	5
Split system	0.5540	A11	6
Heating and Cooling Panels	0.5272	A10	7
All air system .Single Zone	0.5122	A1	8
Air-water system, Fan-Coil Unit	0.5091	A6	9
All air system .VAV	0.4994	A5	10
All air system .Dual Duct	0.4919	A4	11

Table 3.38 The total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.5)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6477	A9	1
All air system .Multi Zone	0.5847	A2	2
All water system .Fan-Coil Unit	0.5750	A7	3
All air system .Terminal Reheat	0.5672	A3	4
Split system	0.5656	A11	5
Air-water system .Induction Unit	0.5613	A8	6
Heating and Cooling Panels	0.5357	A10	7
All air system .Single Zone	0.5242	A1	8
Air-water system, Fan-Coil Unit	0.5196	A6	9
All air system .VAV	0.5104	A5	10
All air system .Dual Duct	0.5026	A4	11

Table 3.39 total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.6)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6544	A9	1
All air system .Multi Zone	0.5921	A2	2
All water system .Fan-Coil Unit	0.5819	A7	3
Split system	0.5772	A11	4
All air system .Terminal Reheat	0.5730	A3	5
Air-water system .Induction Unit	0.5654	A8	6
Heating and Cooling Panels	0.5442	A10	7
All air system .Single Zone	0.5362	A1	8
Air-water system, Fan-Coil Unit	0.5301	A6	9
All air system .VAV	0.5214	A5	10
All air system .Dual Duct	0.5133	A4	11

Table 3.40 total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.7)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6612	A9	1
All air system .Multi Zone	0.5996	A2	2
Split system	0.5889	A11	3
All water system .Fan-Coil Unit	0.5888	A7	4

All air system .Terminal Reheat	0.5788	A3	5
Air-water system .Induction Unit	0.5695	A8	6
Heating and Cooling Panels	0.5527	A10	7
All air system .Single Zone	0.5482	A1	8
Air-water system, Fan-Coil Unit	0.5406	A6	9
All air system .VAV	0.5324	A5	10
All air system .Dual Duct	0.5240	A4	11

Table 3.41 The total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.8)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6680	A9	1
All air system .Multi Zone	0.6070	A2	2
Split system	0.6005	A11	3
All water system .Fan-Coil Unit	0.5957	A7	4
All air system .Terminal Reheat	0.5846	A3	5
Air-water system .Induction Unit	0.5735	A8	6
Heating and Cooling Panels	0.5612	A10	7
All air system .Single Zone	0.5602	A1	8
Air-water system, Fan-Coil Unit	0.5511	A6	9
All air system .VAV	0.5434	A5	10
All air system .Dual Duct	0.5348	A4	11

Table 3.42 Total relative significance of alternatives with different lambda.

<b>Alternatives Lambda (0.9)</b>	<b>Qi</b>	<b>Codes</b>	<b>Rank</b>
Water-source Heat Pumps	0.6747	A9	1.0000
All air system .Multi Zone	0.6145	A2	2.0000
Split system	0.6121	A11	3.0000
All water system .Fan-Coil Unit	0.6026	A7	4.0000
All air system .Terminal Reheat	0.5904	A3	5.0000
Air-water system .Induction Unit	0.5776	A8	6.0000
All air system .Single Zone	0.5722	A1	7.0000
Heating and Cooling Panels	0.5696	A10	8.0000
Air-water system, Fan-Coil Unit	0.5616	A6	9.0000
All air system .VAV	0.5544	A5	10.0000
All air system .Dual Duct	0.5455	A4	11.0000

## CHAPTER 4

### 4. RESULTS AND DISCUSSION

#### 4.1 Weight Results from SWARA Technique

Based on the experts' opinion and as shown in Table (3), the most significant criteria are technical Properties with a significance of 0.2022. The ergonomics criteria achieve second ranking after the criteria of technical Properties with the significance of 0.1953. In the third place the criteria of physical properties with significance of 0.1805. The criteria of economic Cost have significance of 0.1566. The fifth place is the criteria of flexibility with significance of 0.1389. The criteria of reliability have significance of 0.1266. Figure 4.1 shows the weights of main criteria.

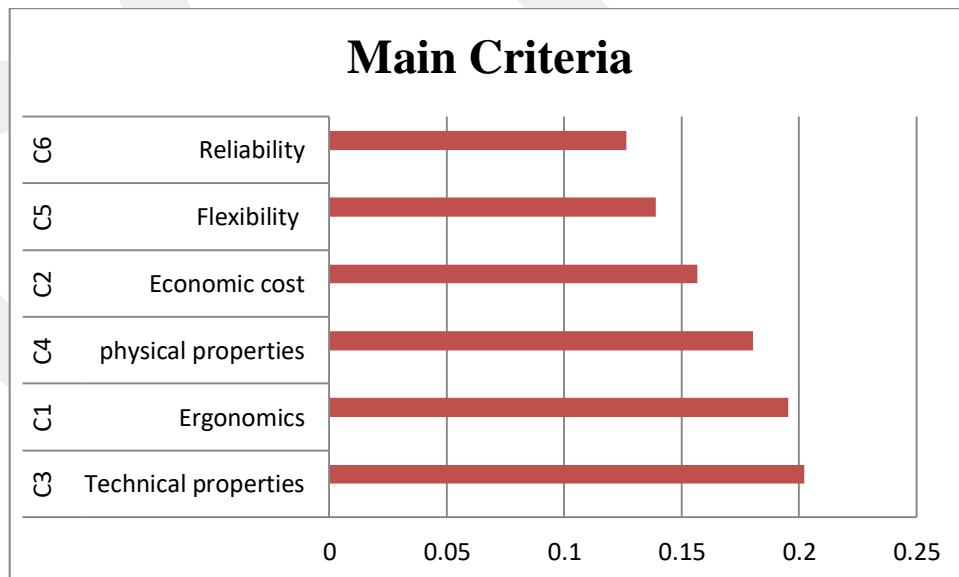


Figure 4.1 The weights of main criteria.

In ergonomics terms, the thermal comfort had a great significance of 0.2610. Ventilation is of great importance to rid the building of emissions and air pollution, so its importance was 0.2070. In the third place is the category of relative humidity with significance of 0.2018. The level of noise and visual impact ranked fourth and fifth respectively, with a significance of 0.2003 and 0.1300. Table 6 shows weights for health standards. Figure 4.2 shows the weights of ergonomics criteria.

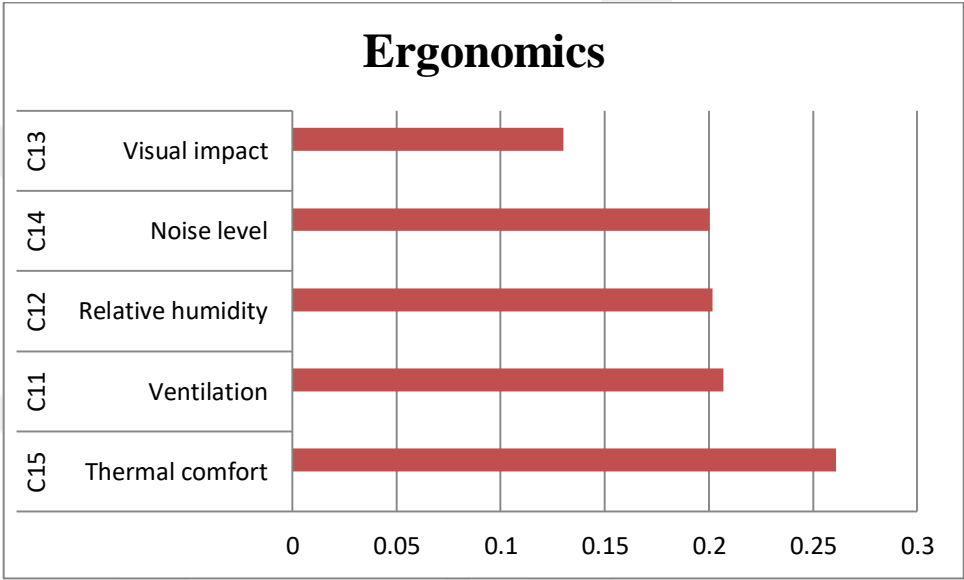


Figure 4.2 The weights of ergonomics criteria

By the category of economic cost, it becomes clear that the main cost has the largest value of 0.5881. The maintenance cost achieves second ranking after the category of capital cost with the significance of 0.4119. Table 9 shows the weights values. Figure 4.3 shows the weights of economic cost criteria.

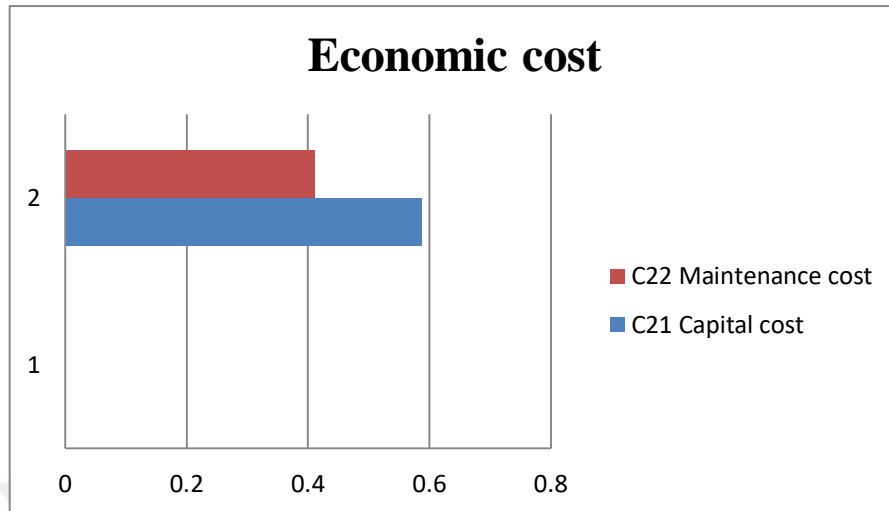


Figure 4.3 The weights of economic cost criteria.

The technical properties category is the most important criterion compared to other major criteria because it focuses on two main issues, which are energy consumption and CO<sub>2</sub> emissions. Energy consumption was an important place in the ranking, compared to 6 criteria, with a value of 0.1755. The categories of COP heating and CO<sub>2</sub> emission have approximately same significance of 0.1646 and 0.1640, respectively. The fourth place is the category of COP cooling with significance of 0.1592. The fifth place occupied the multi-zone control with a significance of 0.1359, while the sixth place occupied the single control zone with a significance of 0.1086. Water consumption in the seventh and last place due to its least importance compared to the previous criteria by a significance of 0.0922. Through Table 12, it is possible to know the arrangement of the criteria for technical properties. Figure 4.4 shows the weights of technical properties criteria.

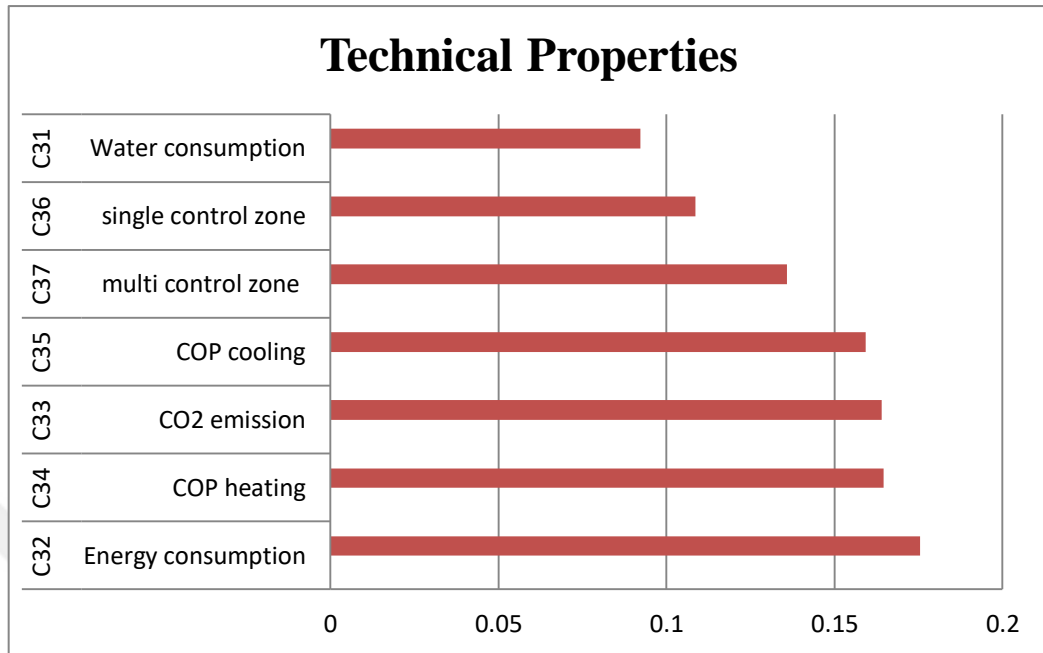


Figure 4.4 The weights of technical properties criteria

Through the evaluation of experts in the physical properties criteria, it was found that the indoor area requirement and indoor appearance occupies the most important position compared to the outside of the building by 0.3497 and 0.2786, respectively. The outdoor area requirement and the outdoor appearance occupied third and fourth places with 0.1909 and 0.1808 respectively. Table 15 shows the values of the four weights. Figure 4.5 shows the weights of physical properties criteria.

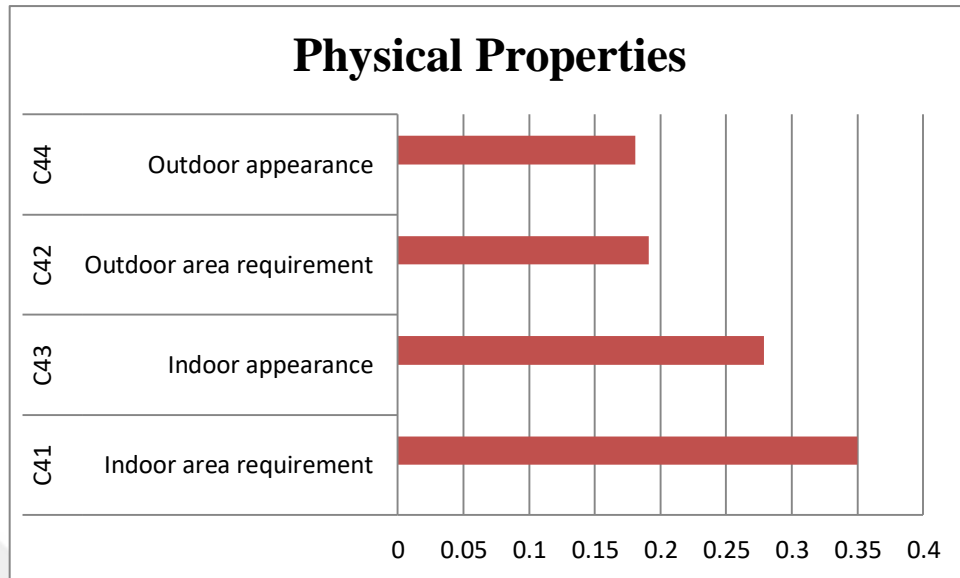


Figure 4.5 the weights of physical properties criteria.

Based on the experts' opinion and shown in Table 18, the most significant criteria is energy source flexibility with a significance of 0.2928. The biggest challenge was between the installation flexibility and the integration flexibility with a significance of 0.2582 and 0.2499 high. Ease of maintenance was last, with a significance 0.1991. Figure 4.6 shows the weights of flexibility criteria.

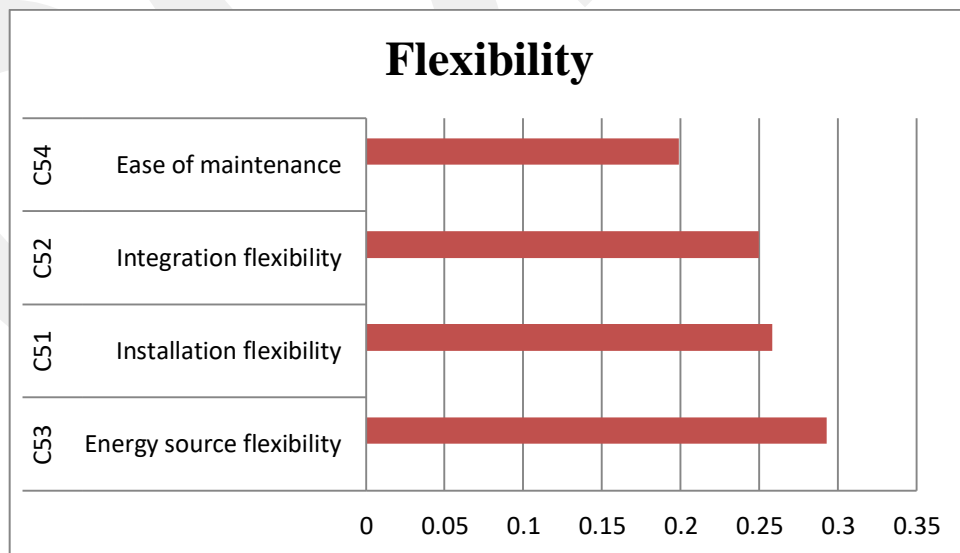


Figure 4.6 The weights of flexibility criteria.

The reliability standard is very important as it consists of several sub criteria as shown in Table 21. The system life ranks first because of its importance among users with a value of 0.2751. The vendor availability and the ability to purchase the specified system occupies the second measure of the reliability criteria, with a significance of 0.2049. The repair time is more important than the lead time, with a significance of 0.2007 and 0.1705 respectively. The fifth place is the fewer component with significance of 0.1487. Figure 4.7 shows the weights of reliability criteria

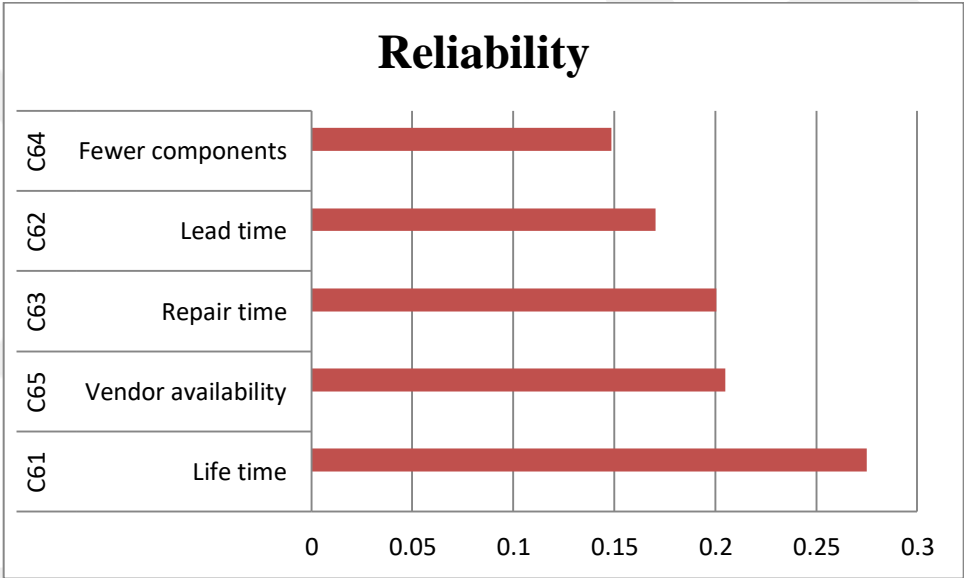


Figure 4.7 The weights of reliability criteria.

Final weights calculation is performed by multiplying the weight of main criteria and sub-criteria in order to obtain the final weight of each individual sub-criteria, and results of the calculation are presented in Figure 4.8 in the form of radar graphic. The sum of all final weights of the sub-criteria is equal to 1. The most influential sub-criteria among each criteria are: (1) capital cost 0.0921;(2) maintenance cost 0.0645;(3) indoor area requirement 0.0631;(4) thermal comfort 0.0510; (5) indoor appearance 0.0503.

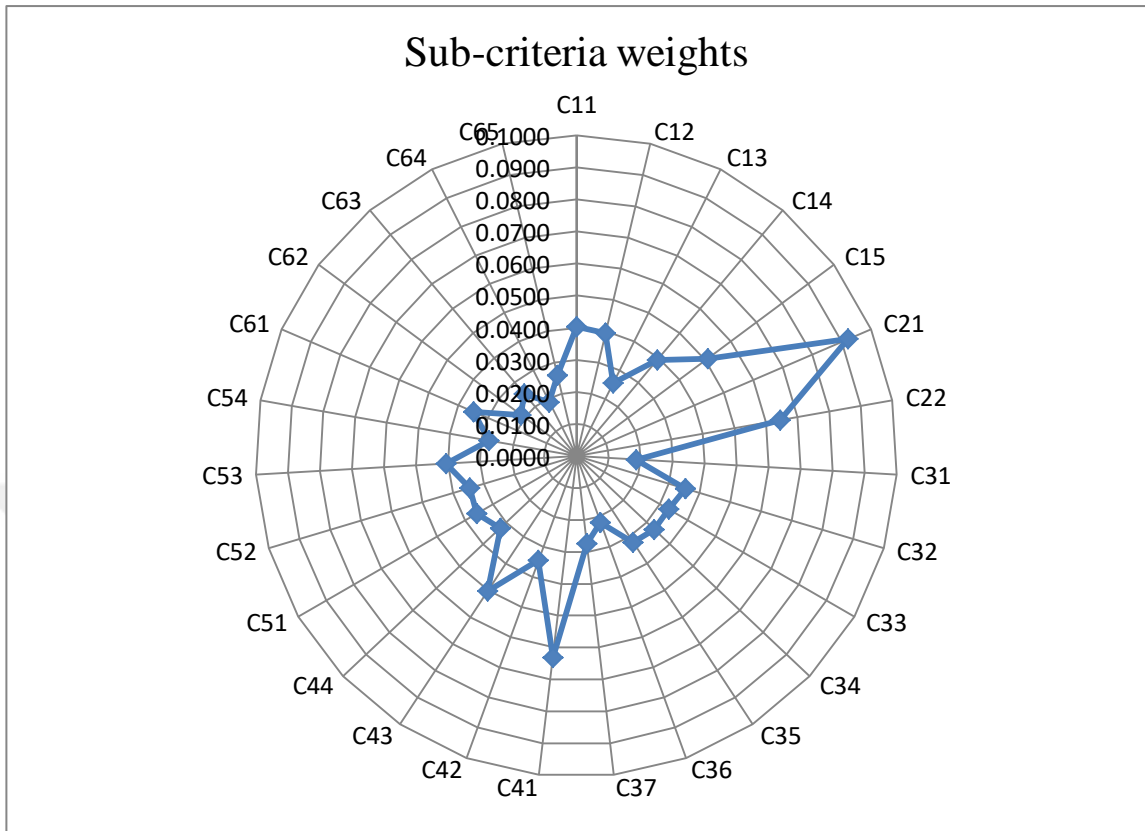


Figure 4.8 Sub-criteria weights.

#### 4.2 Prioritization Results Based on WASPAS

WASPAS is a relatively new MCDM method and has a visual placement in the MCDM literature. In addition to its simplicity, the WASPAS method uses the concept of classification accuracy by combining well-known WSM and WPM. This combination achieved through the optimization criterion provides unique opportunities for decision makers such as assessing confidence intervals for the relative importance of alternatives and reducing estimated variance in classification results. Despite its critical importance, the WSM and WPM mixture is usually performed on an ad hoc basis in the literature.

The parameter  $\lambda$  controls the effect of WSM and WPM on the end result. This parameter improves the accuracy of the request. The symbol ( $\lambda$ ) refers to the combination parameter.

The result obtained from WASPAS method varies with the deviation in WASPAS parameter ( $\lambda$ ), which varies from 0.1 to 0.9. When we consider  $\lambda$  value as 0.1, the A9 alternative acquires maximum WASPAS score (0.6206) and gets 1st rank that represents it as the best HVAC system alternative among all. A4 alternative achieves 0.4597 WASPAS score and obtains 11th rank that represents it as a last alternative. When  $\lambda$  value is considered as 0.2, the A9 (WASPAS score = 0.6274) and A4 (WASPAS score = 0.4705) alternatives hold 1st and 11th rank simultaneously. When  $\lambda$  value is 0.3, A9 (WASPAS score = 0.6342) alternative again holds 1st rank and A4 (WASPAS score = 0.4812) alternative obtains 11th rank. When  $\lambda$  value is considered as 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 the A9 (WASPAS score = 0.6409, 0.6477, 0.6544, 0.6612, 0.6680, 0.6747) and A4 (WASPAS score = 0.4919, 0.5026, 0.5133, 0.5240, 0.5348, 0.5455) alternatives hold 1st and 11th rank in any case. It indicates that A9 is the best alternative whereas A4 is least alternative of HVAC.

WASPAS score and WASPAS rank obtained from WASPAS method for HVAC system selection are represented in Figs. 4.9a and 4.9b respectively. Maximum WASPAS score represents the highest priority alternative while minimal score indicates the lowest priority of alternative. The top-priority alternative coming out from WASPAS result is (A9) in all cases when the  $\lambda$  value is (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9). In the WASPAS method the priority of alternatives is as follows:

$\lambda = 0.1$ : A9 > A2 > A7 > A8 > A3 > A11 > A10 > A6 > A1 > A5 > A4

$\lambda = 0.2$ : A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.3$ : A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.4$ : A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.5$ : A9 > A2 > A7 > A3 > A11 > A8 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.6$ : A9 > A2 > A7 > A11 > A3 > A8 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.7$ : A9 > A2 > A11 > A7 > A3 > A8 > A10 > A1 > A6 > A5 > A4

$\lambda = 0.8$ : A9 > A2 > A11 > A7 > A3 > A8 > A10 > A1 > A6 > A5 > A4

$$\lambda = 0.9: A9 > A2 > A11 > A7 > A3 > A8 > A1 > A10 > A6 > A5 > A4$$

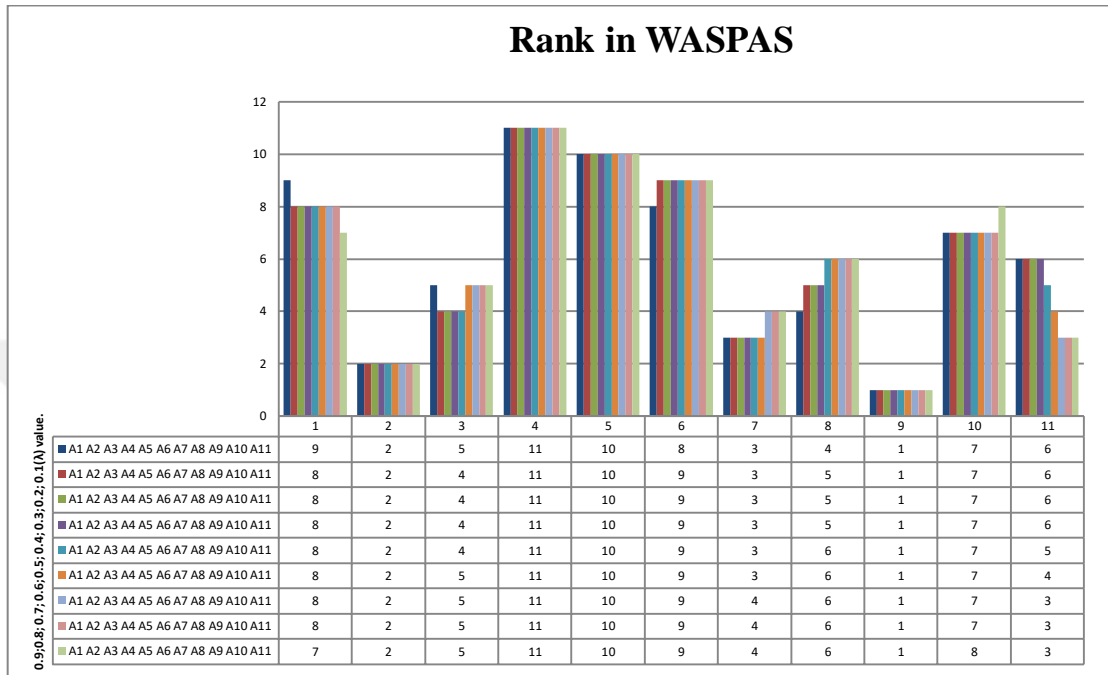


Figure 4.9a Rank obtained from WASPAS method.

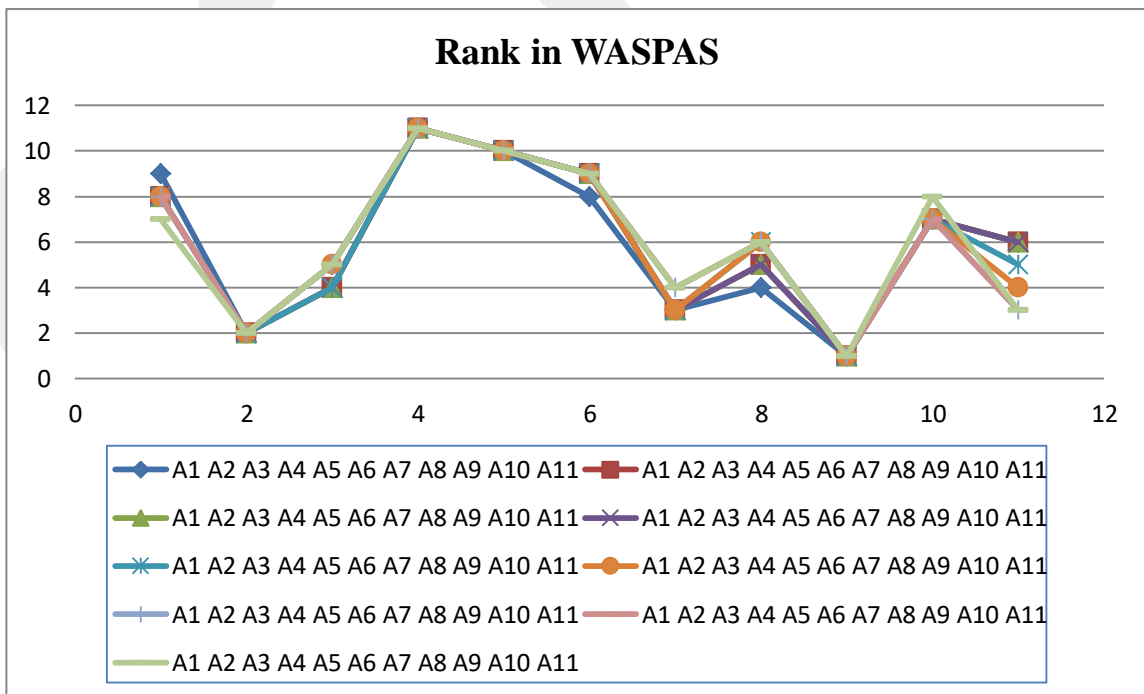


Figure 4.9b Rank obtained from WASPAS method.

According to the result of WASPAS method A9 (water source heat pump) alternative has obtained first rank among the alternatives in all nine cases when WASPAS parameter  $\lambda$  value is (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9). The experts give more weightage to the A9 alternative because it is economically, technically, and environmentally possible while the A4 alternative is the last rank in all cases of lambda.

## CHAPTER 5

### 5. CONCLUSION

There is a wide range of MCDM methods that are applied in various fields. In calculations, it is often difficult to determine the priority of an alternative, as the results obtained may be the same and frequent, but this is not the only drawback that exists for these methods. Given the fact that other methodologies are subject to expert assessments and opinions, this limit is not appropriate. The results are subject to many and many changes, and for this reason, the importance of things may be wrongly calculated. In this case, the alternatives may be evaluated incorrectly and unfairly, due to the above problems, as well as due to a misunderstanding of the method. Other MCDM methods have their disadvantages associated with using the same dimensions to different standards. Environmental impact and technical, economic, and technical performance are measured, and other decision-making methods cannot be applied to solve this problem. The WASPAS method was chosen to solve the problem of choosing a factory-appropriate HVAC system. The WASPAS method was added to MCDM methods in 2012 and was not used in identifying alternatives to HVAC systems, so this method was suggested. It should be noted that the accuracy of the results obtained from all techniques depends on the opinions of experts and the type of technique. In this method, in addition to the cases mentioned, the estimation accuracy in the WASPAS method is higher than the WSM or WPM methods. Also, to increase the accuracy of the calculations, different ( $\lambda$ ) values were used, the results of which were illustrated. Therefore, this research, in addition to analyzing alternatives, provides a method that can lead to different results according to the value ( $\lambda$ ), which is one of the unique advantages of this method compared to other MCDM methods. The WASPAS method combines the benefits of WSM and WPM policies.

In this case, SWARA was applied to determine the relevance of the criteria, while WASPAS was used to rank alternatives. The SWARA method allowed the efficient determination of standard weights. Finally, the WASPAS method was found practical for arranging alternatives. Thus, theoretical research and practical results demonstrated the effectiveness of using the WASPAS method to determine the best alternative. This approach can be used in other buildings to determine the appropriate system for it in different countries as well as to solve other problems. Indeed, the country's social, economic, and sustainable development depend directly on the correct determination of its adaptation system and its reliability. Achieving sustainable performance for all countries through the essential elements in developing their strategies, developing the selection of the optimal solution from several solutions, and improving the response capacity to reduce energy consumption. The choice of the optimal alternative to HVAC systems has a critical impact on the quality of life and environmental development in Turkey. Inaccurate identification may lead to higher pollution and energy consumption, which may negatively affect the environment and economic situation. An accurate model was proposed to solve the problem of defining the best HVAC system by applying the WASPAS approach. 6 main criteria and 27 sub criteria were identified. Criteria weights were calculated based on the SWARA method. As a result, the most important criteria were related to the economic aspect, providing thermal comfort and spatial requirements within the building. The least important criteria were the visual impact, water consumption and maintenance time.

On the basis of the above analysis and results of different types of HVAC system, it was concluded that the A9 (water source heat pump) is ranked first among 11 alternatives. Priority of alternatives in the WASPAS follows:

$$\lambda = 0.1: A9 > A2 > A7 > A8 > A3 > A11 > A10 > A6 > A1 > A5 > A4$$

$$\lambda = 0.2: A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4$$

$$\lambda = 0.3: A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4$$

$$\lambda = 0.4: A9 > A2 > A7 > A3 > A8 > A11 > A10 > A1 > A6 > A5 > A4$$

$\lambda = 0.5: A9 > A2 > A7 > A3 > A11 > A8 > A10 > A1 > A6 > A5 > A4$

$\lambda = 0.6: A9 > A2 > A7 > A11 > A3 > A8 > A10 > A1 > A6 > A5 > A4$

$\lambda = 0.7: A9 > A2 > A11 > A7 > A3 > A8 > A10 > A1 > A6 > A5 > A4$

$\lambda = 0.8: A9 > A2 > A11 > A7 > A3 > A8 > A10 > A1 > A6 > A5 > A4$

$\lambda = 0.9: A9 > A2 > A11 > A7 > A3 > A8 > A1 > A10 > A6 > A5 > A4$

The alternative A9 (Water-source Heat Pumps) succeeded in obtaining a higher weight and greater evaluation by experts and decision makers, while the alternative A4 (All air system dual Duct) failed by obtaining a lower weight for the criteria and lower evaluations compared to other alternatives. As for other alternatives, they were less important by expert evaluation. The A2 (All air system multi Zone (CAV)) alternative was a competitor to the A9 alternative and received a good evaluation by the experts. The A4 (All air system dual Duct) alternative failed in the assessments because it did not meet the criteria used in decision-making.

Among the set of alternatives, A9 (water source heat pump) have top-priority while A4 have last rank in all cases of lambda.

The purpose of the thesis is to use decision-making techniques to choose the heating, ventilation and air-conditioning system and find the best alternative for industrial buildings based on multiple performance criteria including technical performance, economic performance, and environmental performance in addition to the preferences of decision makers. No research was conducted before it systematically combined the overall objective performance of HVAC systems with a personal preference for people together upon selection. SWARA and WASPAS methods has been applied for the purpose of decision making due to its ability to accurately weigh criteria and to choose the most appropriate alternative through subjective and objective assessments with great accuracy. WASPAS is characterized by its ability to facilitate the effective representation of inaccurate data and vague information and to provide a good systematic decision-making analysis. This letter provides decision makers with a comprehensive overview of the performance of HVAC systems, as well as a way to

determine their preferences and realities in the decision-making process. This message is inspired by the growing interest in protecting the environment, reducing energy consumption, and incorporating thought into life-cycle assessment in performance assessment that helps decision makers make the decisions responsible for the environment.



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# APPENDIX-A: Construction material analysis

## Construction materials of walls, roofs, grounds, windows.

Edit construction - Copy of gh

Constructions

Layers Surface properties Image Calculated Cost Condensation analysis

Help Info Data

**General**

Name:

Source:

Category: Walls

Region: TURKEY

Colour:

**Definition**

Definition method: 1-Layers

**Calculation Settings**

Layers: 3

Number of layers: 3

Outermost layer

Material: Gypsum Plastering

Thickness (m): 0.2000

Bridged?

Layer 2

Material: Brick

Thickness (m): 0.5100

Bridged?

Innermost layer

Material: Gypsum Plastering

Thickness (m): 0.3000

Bridged?

**Construction Layers**

Set the number of layers first, then select the r and thickness for each layer.

**Bridging**

You can also add bridging to any layer to mod effect of a relatively more conductive material a less conductive material. For example wood bringing an insulation layer.

*Note that bridging effects are NOT used in EnergyPlus used in energy code compliance checks requiring U-v be calculated according to BS EN ISO 6946.*

**Energy Code Compliance**

You can calculate the thickness of insulation r to meet the mandatory energy code U-value at the Energy Code tab at site level.

This calculation identifies the 'insulation layer' layer having the highest r-value and requires th bridging is used in the construction.

**Model data**

Edit construction - Copy of ghh

**Constructions** | Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Cross Section

Outer surface

200.00mm - 510.00mm - Brick

510.00mm - Brick

510.00mm - 510.00mm - Brick

Inner surface

**Help** | Info | Data

**Image**

This tab shows the construction to scale (except very thin layers) using material textures as specified. Bridging elements are ignored.

Model data

Help | Cancel | OK

**Constructions**

Layers | Surface properties | Image | **Calculated** | Cost | Condensation analysis

---

**Inner surface**

Convective heat transfer coefficient (W/m <sup>2</sup> -K)	2.152
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.540
Surface resistance (m <sup>2</sup> -K/M)	0.130

**Outer surface**

Convective heat transfer coefficient (W/m <sup>2</sup> -K)	19.870
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.130
Surface resistance (m <sup>2</sup> -K/M)	0.040

**No Bridging**

U-Value surface to surface (W/m <sup>2</sup> -K)	0.511
R-Value (m <sup>2</sup> -K/M)	2.128
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.470</b>

**With Bridging (BS EN ISO 6946)**

Thickness (m)	1.0100
Km - Internal heat capacity (KJ/m <sup>2</sup> -K)	100.0000
Upper resistance limit (m <sup>2</sup> -K/M)	2.128
Lower resistance limit (m <sup>2</sup> -K/M)	2.128
U-Value surface to surface (W/m <sup>2</sup> -K)	0.511
R-Value (m <sup>2</sup> -K/M)	2.128
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.470</b>

**Help**

Info | **Data**

---

**Calculated Data**

This tab provides further information on the heat transmission properties of the construction.

**This data is used in Simple calculation methods such as SBEM and generally NOT in Energy simulations.**

Exceptions are window frame U-values and use fixed CIBSE convective heat transfer coefficient (more below).

U-values are shown including and excluding the of surface resistance and are calculated with a without bridging effects.

Note that the outer surface resistance depends exposure to wind (on the Location tab at Site Information).

**Convective heat transfer coefficients**

The convective heat transfer coefficients displayed on the left are used in EnergyPlus only when the 'Inside/Outside convection algorithm' is selected. Otherwise EnergyPlus uses its 'own convection algorithm' as set in the simulation options and transmission data displayed here is not used.

**Model data**

Help | Cancel | **OK**

Edit construction - Project flat roof

**Constructions**

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

**General**

**Name** Project flat roof

Source

Category Roofs

Region TURKEY

Colour

Definition 1-Layers

Calculation Settings

Layers

Number of layers 4

Outermost layer

Material Asphalt 1

Thickness (m) 0.0100

Bridged?

Layer 2

Material MW Glass Wool (rolls)

Thickness (m) 0.1445

Bridged?

Layer 3

Material Air gap >=25mm

Thickness (not used in thermal calcs) (m) 0.2000

Innermost layer

Material Plasterboard

Thickness (m) 0.0130

Bridged?

**Help**

Info | Data

**Construction Layers**

Set the number of layers first, then select the r and thickness for each layer.

Insert layer

Delete layer

**Bridging**

You can also add bridging to any layer to mod effect of a relatively more conductive material a less conductive material. For example wood bringing an insulation layer.

*Note that bridging effects are NOT used in EnergyPlus used in energy code compliance checks requiring U-v; be calculated according to BS EN ISO 6946.*

**Energy Code Compliance**

You can calculate the thickness of insulation r to meet the mandatory energy code U-value a: the Energy Code tab at site level.

This calculation identifies the 'insulation layer' layer having the highest r-value and requires th bridging is used in the construction.

Set U-Value

Reverse construction layers

Model data

Insert layer

Delete layer

Help

Cancel

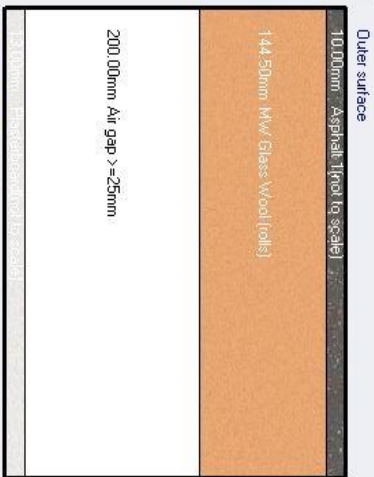
OK

# Edit construction - Project flat roof

## Constructions

Layers Surface properties Image Calculated Cost Condensation analysis

### Cross Section



## Help

Info Data

### Image

This tab shows the construction to scale (except very thin layers) using material textures as specified. Bridging elements are ignored.

## Model data

Help

Cancel

OK

Constructions

Layers Surface properties Image Calculated Cost Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m <sup>2</sup> -K)	4.460
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.540
Surface resistance (m <sup>2</sup> -K/W)	0.100
Outer surface	
Convective heat transfer coefficient (W/m <sup>2</sup> -K)	19.870
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.130
Surface resistance (m <sup>2</sup> -K/W)	0.040
No Bridging	
U-Value surface to surface (W/m <sup>2</sup> -K)	0.258
R-Value (m <sup>2</sup> -K/W)	3.999
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.250</b>
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.3675
Km - Internal heat capacity (kJ/m <sup>2</sup> -K)	32.6144
Upper resistance limit (m <sup>2</sup> -K/W)	3.999
Lower resistance limit (m <sup>2</sup> -K/W)	3.999
U-Value surface to surface (W/m <sup>2</sup> -K)	0.259
R-Value (m <sup>2</sup> -K/W)	3.999
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.250</b>

Model data

Help

Info Data

Calculated Data

This tab provides further information on the he transmission properties of the construction.

**This data is used in Simple calculation met such as SBEM and generally NOT in Energy simulations.**

Exceptions are window frame U-values and us fixed CIBSE convective heat transfer coefficient (more below).

U-values are shown including and excluding th of surface resistance and are calculated with a without bridging effects.

Note that the outer surface resistance depends exposure to wind (on the Location tab at Site I

**Convective heat transfer coefficients**

The convective heat transfer coefficients displi the left are used in EnergyPlus only when the ' Inside/Outside convection algorithm is selecte Otherwise EnergyPlus uses its' own convection algorithm as set in the simulation options and transmission data displayed here is not used.

Help

Cancel

OK

**Constructions**

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

**General**

**Name** Project ground floor

Source

Category Floors (ground)

Region TURKEY

Colour

**Definition**

Definition method 1-Layers

**Calculation Settings**

Layers 4

Number of layers 4

Outermost layer

Material Urea Formaldehyde Foam

Thickness (m) 0.1327

Bridged?

**Layer 2**

Material Cast Concrete

Thickness (m) 0.1000

Bridged?

**Layer 3**

Material Floor/Root Screed

Thickness (m) 0.0700

Bridged?

**Innermost layer**

Material Timber Flooring

Thickness (m) 0.0300

Bridged?

**Help**

Info | Data

**Construction Layers**

Set the number of layers first, then select the r and thickness for each layer.

Insert layer

Delete layer

**Bridging**

You can also add bridging to any layer to mod effect of a relatively more conductive material a less conductive material. For example wood bringing an insulation layer.

*Note that bridging effects are NOT used in EnergyPlus used in energy code compliance checks requiring U-value calculated according to BS EN ISO 6946.*

**Energy Code Compliance**

You can calculate the thickness of insulation r to meet the mandatory energy code U-value at the Energy Code tab at site level.

This calculation identifies the 'insulation layer' layer having the highest r-value and requires th bridging is used in the construction.

Set U-Value

Reverse construction layers

**Model data**

# Edit construction - Project ground floor

## Constructions

- Layers
- Surface properties
- Image
- Calculated
- Cost
- Condensation analysis

## Cross Section

Inner surface

30,00mm	Timber Flooring
70,00mm	Floor/Roof Screed
100,00mm	Cast Concrete
132,70mm	Urea4 Formaldehyde Foam

Outer surface

## Help

- Info
- Data

## Image

This tab shows the construction to scale (except very thin layers) using material textures as specified. Bridging elements are ignored.

## Model data

Help

Cancel

OK

**Constructions**

Layers Surface properties Image Calculated Cost Condensation analysis

**Inner surface**

Convective heat transfer coefficient (W/m <sup>2</sup> -K)	0.342
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.540
Surface resistance (m <sup>2</sup> -K/W)	0.170

**Outer surface**

Convective heat transfer coefficient (W/m <sup>2</sup> -K)	19.870
Radiative heat transfer coefficient (W/m <sup>2</sup> -K)	5.130
Surface resistance (m <sup>2</sup> -K/W)	0.040

**No Bridging**

U-Value surface to surface (W/m <sup>2</sup> -K)	0.264
R-Value (m <sup>2</sup> -K/W)	4.001
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.250</b>

**With Bridging (BS EN ISO 8946)**

Thickness (m)	0.3327
Km - Internal heat capacity (KJ/m <sup>2</sup> -K)	93.9600
Upper resistance limit (m <sup>2</sup> -K/W)	4.001
Lower resistance limit (m <sup>2</sup> -K/W)	4.001
U-Value surface to surface (W/m <sup>2</sup> -K)	0.264
R-Value (m <sup>2</sup> -K/W)	4.001
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>0.250</b>

**Help**

Info Data

**Calculated Data**

This tab provides further information on the heat transmission properties of the construction.

**This data is used in Simple calculation method such as SBEM and generally NOT in EnergyPlus simulations.**

Exceptions are window frame U-values and use of fixed CIBSE convective heat transfer coefficient (more below).

U-values are shown including and excluding the effect of surface resistance and are calculated with and without bridging effects.

Note that the outer surface resistance depends on exposure to wind (on the Location tab at Site Information).

**Convective heat transfer coefficients**

The convective heat transfer coefficients displayed in the left are used in EnergyPlus only when the 'Inside/Outside convection algorithm is selected'. Otherwise EnergyPlus uses its own convection algorithm as set in the simulation options and transmission data displayed here is not used.

Model data
Help
Cancel
OK

Edit glazing - Sgl Blue 6mm

**Glazing** | Layers | Calculated | Cost

**General**

**Name** Sgl Blue 6mm

**Description**

**Source** EnergyPlus dataset

**Category** Single

**Region** TURKEY

**Colour**

**Definition method**

**Definition method** 1-Material layers

**Layers**

**Number layers** 1

**Outermost pane** Generic BLUE 6MM

**Pane type**

Flip layer

**Radiance Daylighting**

---

**Help** | Info | Data

**Legislative regions**

- TONGA
- TRINIDAD AND TOBAGO
- TUNISIA
- TURKEY
- TURKEY
- TURKMENISTAN
- TURKS AND CAICOS ISLANDS
- TUVALU
- U.S. MINOR ISLANDS
- UGANDA

**Data Report (Not Editable)**

**General**

**Category** TURKEY

**Non-Domestic Energy codes**

Code	Energy Code	Standard
Code 1	TURKEY	
Code 2	Turkey	
Code 3	IECC-1998	
Code 4	IECC-2000	
Code 5	General ener	

**Other**

- Minimal insulation standard Uninsulated
- Normal reference standard Reference
- State-of-the-art standard Cold winter'

**Domestic Energy codes**

Help | Cancel | OK

**Locked Library data**

Calculated Values

Total solar transmission (SHGC)	0.62
Direct solar transmission	0.48
Light transmission	0.57
U-value (ISO 10292/EN 673) (W/m <sup>2</sup> -K)	5.718
<b>U-Value (W/m<sup>2</sup>-K)</b>	<b>5.778</b>

Calculated Data

This summary data has been calculated by EnergyPlus and can be useful for setting up data in cases where global glazing system is known rather than data on individual panes and window gases. The data is used in Simple methods such as SBEM.

 [Update data](#)

The U-value is determined by doing a heat calculation on the glazing layers for the following standard ASHRAE winter conditions:

- Inside air temperature = 21 C (69.8F)
- Outside air temperature = -18C (-0.4F)
- Wind speed = 5.5 m/s (12.3 mph)
- Outside convective air film conductance W/m<sup>2</sup>-K (4.58 Btu/h-ft<sup>2</sup>-F)
- Inside convective air film conductance by EnergyPlus
- No solar radiation

The 'Total solar transmission (SHGC)' (Solar Gain Coefficient) is the fraction of incident radiation that enters the zone. This includes transmitted solar radiation and the inward flow from the solar radiation that is absorbed by glazing. SHGC applies only to the center of pane.





Navigate: Site

Untitled: Building 1, Block 1, Zone 1

Analysis Summary

Zone	Block	Design Capacity (kW)	Design Flow Rate (m <sup>3</sup> /s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)	Time of Max Cool...	Max Dp Temp in Day (°C)	Floor Area (m <sup>2</sup> )
- Building 1	Block 1	0.00	0.000	0.00	0.00	0.00	-	-	Jul 14:30	53.73	1584.106
Zone 1	Block 1	249.63	17.762	217.07	217.07	0.00	25.00	33.3	Jul 16:00	30.00	1446.094
Zone 2	Block 1	22.28	1.717	19.37	19.37	0.00	24.00	36.3	Jul 15:00	28.73	261.804
<b>Totals</b>	-	<b>271.91</b>	<b>19.479</b>	<b>236.44</b>	<b>236.44</b>	<b>0.00</b>	<b>13.01</b>	<b>17.7</b>	<b>N/A</b>	<b>53.73</b>	<b>3401.964</b>

**Info Help**  
[Help](#) [Data](#)

**Summer Design Data - Summary**

Use this screen to view the summertime c summary statistics.

The maximum temperatures and cooling are shown with the design cooling capacity requirement highlighted in the leftmost co

To update the data using different calcula or outputs options, click:

[Update](#)

Display Options

General Detailed

Date 1-Norm  
 Totals calcul... 1-Build

[Edit](#) [Visualise](#) [Heating design](#) [Cooling design](#) [Simulation](#) [CFD](#) [Daylighting](#) [Cost and Carbon](#)

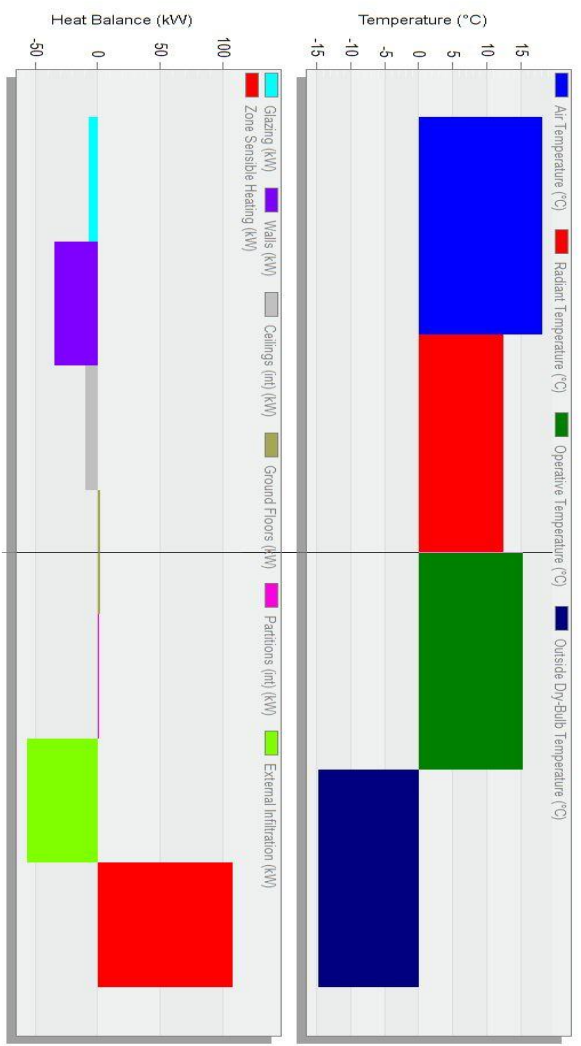
Activate Windows  
 Go to Settings to activate Windows.

Building 1  
 Block 1  
 Zone 1  
 Zone 2  
 Roof 1  
 Zone 1

Display Options

General  
 Detailed  
 Data: 1-All  
 Show as: 3-Grid  
 Normalise by area  
 Y-Axis: Appearance

Temperature and Heat Loss



Air Temperature (°C) 18.00  
 Radiant Temperature (°C) 12.42  
 Operative Temperature (°C) 15.21  
 Outside Dry-Bulb Temperature (°C) -14.80  
 Glazing (kW) -8.03  
 Walls (kW) -10.26  
 Ceilings (m) (kW) 1.77  
 Ground Floors (kW) 0.39  
 Partitions (m) (kW) -56.54  
 External Infiltration (kW) 108.04  
 Zone Sensible Heating (kW)

Winter Design - Steady-State

Use this screen to view the winter steady-state design data for the current zone. Use the controls in the Display Options panel to change the data shown. To view a typical range of winter design data set the Data to 'Air' in the Display Options panel. You can plot a number of different types of data on the same graph by making selections on the Detailed tab of the Display Options panel. To update the data using different calculations or outputs options, click **Update**.

Active Windows

Designbuilder - Untitled 1.dsb - HVAC - Untitled Building 1, Block 1, Zone 1

File Go Tools Help

Navigation: Site

Unified, building 1, Block 1, Zone 1

Steady-state Summary

Block / Zone

Block / Zone	Comfort temperature (°C)	Steady-State Heat Loss (kWh)	Design Capacity (kW)	Design Capacity (W/m2)	Glazing Gain (kWh)	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceiling Ventilation Gain...	Infiltration Gain...
[-] Building 1 Total Design Heating Capacity = 189,460 (kW)									
[-] Block 1 Total Design Heating Capacity = 189,460 (kW)	17.81	43.53	<b>54.41</b>	207.8197	-1.875	-16.798	0.156	-2.043	-11.562
[-] Block 1 Zone 1	15.21	108.04	<b>136.05</b>	93.3962	-9.033	-34.978	1.756	-10.299	0.000
[-] Roof 1 Total Design Heating Capacity = 0.000 (kW)									
[-] Roof 1 Zone 1	-14.62	0.00	<b>0.00</b>	0.0000	0.000	-0.629	12.309	-10.918	0.000
									0.763

Display Outputs

General [Default]

EM Variables Heating design Cooling design Simulation CFD Daylighting Curt and Cation

Info, Help

Help Data

**Winter Design Data - Summary**

Use this screen to view the winter design summary statistics.

The steady-state and intermittent maximum heating loads are shown with the design installed heating requirement highlighted rightmost column.

To update the data using different calculation or outputs options, click:

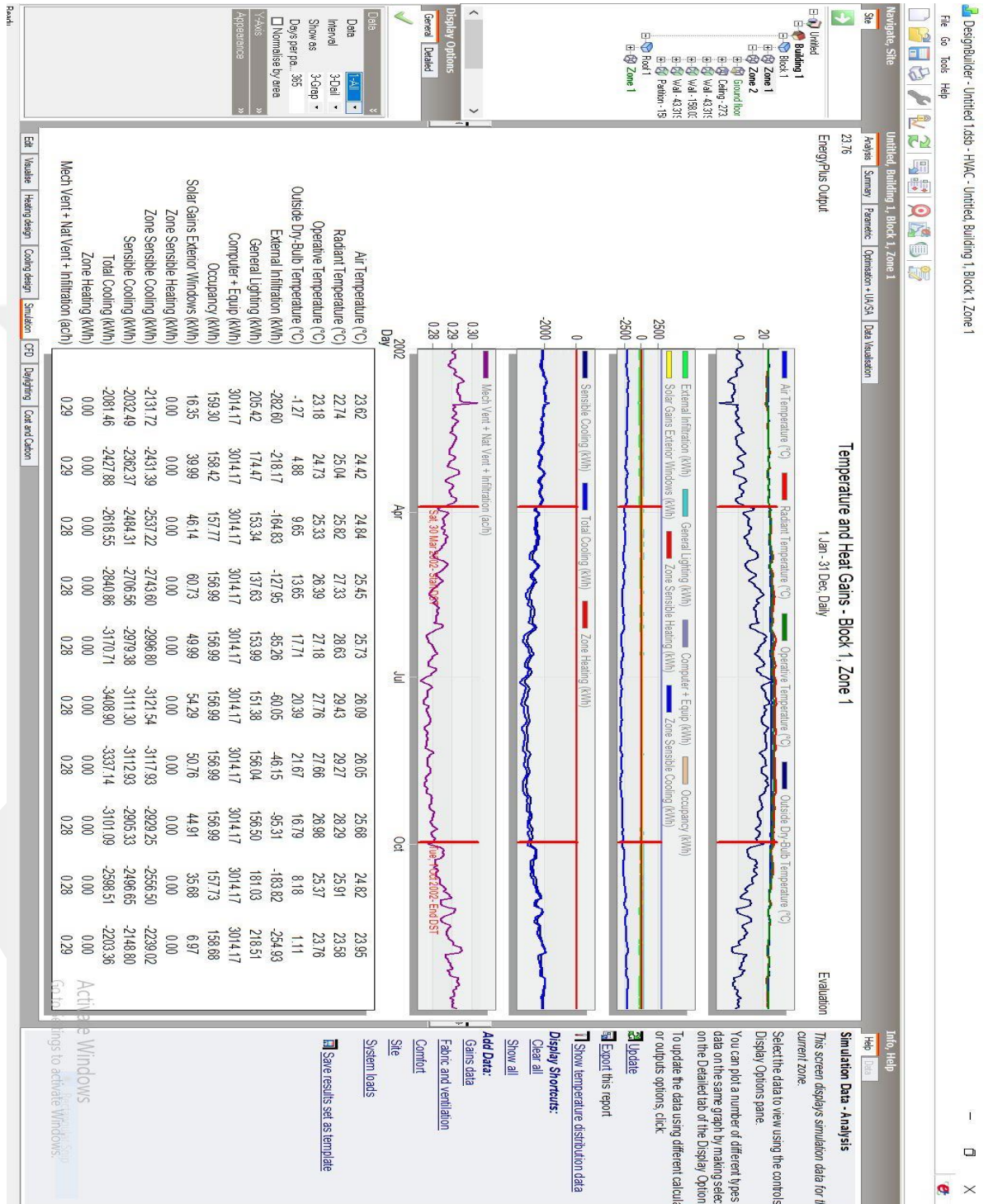
[Update](#)

Active Windows

Go to Settings to activate Windows.

## APPENDIX-C: Simulation of All air system single Zone (CAV)

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, COP heating and COP cooling for All air system single Zone (CAV).



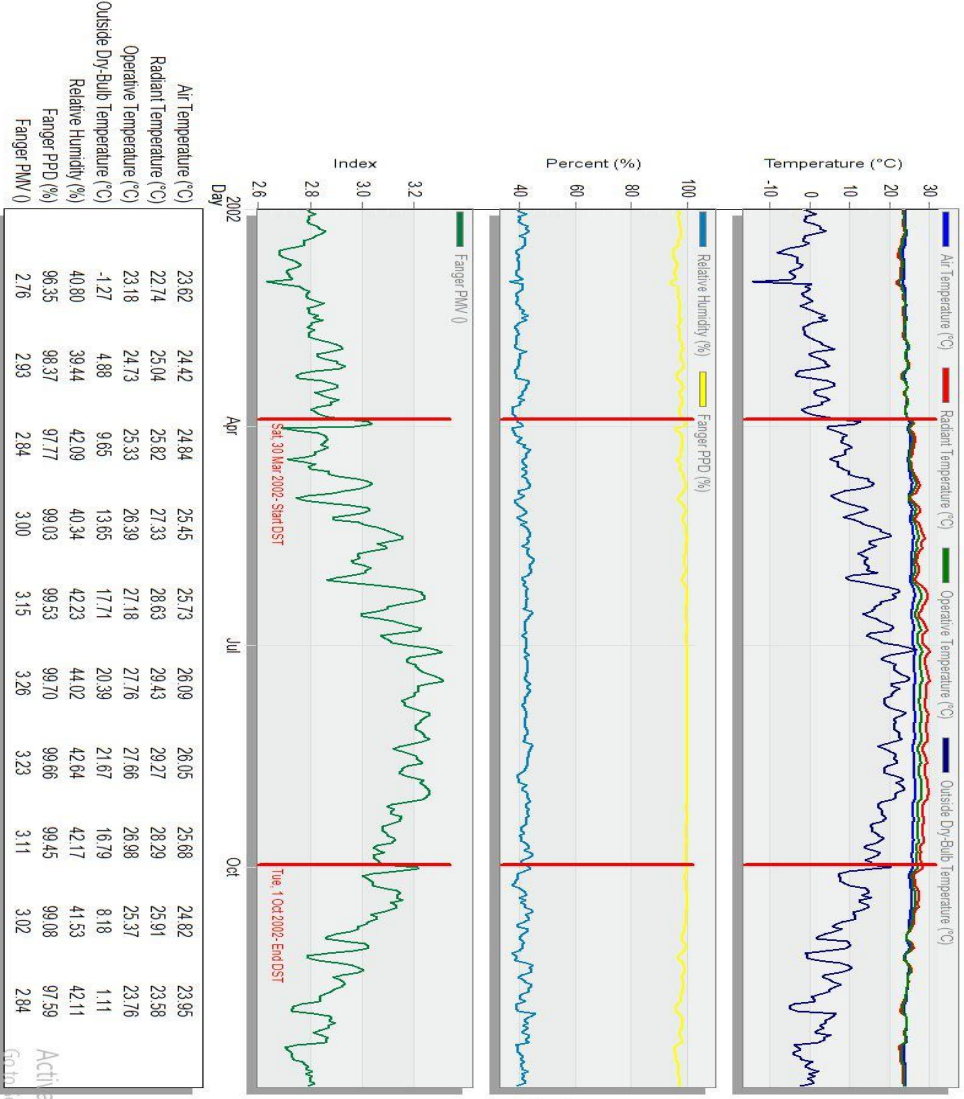
Comfort - Block 1, Zone 1  
 1 Jan - 31 Dec Daily

Evaluation



Display Options  
 General Detailed

Data  
 Interval 3-Daily  
 Show as 3-Gap  
 Day's period 365  
 Normalise by area  
 Y-Axis  
 Appearance



Day	Air Temperature (°C)	Radiant Temperature (°C)	Operative Temperature (°C)	Outside Dry-Bulb Temperature (°C)	Relative Humidity (%)	Fanger PPD (%)	Fanger PMV (I)
23.62	24.42	24.84	25.45	25.73	26.09	26.05	26.88
22.74	25.04	25.82	27.33	28.63	29.43	29.27	28.29
23.18	24.73	25.33	26.39	27.18	27.76	27.66	26.98
-1.27	4.88	9.65	13.65	17.71	20.39	21.67	16.79
40.80	39.44	42.09	40.34	42.23	42.64	42.17	41.53
96.35	98.37	97.77	99.03	99.53	99.70	99.66	99.45
2.76	2.93	2.84	3.00	3.26	3.23	3.11	3.02
							2.84

Info Help  
 Simulation Data - Analysis  
 This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane. You can plot a number of different types of data on the same graph by making a selection in the Detailed tab of the Display Options. To update the data using different calculations or outputs options, click:

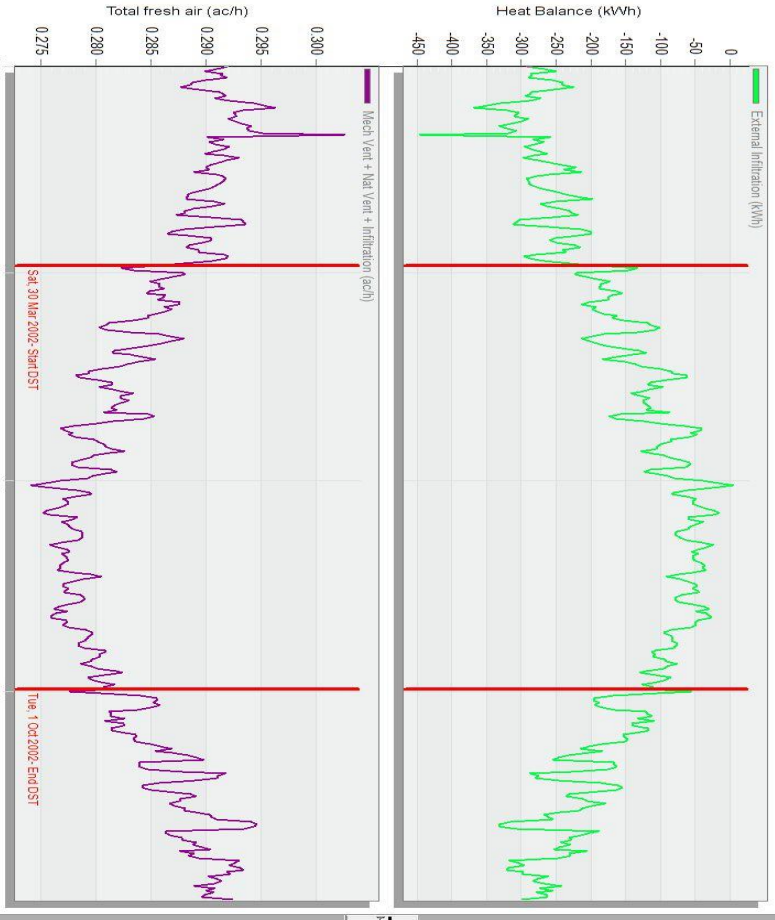
- Export this report
- Show temperature distribution data
- Display Shortcuts: Clear all, Show all
- Add Data: Gains data, Fabric and ventilation, Comfort, Site, System loads
- Save results set as template

Activate Windows  
 Go to Settings to activate Windows.

Fabric and Ventilation - Block 1, Zone 1

1 Jan - 31 Dec, Daily

Evaluation



Day	External Infiltration (kWh)	Mech Vent + Nat Vent + Infiltration (ac/h)
2002	-282.60	0.29
2003	-218.17	0.29
2004	-164.83	0.28
2005	-127.95	0.28
2006	-85.26	0.28
2007	-60.05	0.28
2008	-40.15	0.28
2009	-95.31	0.28
2010	-183.82	0.28
2011	-254.93	0.29

- Building 1
- Block 1
- Zone 1
- Zone 2
- Ground floor
- Ceiling - 273
- Wall - 43.316
- Wall - 18.000
- Wall - 43.316
- Partition - 15
- Room 1
- Zone 1

**HVAC Templates**

**1 Template** Copy of Constant volume DX

On

Mechanical Ventilation

Outside air definition method: 44k/m³ fresh air (Cum per person + per area)

Operation: Indust\_LoopProcess\_Occ

Economiser (Free Cooling):  Schedule

Type: 1-None

Heat Recovery:  Auxiliary Energy

Pump etc energy (kWh/m²): 0.0000

Schedule: Indust\_LoopProcess\_Occ

Heating:  Heated

Fuel: 1-Electricity from grid

Heating system seasonal COP: 2.000

String Zone Equipment

Type:  Schedule

Supply Air Condition: Indust\_LoopProcess\_Heat

Operation:  Schedule

Cooling

Cooled

Free Cooling system: Default

Fuel: 1-Electricity from grid

Cooling system seasonal COP: 2.500

Supply Air Condition: Indust\_LoopProcess\_Cool

Operation:  Schedule

Humidity Control

On

On

Natural Ventilation

On

Earth Tide

Air Temperature Distribution

Cost

Info Data

Help Data

**HVAC Templates**

Data Report (Not Editable)

**General**

Copy of Constant volume DX

Source: DB

Category: Generic

Region: TURKEY

Simple

Auxiliary energy (kWh/m²): 42.00

Colour Shading in Model:  Floor shade colour

**NOM HVAC system type**

NOM HVAC system type: Consistent

**Natural Ventilation**

On: No

**Mechanical Ventilation**

On: Yes

Rate (ach): 3.00

**Fans**

Fan type: 1-Supply

Pressure rise (Pa): 600.0

Total efficiency (%): 70.0

Economiser (free cooling):  None

Economiser type: 1-None

Max outdoor air rate: 15.0

Heat Recovery:  On

On: No

**Heating**

On: Yes

Fuel: 1-Electricity

Pressure rise (Pa): 1.0

Heating system seasonal COP: 2.00

Heating system type: 1-Convect

**Supply Air Condition**

Maximum supply air temp.: 35.00

Minimum supply air temp.: 0.00

**Cooling**

Cooling On: Yes

Precool (hr): 0.0

Cooling system seasonal COP: 2.50

**Supply Air Condition**

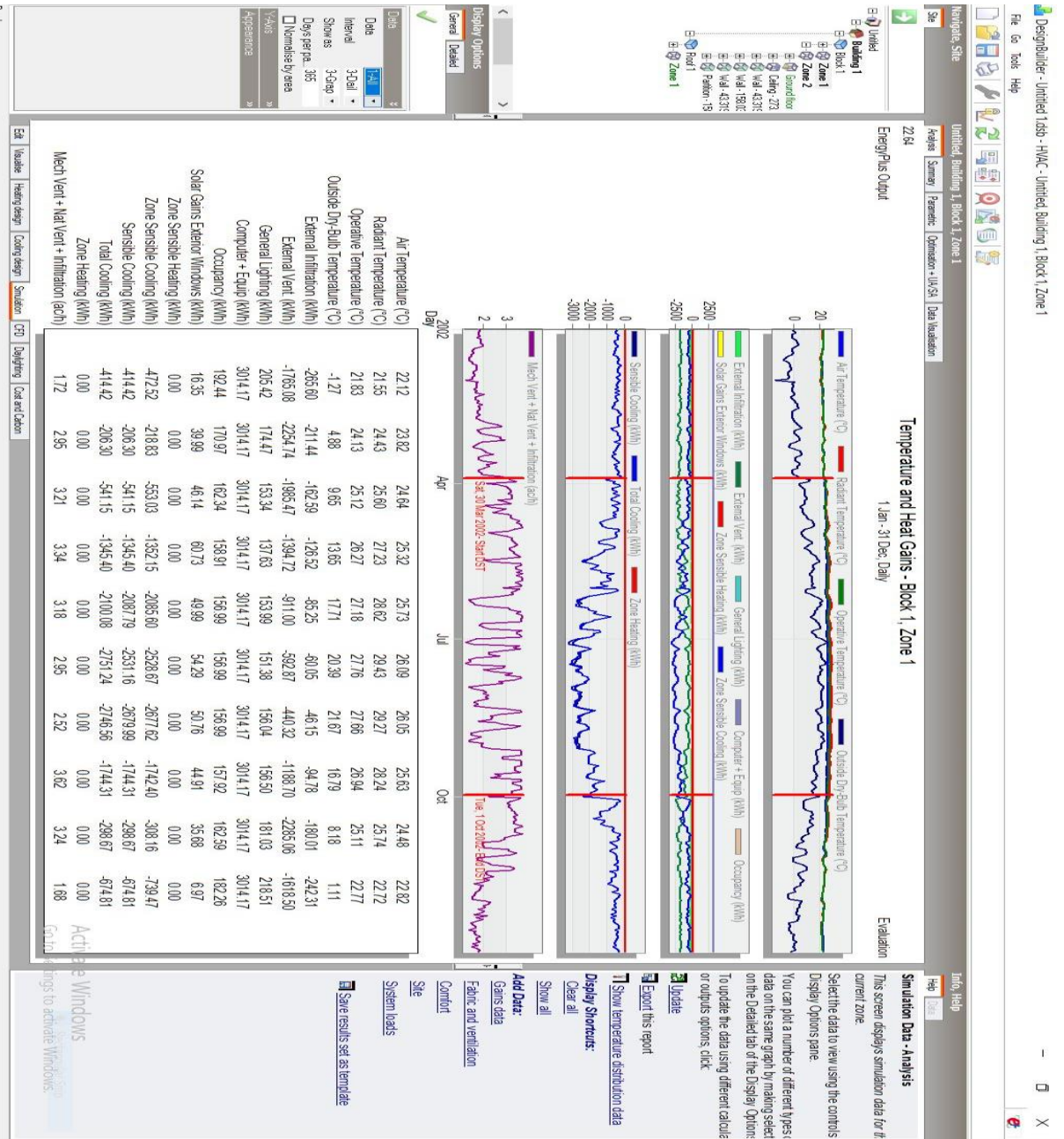
Maximum supply air temp.: 12.00

Minimum supply air temp.: 0.000

Go to Settings

# APPENDIX-D: Simulation of All air system multi Zone (CAV)

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All air system multi Zone (CAV).





- [-] Untitled
- [-] Building 1
- [-] Block 1
- [-] Zone 1
- [-] Zone 2
- [-] Ground floor
- [-] Ceiling - 273
- [-] Wall - 43.316
- [-] Wall - 150.06
- [-] Wall - 43.316
- [-] Partition - 15
- [-] Roof 1
- [-] Zone 1

Display Options

General Detailed

Data

3-Zone

Interval 3-Daily

Show as 3-Group

Days per period 365

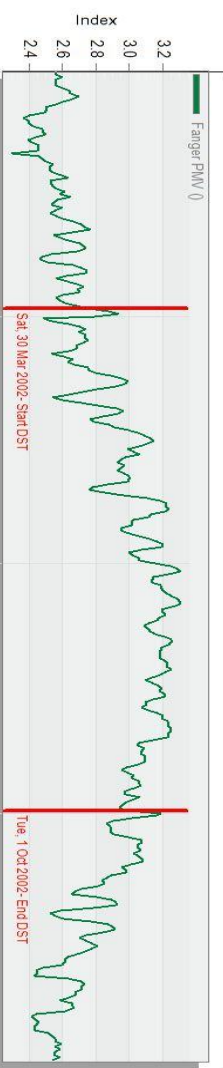
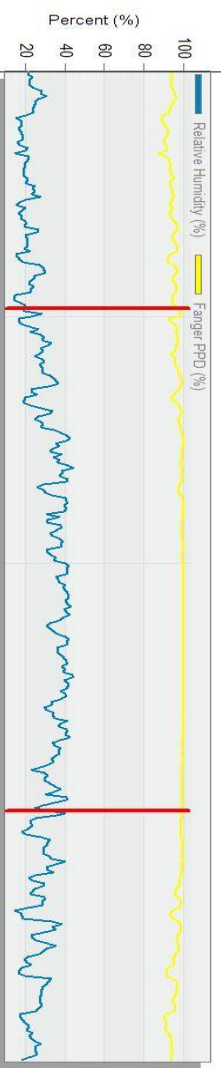
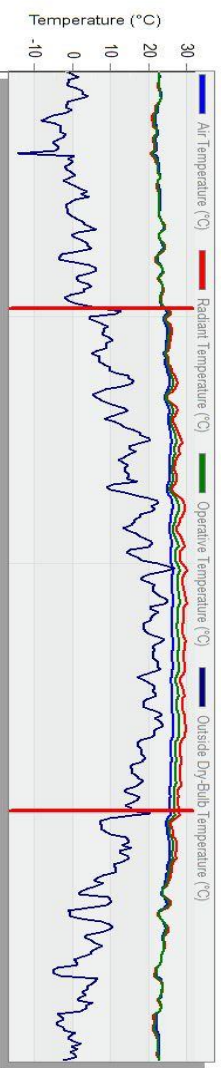
Normalise by area

Y-Axis

Appearance

Comfort - Block 1, Zone 1

1 Jan - 31 Dec Daily



Day	2002	Apr	Jul	Oct						
Air Temperature (°C)	22.12	23.82	24.64	25.32	25.73	26.09	26.05	25.63	24.48	22.82
Radiant Temperature (°C)	21.55	24.43	25.60	27.23	28.62	28.62	29.27	28.24	25.74	22.72
Operative Temperature (°C)	21.83	24.13	25.12	26.27	27.18	27.76	27.66	26.94	25.11	22.77
Outside Dry-Bulb Temperature (°C)	-1.27	4.88	9.65	13.65	17.71	20.39	21.67	16.79	8.18	1.11
Relative Humidity (%)	21.77	19.46	29.72	27.95	37.29	43.31	40.02	35.13	25.13	22.95
Fanger PPD (%)	92.29	96.63	96.75	98.49	99.44	99.69	99.63	99.27	98.43	94.85
Fanger PMV 0	2.48	2.74	2.73	2.91	3.11	3.25	3.21	3.06	2.89	2.60

Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls

Display Options name

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculation or outputs options, click

Update

Export this report

Show temperature distribution data

Display Shortcuts:

Clear all

Show all

Add Data:

Gains data

Fabric and ventilation

Comfort

Site

System loads

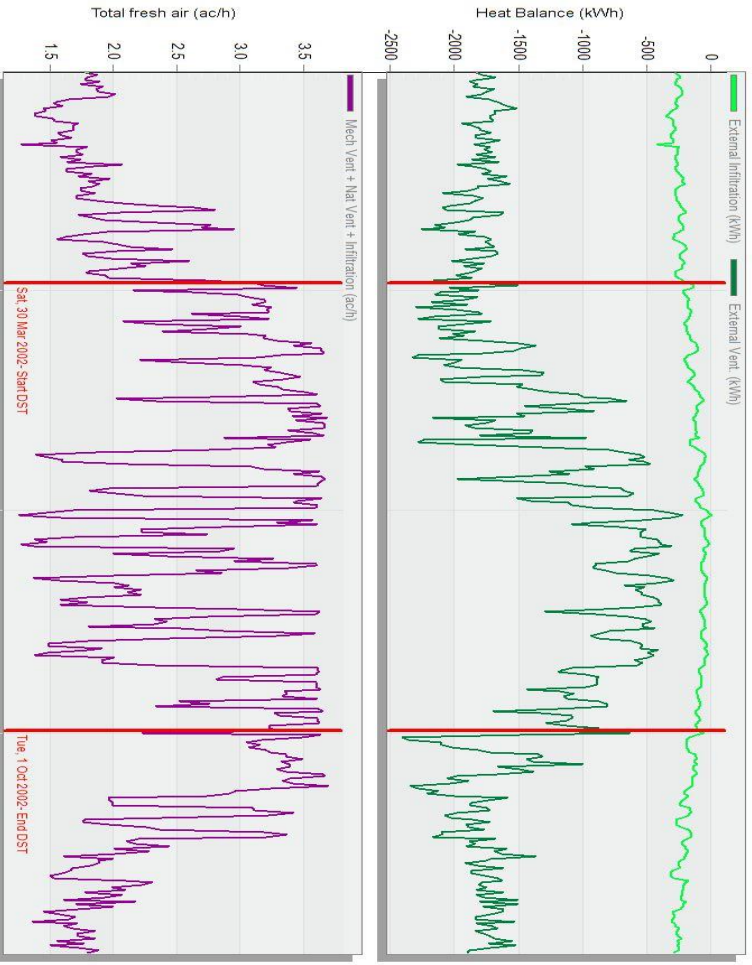
Save results set as template

280 21

### Fabric and Ventilation - Block 1, Zone 1

1 Jan - 31 Dec, Daily

Evaluation



Day	External Infiltration (kWh)	Mech Vent + Nat Vent + Infiltration (ac/h)
-265.60	-211.44	-162.59
-1765.08	-2254.74	-1985.47
1.72	2.95	3.21
	3.34	3.18
	3.18	2.95
	4.40	2.52
	-1188.70	3.62
	-180.01	3.24
	-242.31	1.68

Active Windows  
 Click on the title bar to activate Windows.

Info, Help

#### Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selections on the Detailed tab of the Display Options. To update the data using different calculations or outputs options, click **Update**.

**Export this report**

**Show temperature distribution data**

**Display Shortcuts:**

**Clear all**

**Show all**

**Add Data:**

**Gains data**

**Fabric and ventilation**

**Comfort**

**Site**

**System loads**

**Save results set as template**

HVAC template  
 Mechanical Ventilation  
 On  
 Anomaly/Energy  
 Pump etc energy (kWh/m2) 0.0100  
 Indust\_IndProcess\_Occ  
 Schedule  
 Heating  
 Heated  
 Heating system seasonal CpP 2.000  
 2/Neutral Gas  
 Heating system seasonal CpP  
 Storage Zone Equipment  
 Type  
 Supply Air Condition  
 Operation  
 Schedule  
 Indust\_IndProcess\_Heat  
 Heating  
 Cooled  
 Cooling system  
 Detail  
 Fuel 1/Electricity from grid  
 Cooling system seasonal CpP 4.000  
 Supply Air Condition  
 Operation  
 Schedule  
 Indust\_IndProcess\_Cool  
 Humidity Control  
 DRW  
 On  
 Natural Ventilation  
 On  
 Outside air definition method 1-By zone  
 Outside air (each) 5.000  
 Operation  
 Schedule  
 Indust\_IndProcess\_Occ  
 Outdoor temperature limits  
 Outdoor min temperature control  
 Outdoor max temperature control  
 Delta T limits  
 Delta T and Wind Speed Coefficients  
 Mixed Mode Zone Equipment  
 Mixed mode on  
 Mixed mode on  
 Effort Time

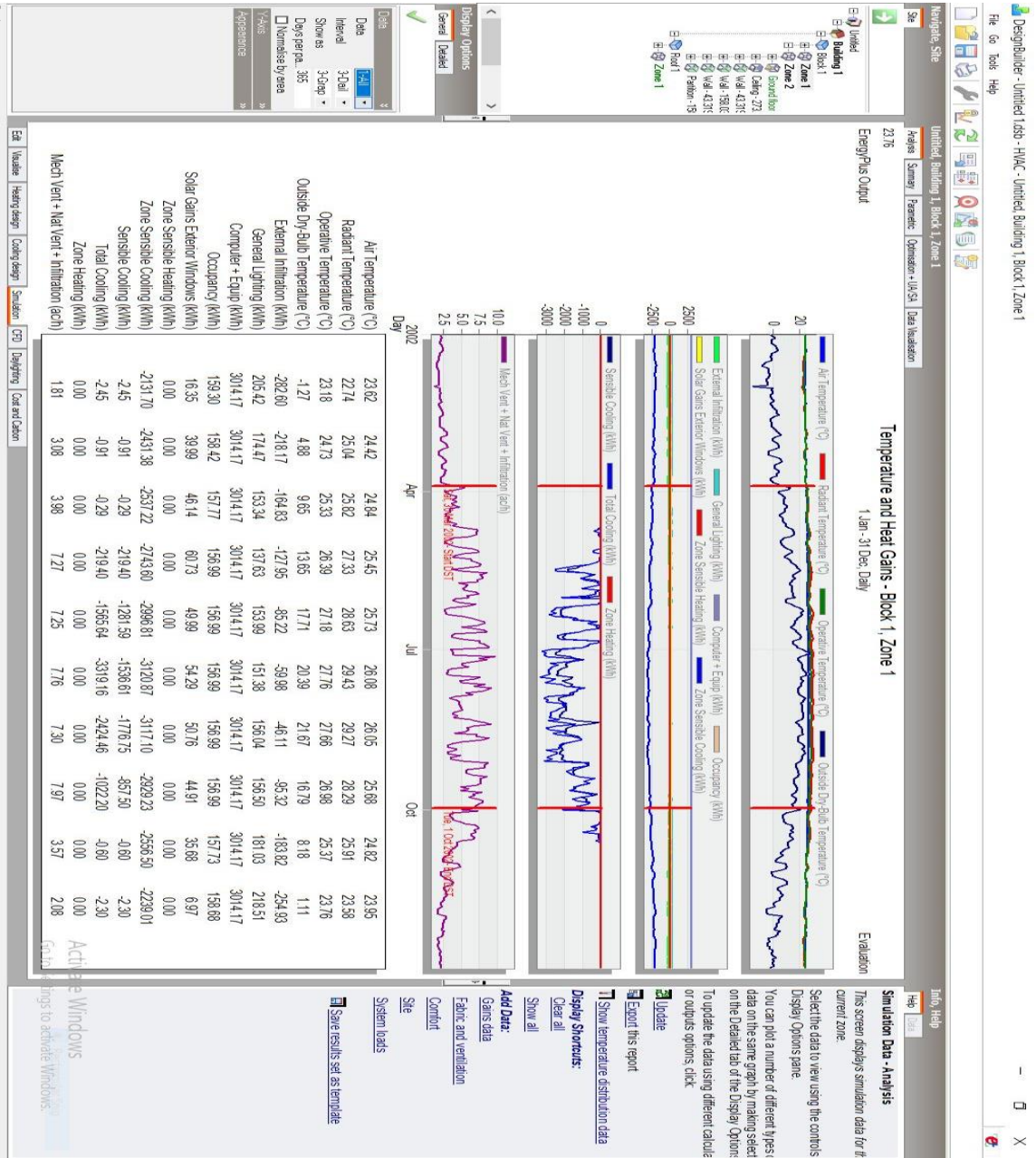
Info, Data  
 Help Data  
 HVAC templates  
 Data Report (Not Editable)  
 General  
 Copy of Chilled Ceiling Free Cool  
 Source DB  
 Category Generic  
 Region General  
 Simple  
 Anomaly energy (kWh/m2) 15.00  
 Floor slabs colour  
 NCM HVAC system type  
 NCM HVAC system type - Fan coil sy  
 Neutral Ventilation  
 On  
 Rate (ach) Yes  
 Rate (ach) 5.00  
 Mixed mode on No  
 Mechanical Ventilation  
 On No  
 Heating  
 On Yes  
 Fuel 2/Neutral G  
 Preheat (h) 1.0  
 Heating system season. 2.00  
 Heating system type 2/cooling/  
 Supply Air Condition  
 Maximum supply air L 35.00  
 Maximum supply air h. 0.016  
 Cooling  
 Cooling On Yes  
 Precool (h) 0.0  
 Cooling system season. 4.00  
 Supply Air Condition  
 Minimum supply air L 12.00  
 Minimum supply air h. 0.008  
 Humidification  
 Humidification Yes  
 Humidification control L 2-humidist  
 Dehumidification  
 Dehumidification No  
 Air Temperature Distribution  
 Air Temperature Distribution  
 Distribution mode mixed/Hybrid  
 Interception mode 3-hybrid-on

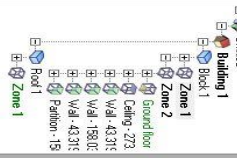
Active  
 Go to Site

Edit | Visualize | Heating design | Cooling design | Simulation | CTO | Daylighting | Cost and Carbon

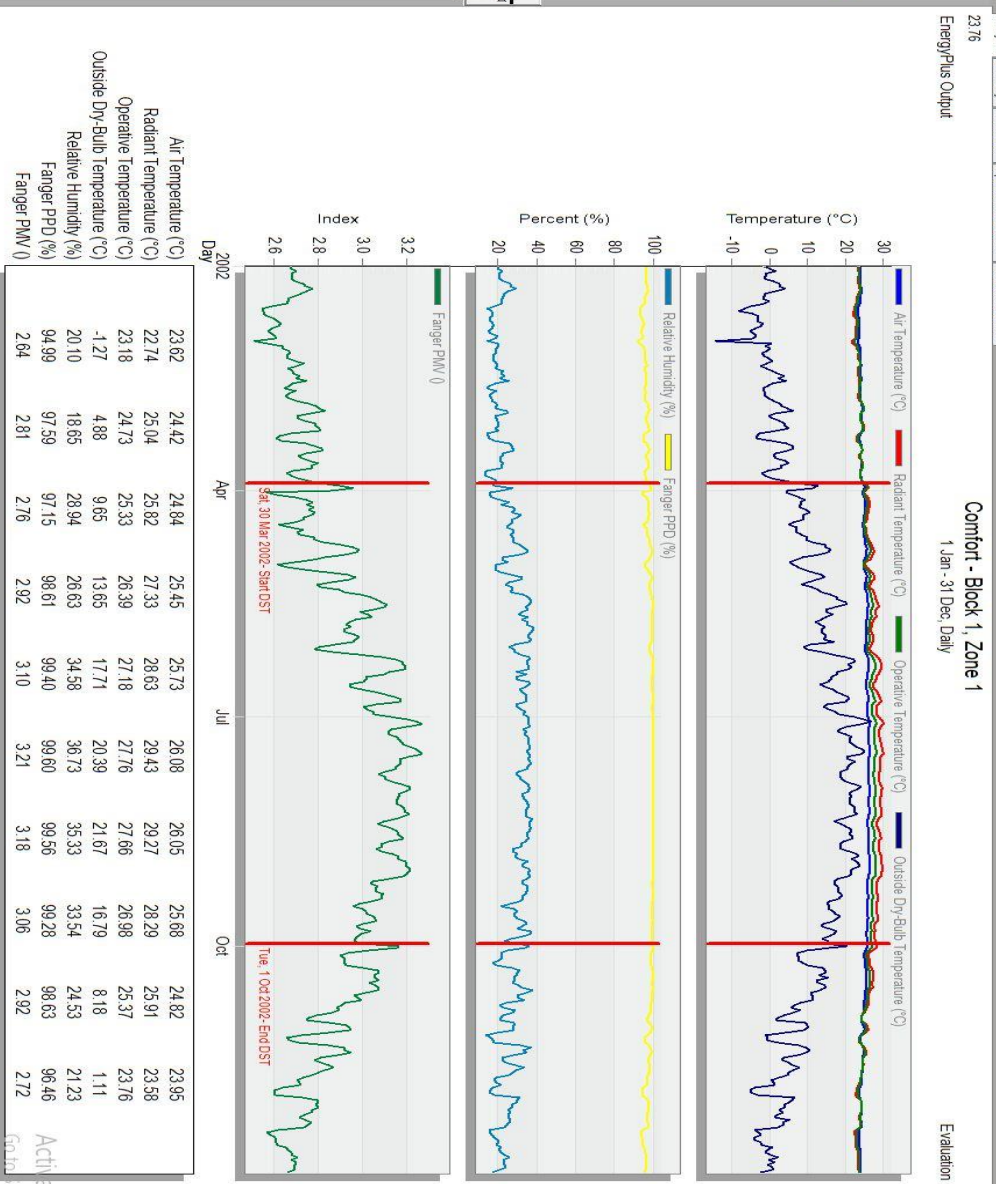
# APPENDIX-E: Simulation of All air system terminal reheat (CAV)

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All air system terminal reheat (CAV).





Display Options  
 General Detailed  
 Date: 3-Oct  
 Interval: 3-Daily  
 Shows: 3-Gap  
 Days per pa: 365  
 Normalise by area  
 Axes: Appearance



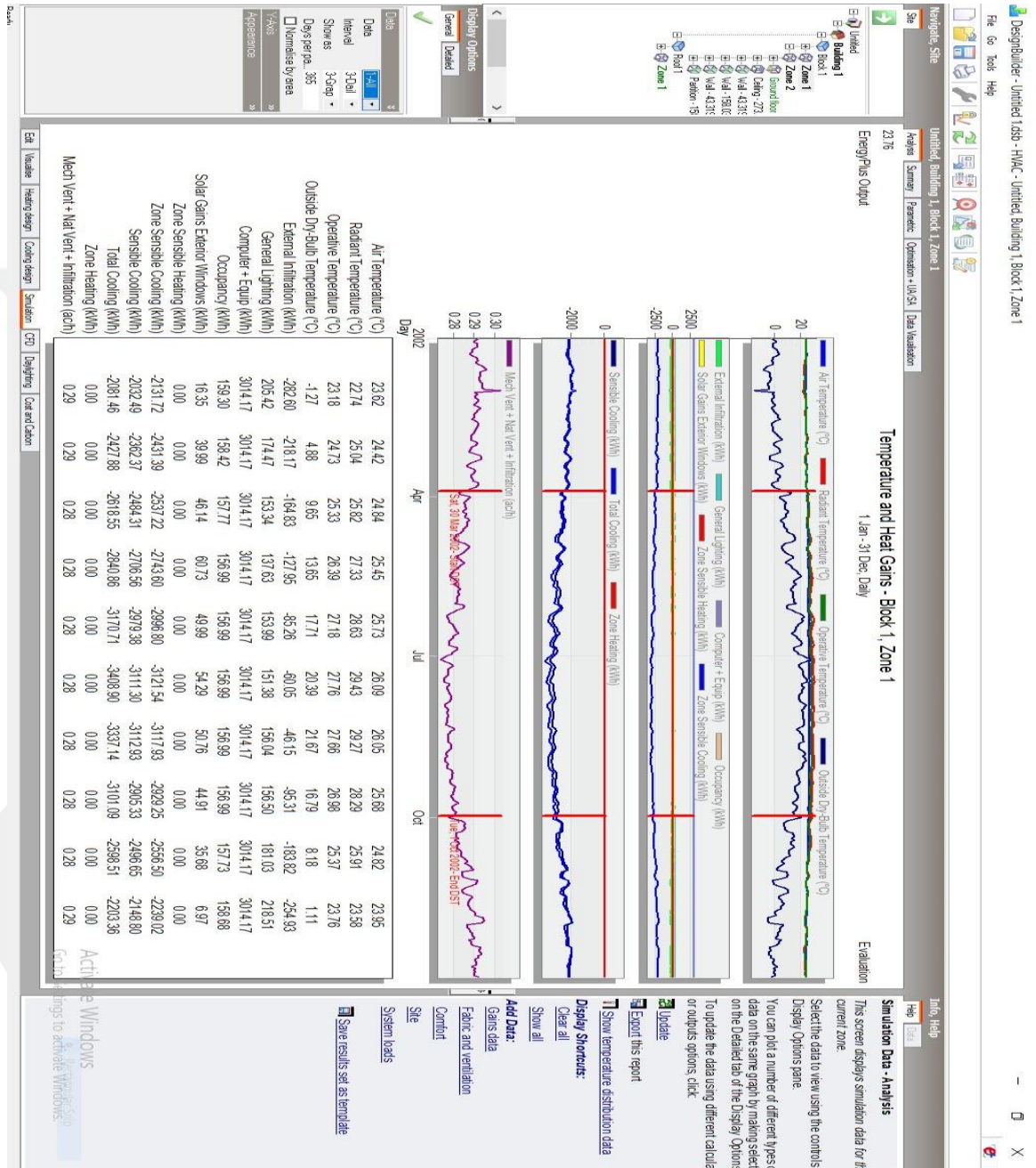
Info Help  
 Help Data  
**Simulation Data - Analysis**  
 This screen displays simulation data for the current zone.  
 Select the data to view using the controls below.  
 Display Options pane.  
 You can plot a number of different types of data on the same graph by making select on the Detailed tab of the Display Options.  
 To update the data using different calculation or outputs options, click:  
 Update  
 Export this report  
 Show temperature distribution data  
**Display Shortcuts:**  
 Clear all  
 Show all  
**Add Data:**  
 Gains data  
 Fabric and ventilation  
 Comfort  
 Site  
 System loads  
 Save results set as template

Active Windows  
 DesignBuilder - HVAC - Untitled Building 1, Block 1, Zone 1  
 Click on the title bar to activate Windows.





Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All air system dual duct.



Navigation Site

23.76

Analysis Summary Parameters Optimisation - UV-51 Data Visualisation

Untitled Building 1, Block 1, Zone 1

EnergyPlus Output

Building 1

- Block 1
- Zone 1
- Zone 2
- Ground floor
- Canopy - 273
- NVA - 43.316
- NVA - 150.02
- NVA - 43.316
- Patron - 15
- Road 1
- Zone 1

Display Options

General Detailed

Date 3-Jan

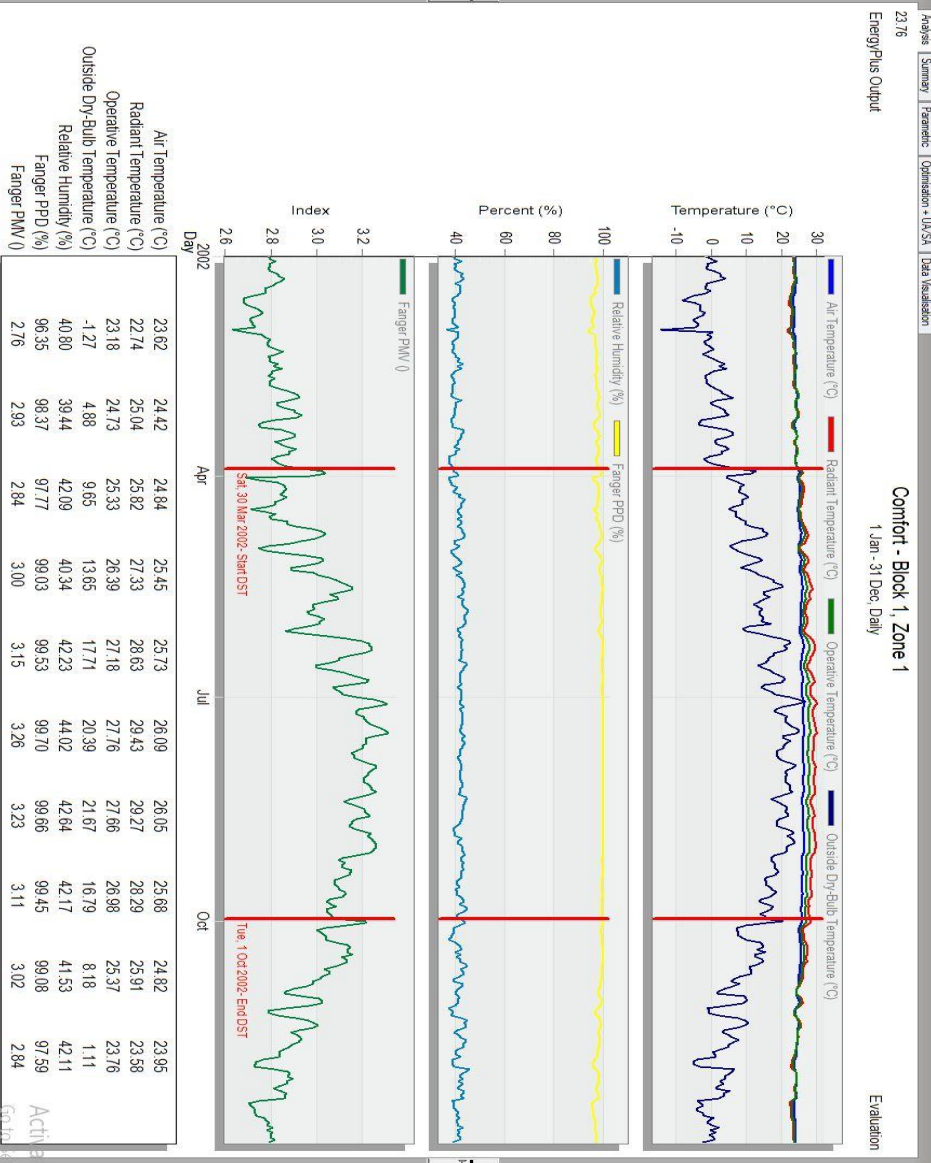
Interval 3-Daily

Show as 3-Gap

Days per gap 365

Normalise by area

Appearance



Simulation

CFD Daylighting

Cost and Carbon

Active Windows

Go to settings to activate Windows

Info, Help

Help

#### Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculations or outputs options, click:

- Update
- Export this report
- Show temperature distribution data

Display Shortcuts:

- Clear all
- Show all

Add Data:

- Gains data
- Fabric and ventilation
- Comfort
- Site
- System loads

Save results set as template



Navigate, Site

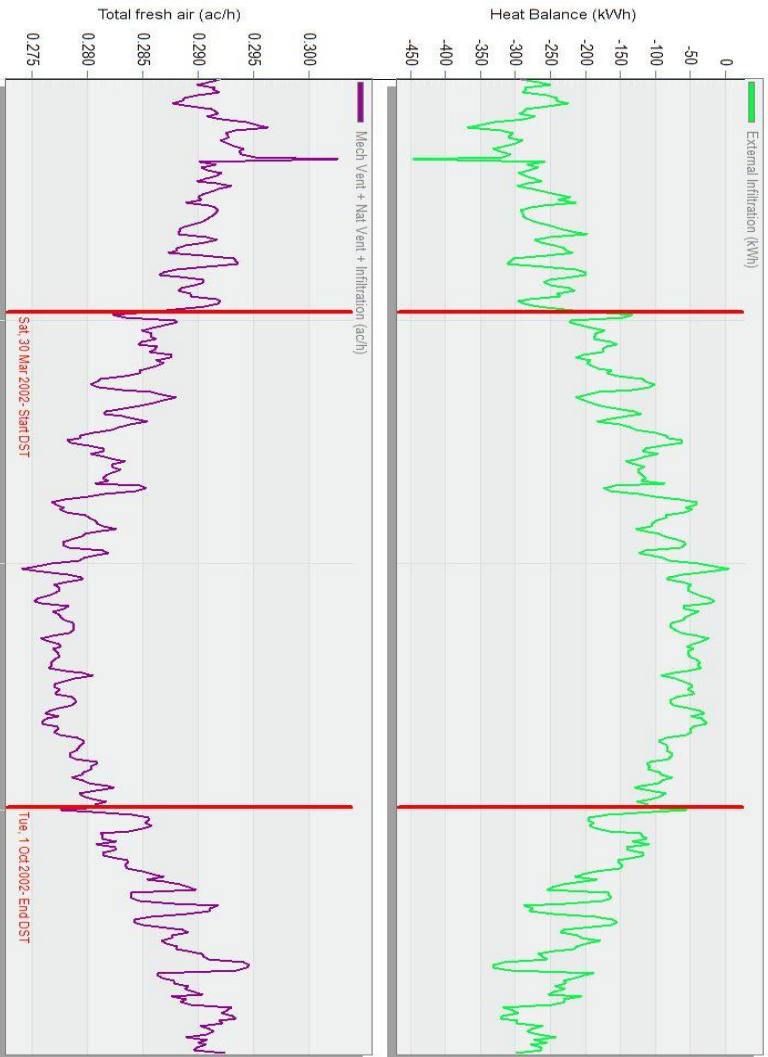
Untitled, Building 1, Block 1, Zone 1

EnergyPlus Output

### Fabric and Ventilation - Block 1, Zone 1

1 Jan - 31 Dec, Daily

Evaluation



External Infiltration (KWh)  
Mech Vent + Nat Vent + Infiltration (ac/h)

Edit Visualize Heating design Cooling design Simulation CFD Daylighting Cost and Carbon

**Display Options**

General Detailed

Data

Interval 3-Detail

Show as 3-Group

Days per pa. 365

Normalise by area

Appearance

Building 1

- Block 1
  - Zone 1
    - Zone 2
    - Sound floor
    - Ceiling - 273
    - WAI - 43.316
    - WAI - 158.01
    - WAI - 43.316
    - Partition - 15
    - Roof 1

Info, Help

Help Data

#### Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options pane.

To update the data using different calculation or outputs options, click:

Update

Export this report

Show temperature distribution data

**Display Shortcuts:**

Clear all

Show all

**Add Data:**

Gains data

Fabric and ventilation

Comfort

Site

System loads

Save results set as template

Active Windows

Go To Settings to activate Windows

Site

- Building 1
  - Block 1
    - Zone 1
      - Ground floor
        - CAFD - 273
        - VAV - 431C
        - VAV - 180UC
        - VAV - 431C
        - Falshn - 15
      - Row 1

HVAC Template

**Copy of VAV, Dual duct, Air-cooled Chiller**

On

Mechanical Ventilation

Outside air definition method: 44/m fresh air (Sum per person + per area)

Operation: Indust\_IndProcess\_Occ

Economiser (Free Cooling):  Schedule

Type: 1-None

Heat Recovery:  Auxiliary Energy

Pump etc energy (kWh/m2): 0.000

Schedule: Indust\_IndProcess\_Occ

Heating:  Heated

Fuel: 1-Electricity from grid

Heating system seasonal COP: 0.850

String Zone Equipment

Type:  Supply Air Condition

Operation: Indust\_IndProcess\_Heal

Schedule:  Cooling

Free Cooling system:  Default

Fuel: 1-Electricity from grid

Cooling system seasonal COP: 1.800

Supply Air Condition

Operation: Indust\_IndProcess\_Cool

Schedule:  Humidity Control

Control:  DHW

Neutral Ventilation:  On

Earth Tube:  On

Air Temperature Distribution:  Core

HVAC templates

Data Report (Not Editable)

General

**Copy of VAV, Dual duct, Air-cool**

Source: DB

Category: Generic

Region: TURKEY

Sample:  Floor shade colour

Auxiliary energy (kWh/m2): 80.00

Colour Shading in Model:  Floor shade colour

NCM HVAC system type:  Non-HVAC system

Natural Ventilation:  Dual-duct

Mechanical Ventilation:  On

Fans:  On

Fan type: 1-Supply

Pressure rise (Pa): 7000

Total efficiency (%): 70.0

Economiser (free cooling):  Economiser type

Max outdoor air rate: 15.0

Heat Recovery:  On

Heating:  On

Fuel: 1-Electricity

Preheat (h): 1.0

Heating system season: 0.85

Heating system type: 1-Corneract

Supply Air Condition:  Maximum supply air t. 35.00

Maximum supply air h.: 0.016

Cooling:  On

Precool (h): 0.0

Cooling system season: 1.80

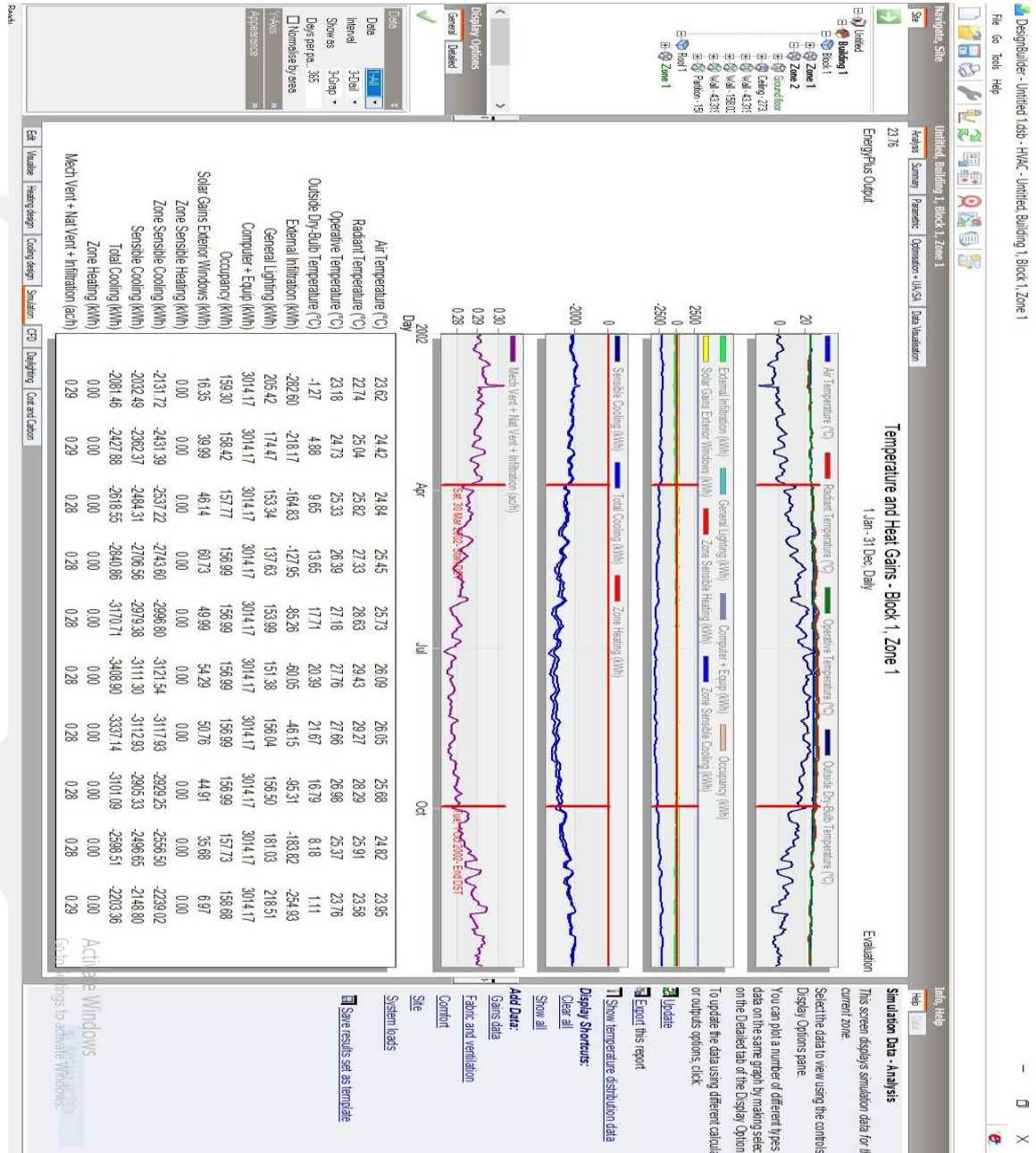
Minimum supply air t.: 12.00

Minimum supply air h.: 0.008

Active VAV  
Go to Settings

# APPENDIX-G: Simulation of All air system (VAV)

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All air system (VAV).



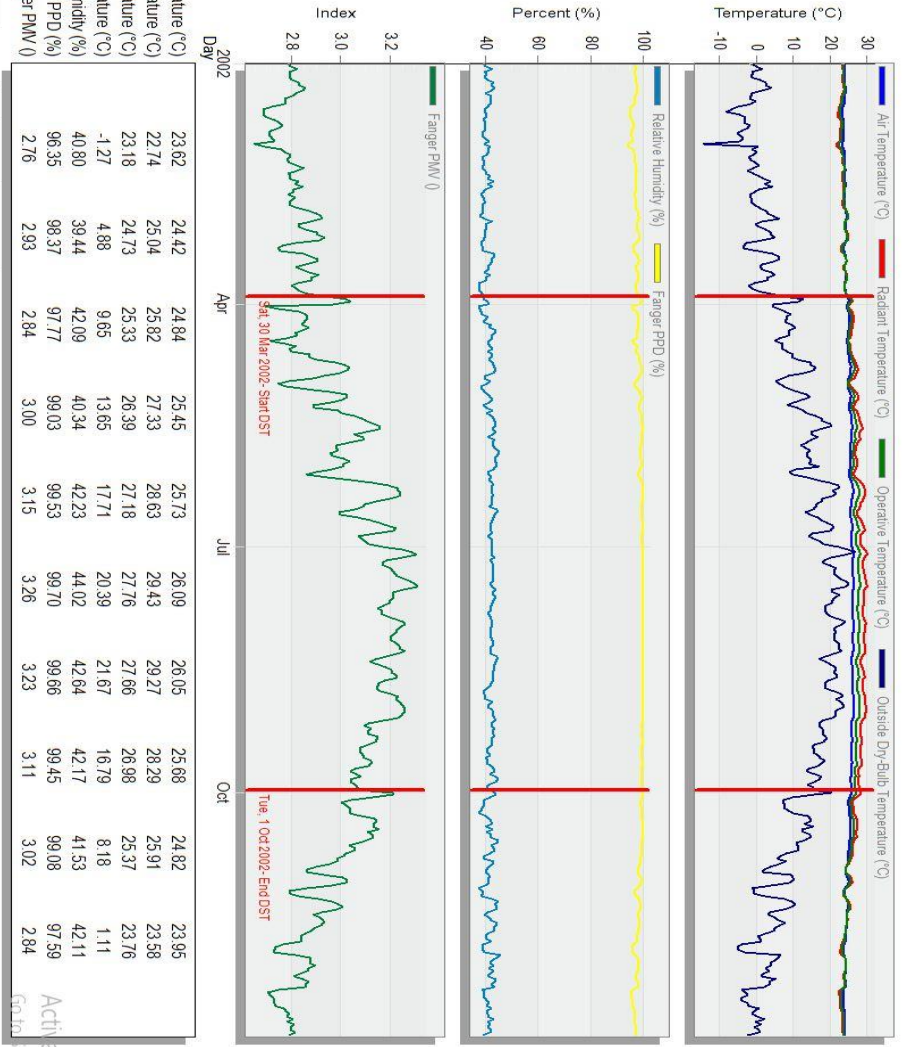
Building 1  
 Block 1  
 Zone 1  
 Zone 2  
 Ground floor  
 Ceiling-273  
 Wall-43315  
 Wall-158.00  
 Wall-43315  
 Partition-15  
 Roof 1

Display Options  
 General Detailed

Date 3-Cont  
 Interval 3-Daily  
 Shows 3-Graph  
 Days per pa. 365  
 Normalise by area  
 Y-Axis  
 Appearance

Untitled Building 1, Block 1, Zone 1  
 23.76  
 EnergyPlus Output

Comfort - Block 1, Zone 1  
1 Jan - 31 Dec, Daily



Info, Help  
 Help Data

**Simulation Data - Analysis**  
 This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane. You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options. To update the data using different calculation or outputs options, click

- Update
- Export this report
- Show temperature distribution data
- Display Shortcuts: Clear all Show all
- Add Data: Gains data Fabric and ventilation Comfort Site System loads
- Save results set as template

Activate Windows  
 Go to Settings to activate Windows.

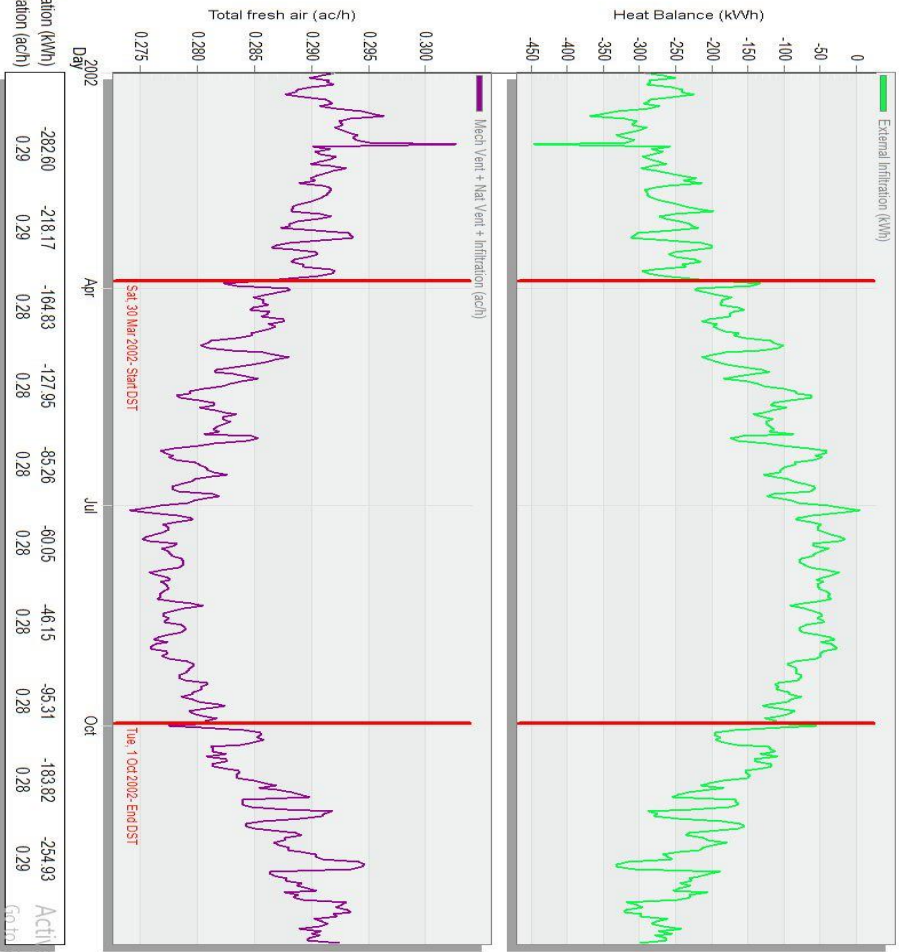
Building 1  
 Block 1  
 Zone 1  
 Zone 2  
 Groundbox  
 Ceiling - 273  
 Wall - 43316  
 Wall - 18800  
 Wall - 43316  
 Partition - 19  
 Roof 1  
 Zone 1

Display Options  
 General Detailed

Date: 5-Feb  
 Interval: 3-Daily  
 Shows as: 3-Daily  
 Days per row: 365  
 Normalise by area  
 Y-Axis: Appearance

EnergyPlus Output  
 -293.03

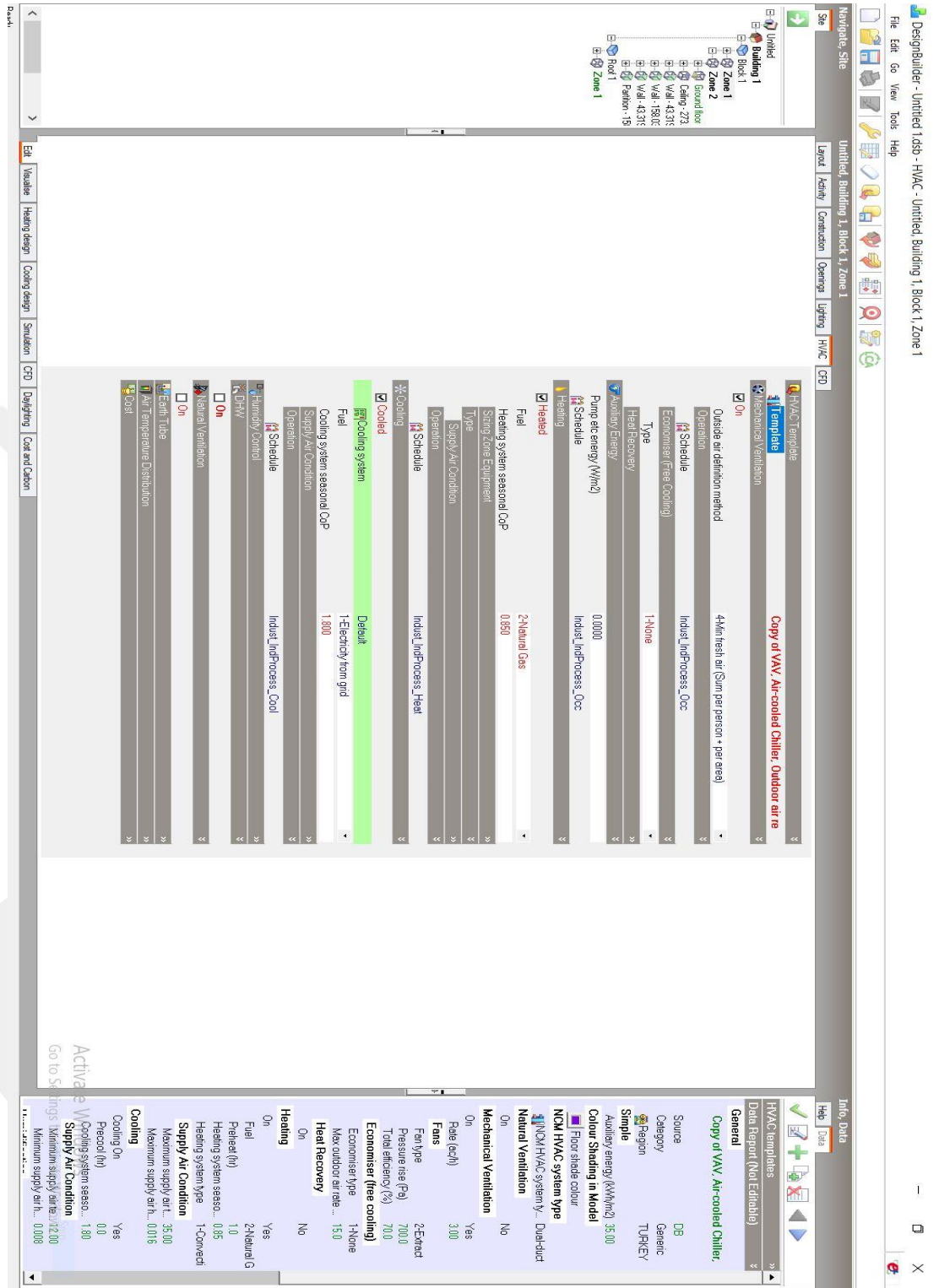
Fabric and Ventilation - Block 1, Zone 1  
 1 Jan - 31 Dec Daily



Simulation Data - Analysis

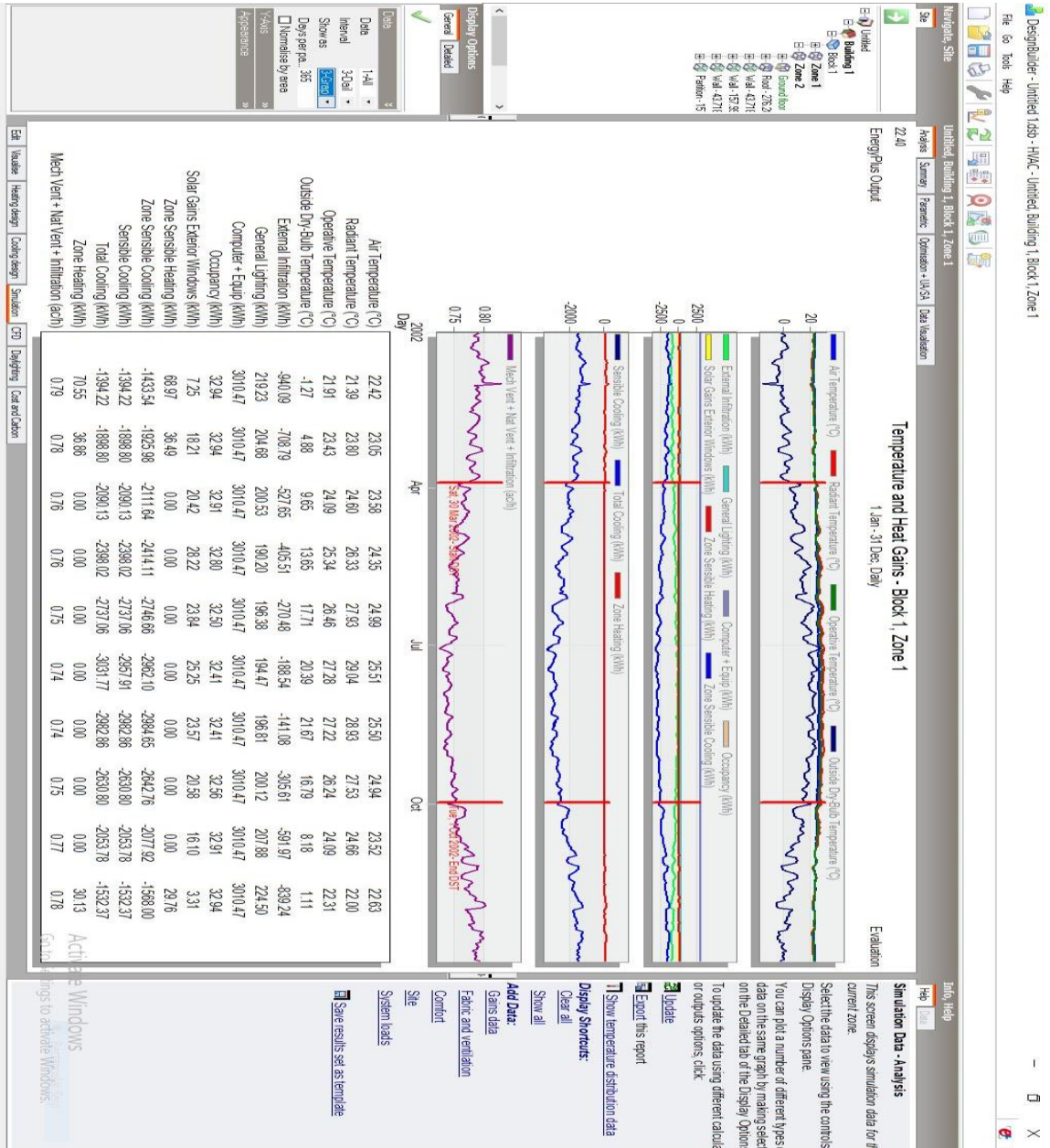
This screen displays simulation data for current zone.  
 Select the data to view using the control buttons.  
 You can plot a number of different types of data on the same graph by making selections on the Detailed tab or the Display Options.  
 To update the data using different calculations or outputs options, click:

- Update
- Export this report
- Show temperature distribution data
- Display Shortcuts:
- Clear all
- Show all
- Add Data:
- Gains data
- Fabric and ventilation
- Comfort
- Site
- System loads
- Save results set as template

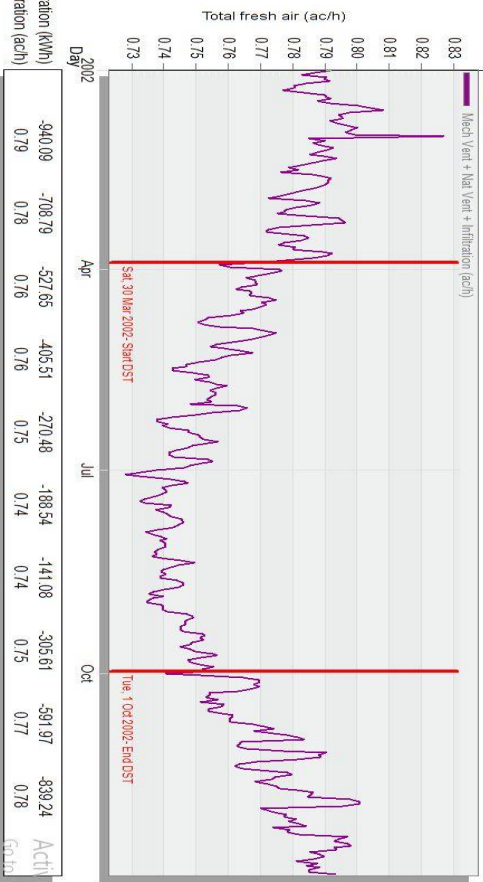
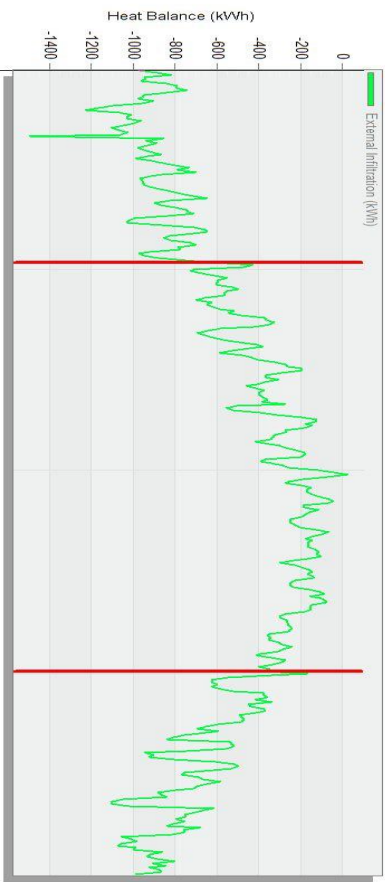


## APPENDIX-H: Simulation of Air-water system fan-Coil Unit

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for Air-water system fan-Coil Unit.







**Simulation Data - Analysis**  
 This screen displays simulation data for the current zone.

Select the data to view using the controls below.

**Display Options pane:**  
 You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options pane.

To update the data using different calculations or outputs options, click:

- Update
- Export this report
- Show temperature distribution data

**Display Shortcuts:**  
 Clear all  
 Show all  
 Add Data:  
 Gains data  
 Fabric and ventilation  
 Comfort  
 Site  
 System loads

Save results set as template

Display Options

General Detailed

Color: **External**

Date: **3-01-02**

Interval: **30min**

Show as: **3-D area**

Days per period: **365**

Normalise by area

Y-axis: **External**

Appearance: **3-D**

- ↳ Unlabeled
- ↳ Building 1
  - ↳ Block 1
    - ↳ Zone 1
    - ↳ Zone 2
  - ↳ Ground floor
    - ↳ Roof - 276, 21
    - ↳ Wall - 43,716
    - ↳ Wall - 157, 96
    - ↳ Wall - 43,716
    - ↳ Partition - 15

Outside air definition method

4Min fresh air (Sum per person + per area)

Operation

Schedule

Indust\_InclProcess\_Doc

Economiser (Free Cooling)

HeatRecovery

Auxiliary Energy

Pump etc energy (MWh/2)

0.0000

Schedule

Indust\_InclProcess\_Doc

Heating

Heated

Fuel

2-Natural Gas

0.850

Heating system seasonal COP

String Zone Equipment

Type

Operation

Schedule

Indust\_InclProcess\_Heat

Cooling

Cooled

Cooling system

Detail

1-Electricity from grid

1.800

Cooling system seasonal COP

Supply Air Condition

Operation

Schedule

Indust\_InclProcess\_Cool

Humidity Control

DHW

On

Natural Ventilation

On

Earth Tube

Air Temperature Distribution

Cost

Info, Help

Edit Heating Cooling System

Simple HVAC detail

Using Ideal Loads for mechanical ventilation  
 Use this screen to edit the heating, cooling and mechanical ventilation system for the current zone

You can set the fuel used by the boiler and the boiler's seasonal efficiency (average over the year).

Data shown with a green background is only used in Heating and/or Cooling design calculations and is NOT used in Simulations.

Mechanical Ventilation

The outside mechanical ventilation air flow rate and its operation can be defined. The flow rate is set either by specifying it directly as air changes per hour (ach) or by accessing the minimum ventilation per person data on the Activity tab together with the number of people.

Natural Ventilation

The natural ventilation rate and its operation can be set.

Scheduled natural ventilation is active when the air temperature in the zone is higher than the natural ventilation set-point temperature (as set on the Activity tab under the Environmental Control header). You can set a very low value to avoid temperature control of natural ventilation.

Air Temperature Distribution

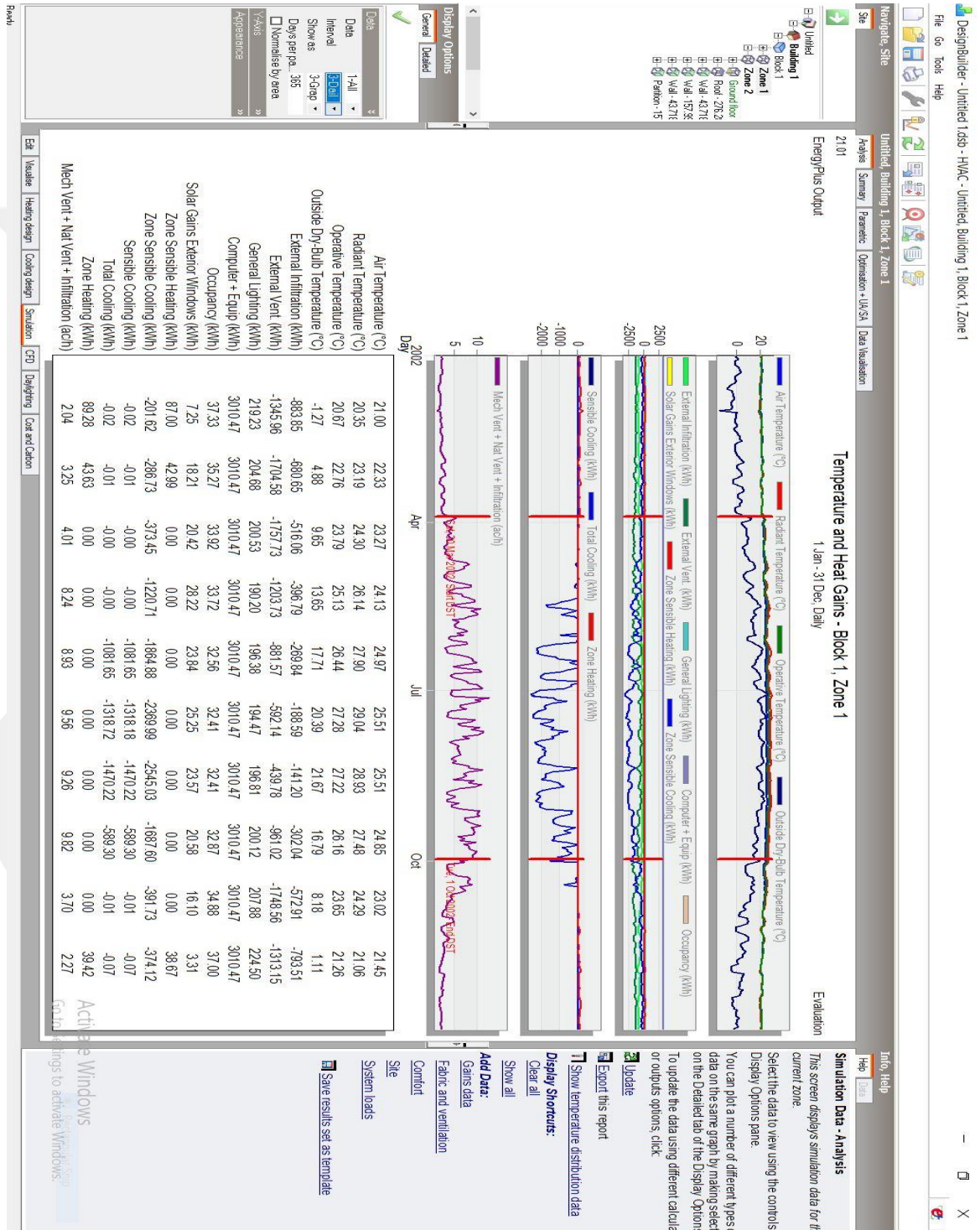
By default, EnergyPlus assumes that air temperature within a zone is completely uniform (i.e. the air is fully mixed). The Air Temperature Distribution data allows you to set up a vertical temperature gradient which varies dynamically depending on:

- Outside temperature.
- Inside temperature.
- Inside-outside temperature difference.

ACHIEVE WINDOWS  
 Heating loads activate Windows.

# APPENDIX-I: Simulation of All water system fan-Coil Unit

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All water system fan-Coil Unit.





External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

External Infiltration (kWh)	-883.85	-680.65	-516.06	-396.79	-269.84	-188.59	-141.20	-302.04	-572.91	-793.51
External Vent (kWh)	-1345.96	-1704.38	-1757.73	-1203.73	-881.57	-592.14	-439.78	-961.02	-1748.56	-1313.15
Mech Vent + Nat Vent + Infiltration (ac/h)	2.04	3.25	4.01	8.24	8.93	9.56	9.26	9.82	3.70	2.27

Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculation or outputs options, click:

Update

Export this report

Show temperature distribution data

Display Shorcuts:

Clear all

Show all

Add Data:

Gains data

Fabric and ventilation

Comfort

Site

System loads

Save results set as template

Active Windows

Active Windows

Active Windows

Active Windows

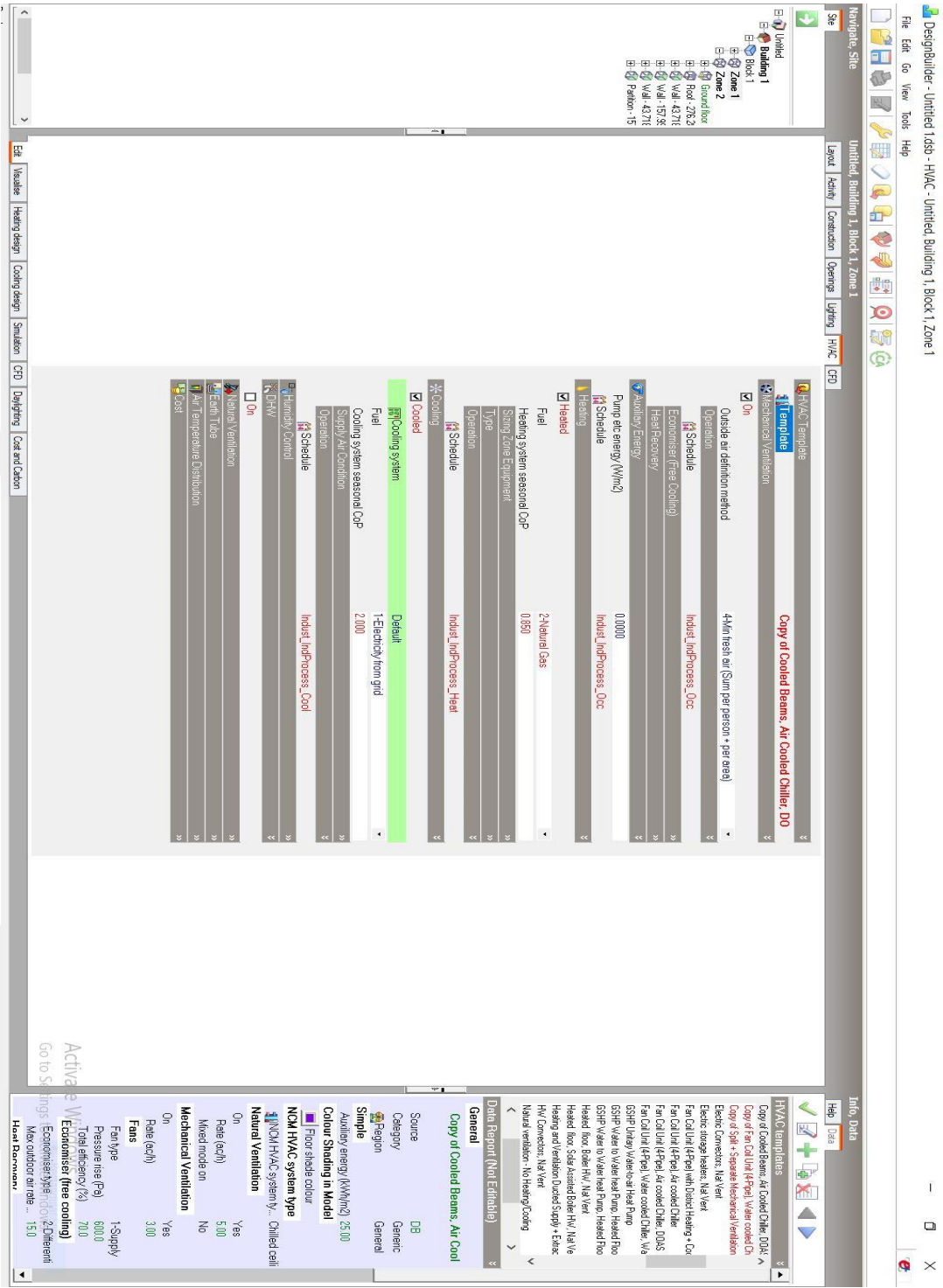
Active Windows

Active Windows

Active Windows

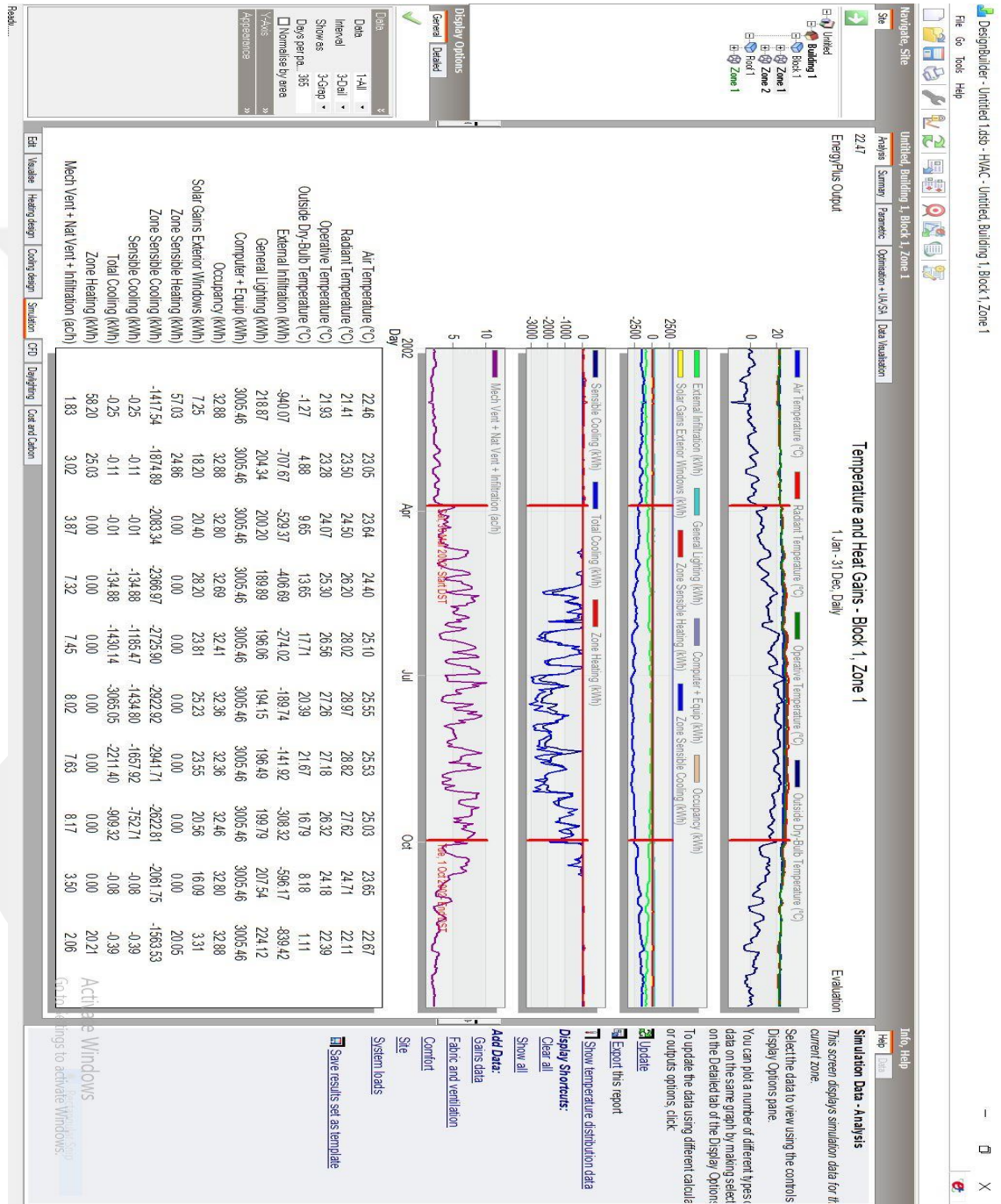
Active Windows

Active Windows



## APPENDIX-J: Simulation of Air-water system induction Unit

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for All water system induction Unit.





Buildings

- Building 1
- Block 1
- Zone 1
- Zone 2
- Roof 1
- Zone 1

Unlabeled Building 1, Block 1, Zone 1

EnergyPlus Output

-971.09

Analysis Summary Parametric Optimization HVAC Data Visualization

Info Help

Help Data

### Fabric and Ventilation - Block 1, Zone 1

1 Jan - 31 Dec, Daily

Heat Balance (kWh)

External Infiltration (kWh)

Total fresh air (ac/h)

Day	2002	Apr	Jul	Oct
External Infiltration (kWh)	-940.07	-707.67	-529.37	-408.69
Mech Vent + Nat Vent + Infiltration (ac/h)	1.83	3.02	3.87	7.32
				7.45
				8.02
				7.83
				8.17
				3.50
				-839.42
				2.06

**Simulation Data - Analysis**

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selections on the Detailed tab of the Display Options.

To update the data using different calculations or outputs options, click **Update**.

**Export this report**

**Show temperature distribution data**

**Display Shortcuts:**

- Clear all
- Show all

**Add Data:**

- Gains data
- Fabric and ventilation
- Comfort
- Site
- System boards

Save results set as template

**Display Options**

General Detailed

Data

Interval

Show as

Days per page

Normalise by area

Y-Axis

Appearance

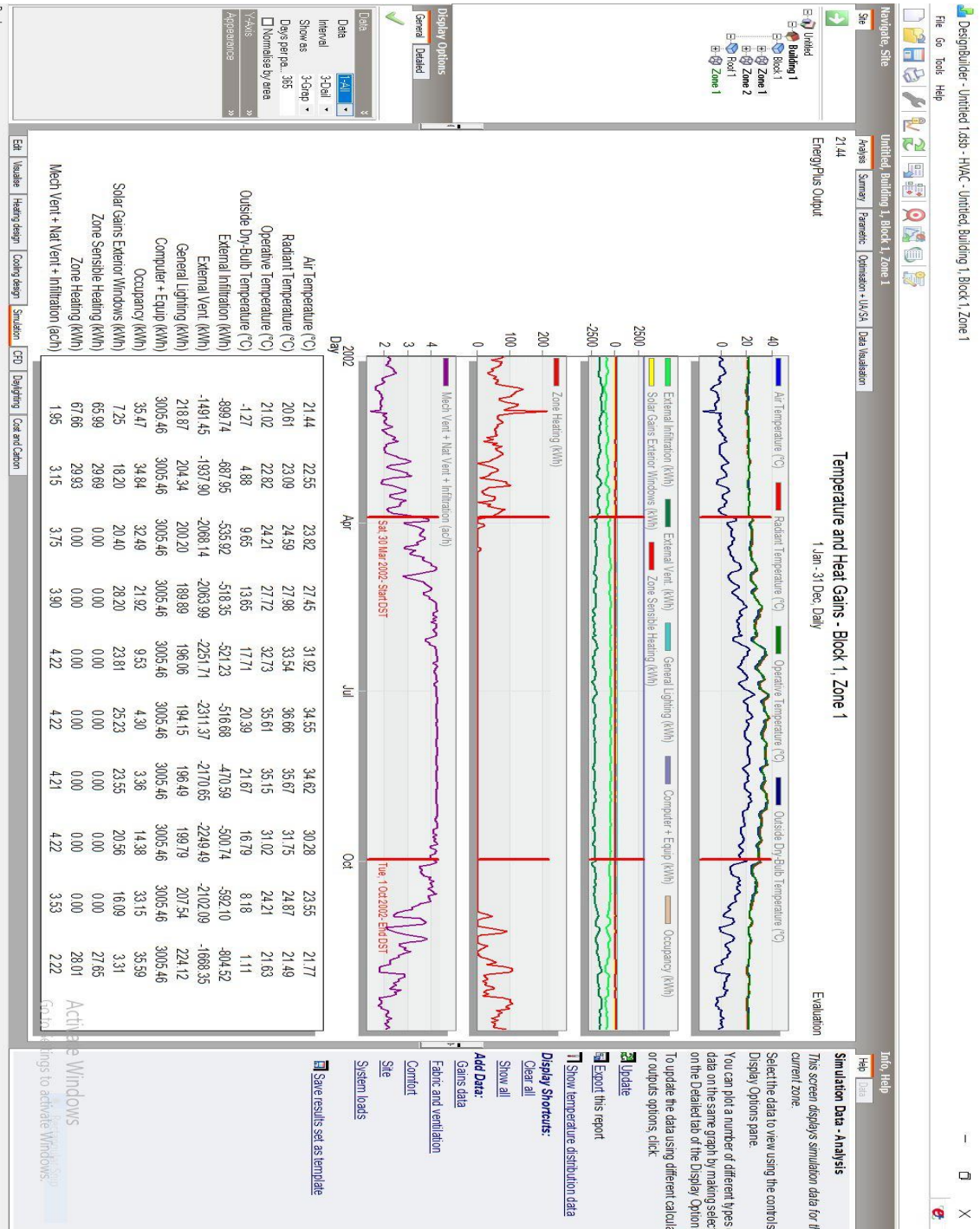
**Active Windows**

Click on the window title bar to activate Windows.



## APPENDIX-K: Simulation of Water-source Heat Pumps

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for Water-source Heat Pumps.



This screen displays simulation data for the current zone. Select the data to view using the controls in the Display Options pane. You can plot a number of different types of data on the same graph by making select on the Detailed tab or the Display Options. To update the data using different calculation or outputs options, click **Update**.

- Export this report**
- Show temperature distribution data**
- Display Shortcuts:**
  - Clear all
  - Show all
- Add Data:**
  - Gains data
  - Fabric and ventilation
  - Control
  - Site
  - System loads
- Save results set as template

Active Windows

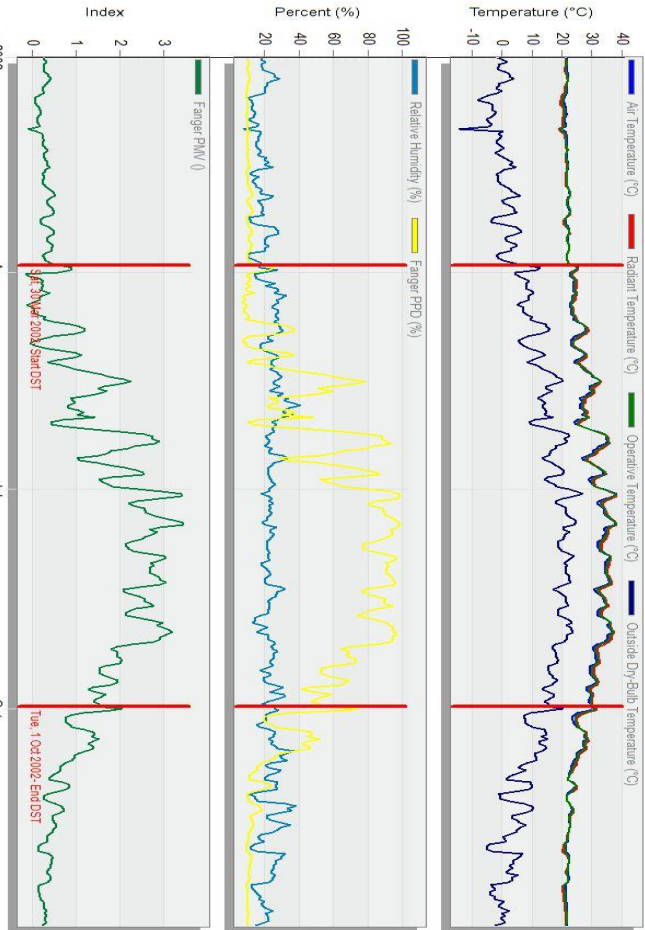
Go to...

Navigation tree:

- Unified
  - Building 1
    - Block 1
      - Zone 1
        - Floor 1
          - Zone 1

Display options:

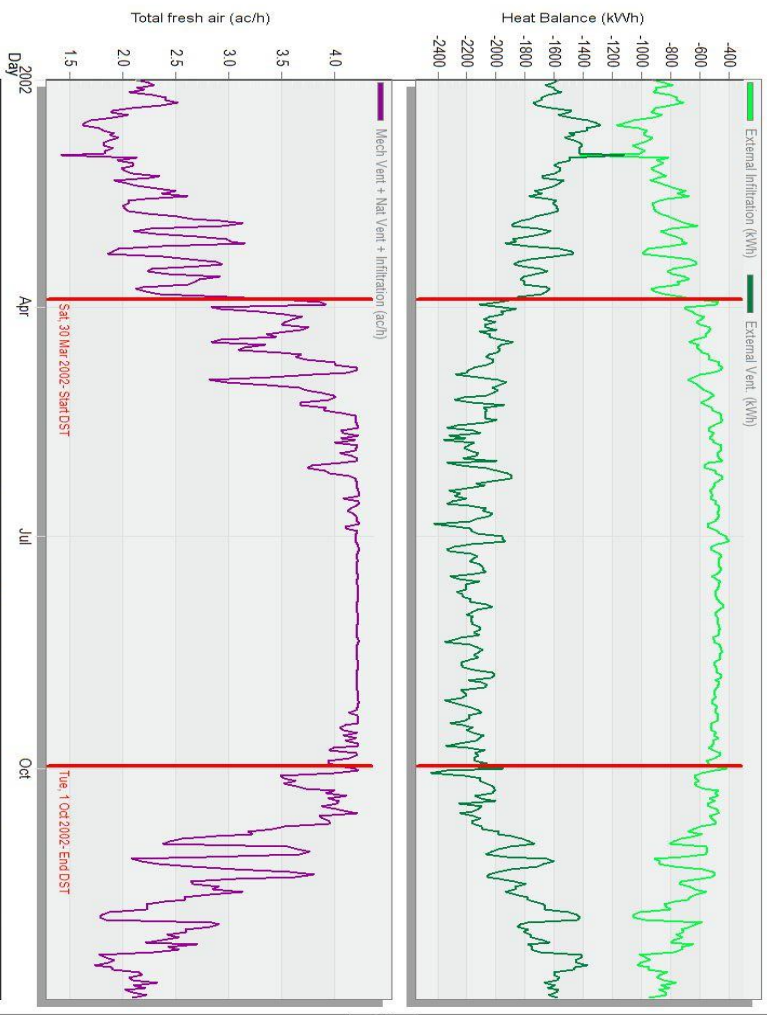
- General  Detailed



Day	Air Temperature (°C)	Radiant Temperature (°C)	Outside Dry-Bulb Temperature (°C)	Relative Humidity (%)	Fanger PPD (%)	Fanger PMV (0)
2002	21.44	22.55	23.82	27.45	31.92	34.55
	20.61	23.09	24.59	27.98	33.54	36.66
	21.02	22.82	24.21	27.72	32.73	35.61
	-1.27	4.88	9.65	17.71	20.39	21.67
	17.92	17.88	28.34	23.06	24.45	26.63
	9.47	13.07	9.87	32.78	79.50	94.95
	0.23	0.51	0.24	1.02	2.21	2.78
						1.81
						0.77
						0.34
						21.77
						21.49
						21.63
						8.18
						1.11
						23.42
						19.75
						18.80
						9.92
						0.34

EnergyPlus Output

Fabric and Ventilation - Block 1, Zone 1  
 1 Jan - 31 Dec Daily



Day	External Infiltration (kWh)	External Vent. (kWh)	Mech Vent + Nat Vent + Infiltration (ac/h)
2002	-899.74	-887.95	3.53
Jan	-1491.45	-1937.90	3.15
Feb	-2068.14	-2068.14	3.75
Mar	-518.35	-2063.99	3.90
Apr	-521.23	-2251.71	4.22
May	-516.68	-2311.37	4.22
Jun	-470.59	-2170.65	4.21
Jul	-500.74	-2249.49	4.22
Aug	-592.10	-2102.09	3.53
Sep	-804.52	-1688.35	2.22
Oct			

Info, Help  
 Help Data

Simulation Data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculations or outputs options, click **Update**.

**Export this report**

**Show temperature distribution data**

**Display Shortcuts:**

**Clear all**

**Show all**

**Add Data:**

Gains data

Fabric and ventilation

Comfort

Site

System loads

Save results set as template

Active Windows  
 Click on the title bar to activate Windows.

Site  
 Building 1  
 Block 1  
 Zone 1  
 Zone 2  
 Room 1  
 Zone 1

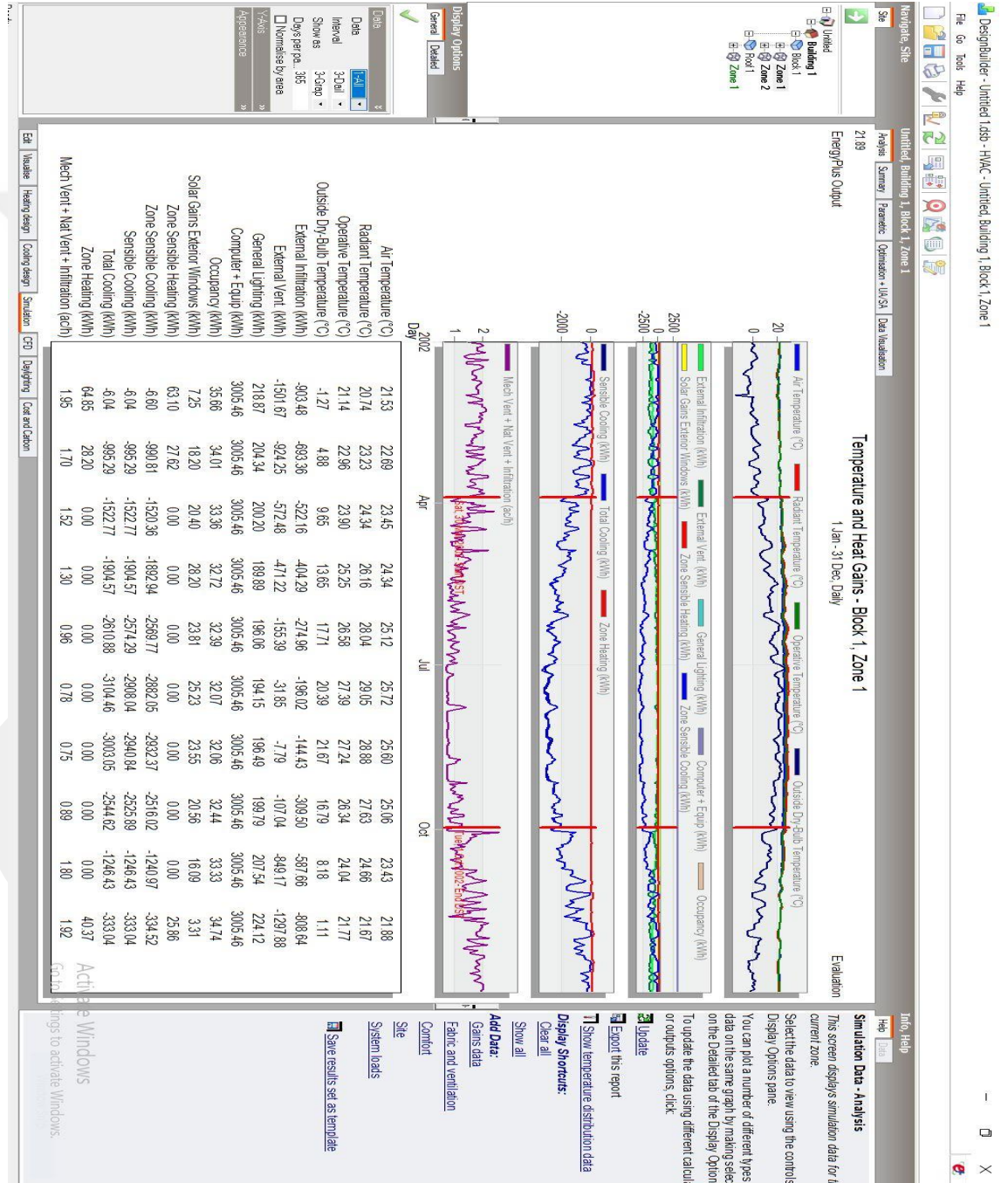
HVAC template  
 Mechanical Ventilation  
 On  
 Auxiliary Energy  
 Pump efficiency (W/m²) 0.0000  
 Schedule Industrial\_IndProcess\_Occ  
 Heating  
 Heated  
 Fuel 2-Natural Gas  
 Heating system seasonal COP 0.850  
 Heating Zone Equipment  
 Type  
 Operation  
 Schedule Industrial\_IndProcess\_Heat  
 Cooling  
 Cooled  
 Priority Control  
 DHW  
 On  
 Natural Ventilation  
 Earth Tube  
 Air Temperature Distribution  
 Cost

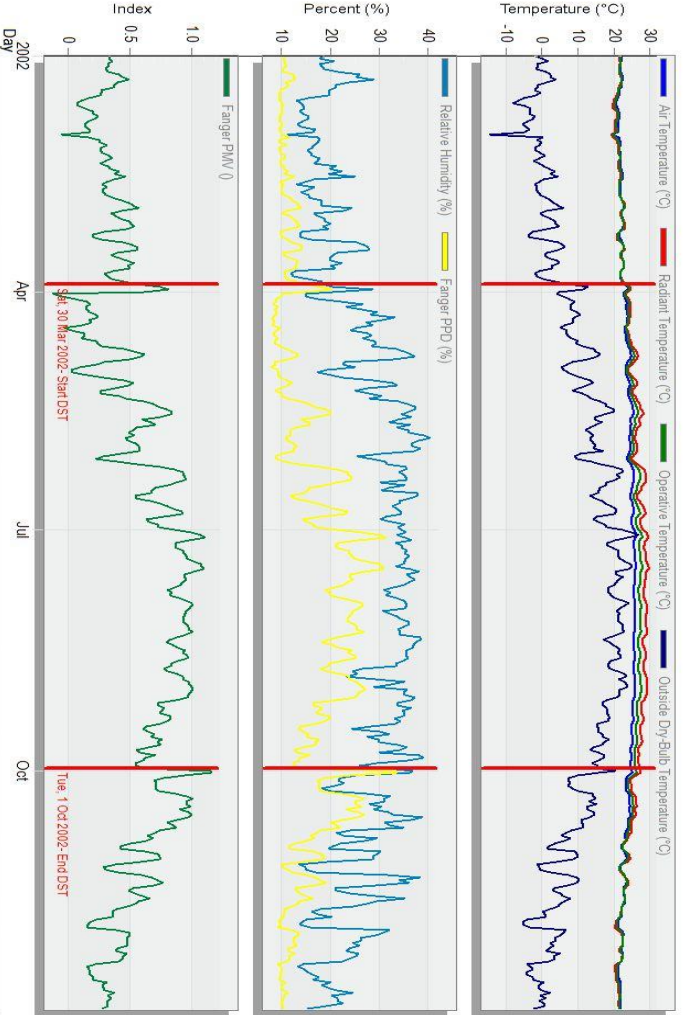
HVAC templates  
 Copy of Heated floor Boiler HW, Nat Vent  
 Copy of Split - Separate Mechanical Ventilation  
 Electric Connectors, Nat Vent  
 Electric storage heaters, Nat Vent  
 Fan Coil Unit (FCU) with Outdoor Heating - Cox  
 Fan Coil Unit (FCU) Air cooled Chiller, ODS  
 Fan Coil Unit (FCU) Water cooled Chiller, Wa  
 GSHP Under Water at Heat Pump  
 GSHP Water to Water heat Pump, Heated floo  
 GSHP Water to Water heat Pump, Heated floo  
 Heated floor Boiler HW, Nat Vent  
 Heated floor Solar Assisted Boiler HW, Nat Ve  
 Heating and Ventilation Ducted Supply - Electric  
 HW/Connectors, Nat Vent  
 Natural ventilation - No Heating/Cooling  
 Pod-aged DX

Data Report (Not Editable)  
**General**  
**Copy of Heated floor Boiler HW**  
 Source DB  
 Category Generic  
 Region TURKEY  
 Simple  
 Auxiliary energy (kWh/m²) 3.26  
 Colour Shading in Model  
 Floor shade colour  
 NCM HVAC system type  
 NCM HVAC system type Central has  
 Natural Ventilation  
 On Yes  
 Rate (ach) 5.00  
 Mixed mode on No  
**Mechanical Ventilation**  
 On No  
**Heating**  
 On Yes  
 Fuel 2-Natural G  
 Preheat (°F) 1.0  
 Heating system season 0.85  
 Heating system type 2-Phase/  
 Supply Air Condition  
 Maximum supply air L 35.00  
 Maximum supply air T 10.0

# APPENDIX-L: Heating and Cooling Panels

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for Heating and Cooling Panels.





Day	2002	Apr	Jul	Oct						
Air Temperature (°C)	21.53	22.69	23.45	24.34	25.12	25.72	25.60	25.06	23.43	21.88
Radiant Temperature (°C)	20.74	22.23	24.34	26.16	28.04	29.05	28.88	27.63	24.66	21.67
Operative Temperature (°C)	21.14	22.96	23.90	25.25	26.58	27.39	27.24	26.34	24.04	21.77
Outside Dry-Bulb Temperature (°C)	-1.27	4.88	9.65	13.65	17.71	20.39	21.67	16.79	8.18	1.11
Relative Humidity (%)	17.81	18.53	29.68	28.05	35.25	38.16	35.90	33.76	24.24	20.34
Fanger PPD (%)	9.53	13.78	8.91	11.29	18.95	27.20	25.00	17.00	18.13	10.38
Fanger PMV (0)	0.25	0.54	0.17	0.46	0.81	1.02	0.97	0.75	0.74	0.36

Display Options  
General Detailed

Date 3-Com Interval 3-Cell Show as 3-Comp Days per pa. 365 Normalise by area Y-Axis Appearance

Info, Help  
Help Data

Simulation Data - Analysis

This screen displays simulation data for the current zone.  
Select the data to view using the controls below.  
You can plot a number of different types of data on the same graph by making select on the Detailed tab of the Display Options.  
To update the data using different calculation or outputs options, click

- Update
- Export this report
- Show temperature distribution data
- Display Shortcuts: Clear all Show all Add Data: Gains data Fabric and ventilation Comfort Site System loads Save results set as template

Fabric and Ventilation - Block 1, Zone 1  
1 Jan - 31 Dec Daily

Simulation Data - Analysis  
This screen displays simulation data for the current zone.

Select the data to view using the controls in the Display Options pane.

You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculation or outputs options, click:

- Update
- Export this report
- Show temperature distribution data
- Display Storcuris:
- Clear all
- Show all

Add Data:

- Gains data
- Fabric and ventilation
- Comfort
- Site
- System loads
- Save results set as template

EnergyPlus Output

947.63

Display Options

General Detailed

Display Options

General Detailed

Units: Metric

Date: 3-01-2012

Interval: 3-0-0

Show as: 3-0-0

Days per year: 365

Normalise by area:

Y-Axis: Appearance

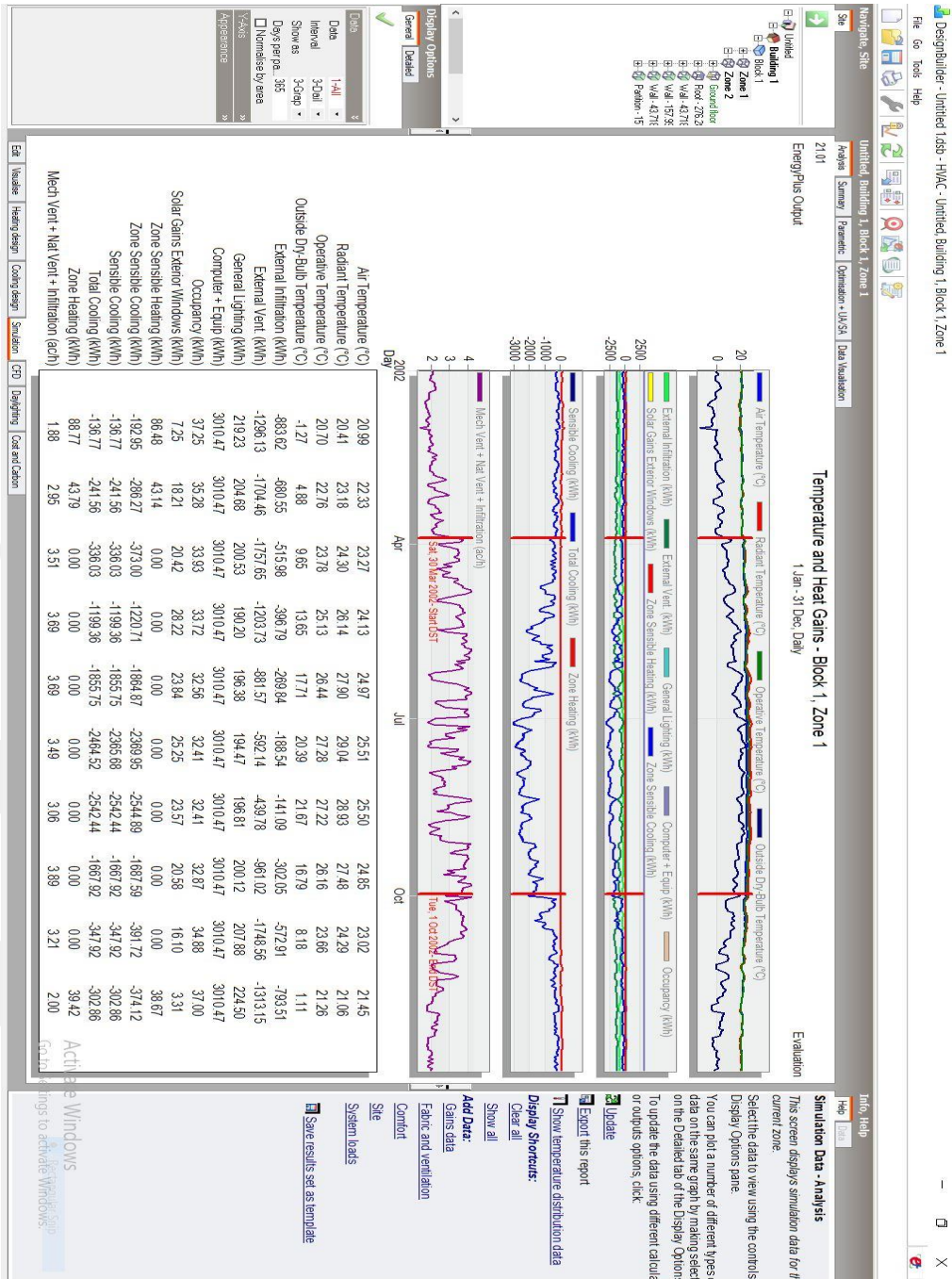


Day	External Infiltration (kWh)	External Vent (kWh)	Mech Vent + Nat Vent + Infiltration (ac/h)
2002	-903.48	-693.36	-522.16
Apr	-1501.67	-924.25	-572.48
May	1.95	1.70	1.52
Jun	-274.96	-404.29	1.30
Jul	-196.02	-31.85	0.96
Aug	-144.43	-7.79	0.75
Sep	-309.50	-107.04	0.89
Oct	-587.66	-849.17	1.80
Nov	-808.64	-1297.88	1.92



# APPENDIX-M: Simulation of Split system

Value of the criteria: Time not comfortable, Energy Consumption, Ventilation, Relative humidity, CO<sub>2</sub> emission, COP heating and COP cooling for Split system.





Unified Building 1, Block 1, Zone 1

Navigation: Home | Settings | Summary | Parameters | Operators | Units | Data Visualization

Unified Building 1, Block 1, Zone 1

EnergyPlus Output

Simulation: 1 Jan. - 31 Dec. Day

Simulation data - Analysis

This screen displays simulation data for the current zone.

Select the data to view using the controls below.

Select the data to view using the controls below.

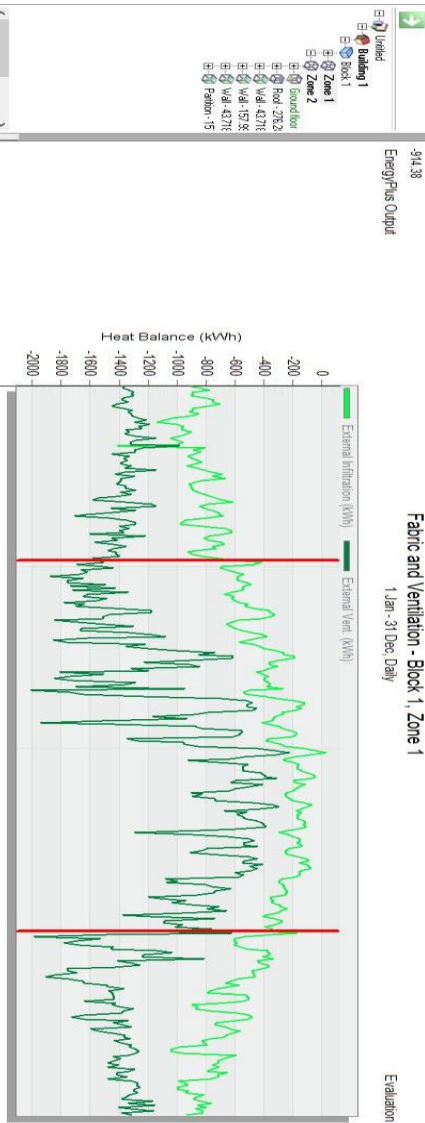
You can plot a number of different types of data on the same graph by making selection on the Detailed tab of the Display Options.

To update the data using different calculation or outputs options, click:

- Update
- Export this report
- Show temperature distribution data
- Display Shortcuts
- Clear all
- Show all

Add Data:

- Gains data
- Fabric and ventilation
- Control
- Site
- System loads
- Save results set as template



Day	2012	Apr	Jul	Oct
External Infiltration (kWh)	-883.02	-680.55	-515.98	-396.79
External Vent (kWh)	-1296.13	-1704.46	-1757.05	-1203.73
Mech Vent + Nat Vent + Infiltration (ac/h)	1.88	2.95	3.51	3.89
				3.89
				3.49
				3.06
				3.89
				3.21
				2.00

Display Options

General [Label]

Table

- EFactor
- Internal
- Show as
- Days per mo. 365
- Normalise by area
- Y-Axis
- Aggregation

Simulation: Heating design | Cooling design | Simulation | Displaying | Control and Climate

Active Windows

Click on the title bar of any window to activate Windows.

