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UTILIZING ARTIFICIAL NEURAL NETWORKS TO PREDICT HUMAN BODY EXERGY CONSUMPTION

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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YOUSIF LAYTH

A MASTER OF SCIENCE THESIS
IN
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YOUSIF LAYTH YOUSIF

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

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

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ABSTRACT

UTILIZING ARTIFICIAL NEURAL NETWORK TO PREDICT HUMAN BODY EXERGY CONSUMPTION

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The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines *thermal comfort* as "the state of mind that conveys happiness with the thermal environment”. Energy and Matter can scatter as a system and move toward equilibrium with their surrounding environment, and this is referred to as exergy in thermodynamics. Predicted Mean Vote (PMV)/Percentage of Predicted Dissatisfied (PPD) model and adaptive thermal comfort approach are the two most widely used methods for assessing thermal comfort. However, it is also possible to apply the exergy notion to the human body system as an index of thermal comfort. The relationship between a person's exergy balance and their level of thermal comfort is that effectively dissipating heat and water from the body is essential to human well-being. For this reason, the lowest human body exergy consumption rate mostly gives the optimum thermal comfort level. In this thesis, an Artificial Intelligence-based work was conducted in a room of engineering faculty of the Atilim University, Ankara, Turkey, with an occupant being inside the room to obtain the best condition for his exergy and thermal comfort. Human body exergy consumption is extracted via a computer programme and environmental parameters are measured by objective sensors. Then, an Artificial Neural Network (ANN) model is developed in Python environment.

A back propagation and sigmoid function is used in the neural network technique. A total of 133 data are included in the ANN model, with 75% (99 datasets) being used for training and the remaining for testing. A Mean Absolute Percentage Error (MAPE) of 1.98 and an accurate prediction rate (R^2) of 0.91 are found under the provided conditions, indicating a good coordination between the artificial neural network model outputs and the human body exergy data. Simplicity, speed of analysis, and learning from restricted data sets are all features of an ANN model over human body exergy simulation. This thesis presents a novel concept that uses an ANN model to determine how much exergy rate people consume (HBExC). This is because artificial neural networks (ANNs) are the most commonly used artificial intelligence technique in the field of buildings and thermal comfort fields. After all, they can handle nonlinear variables' interactions rapidly and correctly, especially, exergy concept which has complex nonlinear relationships between its variables.

Keywords: human body exergy consumption, python, artificial neural network.

ÖZ

İNSAN VÜCUDU EKSERJİ TÜKETİMİNİ ÖNGÖRMEK İÇİN YAPAY SİNİR AĞLARININ KULLANILMASI

Layth, Yousif
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Amerikan Isıtma, Soğutma ve İklimlendirme Mühendisleri Derneği (ASHRAE), termal konforu "ısıl çevre ile mutluluk veren zihin durumu" olarak tanımlar. Enerji ve Madde bir sistem olarak dağılabilir ve çevreleriyle dengeye doğru hareket edebilir ve buna termodinamikte ekserji denir. Tahmini Ortalama Oy (PMV)/Öngörülen Memnuniyetsizlik Yüzdesi (PPD) modeli ve uyarlanabilir termal konfor yaklaşımı, termal konforu değerlendirmek için en yaygın kullanılan iki yöntemdir. ekserji kavramını termal konforun bir indeksi olarak insan vücudu sistemine uygulayın. Bir kişinin ekserji dengesi ile termal konfor seviyeleri arasındaki ilişki, vücuttan ısı ve suyu etkili bir şekilde dağıtmanın insan refahı için gerekli olmasıdır. Bu nedenle , en düşük insan vücudu ekserji tüketim oranı çoğunlukla optimum termal konfor seviyesini verir.Bu tezde Yapay Zeka tabanlı bir çalışma yapılmıştır. Ekserji ve termal konfor açısından en iyi koşulu elde etmek için, Atılım Üniversitesi'nin Mühendislik Fakültesi binasında içinde bir kiş olan bir odada deneyler yapılmıştır. İnsan vücudunun ekserji tüketimi bir bilgisayar programı aracılığıyla çıkarılmakta ve çevresel parametreler objektif sensörler ile ölçülmektedir. Daha sonra Python ortamında bir Yapay Sinir Ağı (YSA) modeli geliştirilmiştir.

Sinir ağı tekniğinde bir geri yayılım ve sigmoid işlevi kullanılır. YSA modeline toplam 133 veri dahil edilmiş olup, verilerin 75% yani 99 veri seti eğitim ve geri kalanı test için kullanılmıştır. Sağlanan koşullar altında 1,98'lik bir Ortalama Mutlak Yüzdelik Hatası (MAPE) ve 0,91'lik bir doğru tahmin oranı (R2) bulunur ve bu, yapay sinir ağı modeli çıktıları ile insan vücudu ekserji verileri arasında iyi bir koordinasyon olduğunu gösterir. Basitlik, analiz hızı ve kısıtlı veri kümelerinden öğrenme, insan vücudu ekserji simülasyonu üzerindeki bir YSA modelinin avantajı olarak gösterilebilir.

Bu tez, insanların ne kadar ekserji oranı tükettiğini (HBExC) belirlemek için bir YSA modeli kullanan yeni bir konsept sunmaktadır. Bunun nedeni, yapay sinir ağlarının (YSA) bina ve termal konfor alanlarında en yaygın olarak kullanılan yapay zeka tekniği olmasıdır. Sonuçta, doğrusal olmayan değişkenlerin etkileşimlerini, özellikle değişkenleri arasında karmaşık doğrusal olmayan ilişkilere sahip olan ekserji kavramını hızlı ve doğru bir şekilde ele alabilirler.

Anahtar Kelimeler: insan vücudu ,ekserjisi, piton, yapay sinir ağı, ısı yükü.

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To my family.

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CHAPTER 1

INTRODUCTION

Thermodynamics is the analysis of heat, function, energy, and the changes they create in the states of systems. The word has its roots in Greek, therme meaning "heat" and dynamics meaning "power." In a general context, this field covers the study of the interactions between a system's macroscopic properties [1].

Thermodynamics is based mainly on two simple universal rules: conservation of energy theory; energy is a thermodynamic property that can change from one form to another through interaction, but the overall volume remains constant. The second law of thermodynamics states that energy has both quantity and quality and that natural systems aim to decrease energy rate while holding the endless amount. This law pertains to entropy, exergy, and energy to measure work potential [2].

The thermodynamic principles of energy, entropy, and exergy (the energy available to be used) are essential to all areas of science and engineering. Other fields also use entropy and exergy (such as statistics and information theory). However, entropy only encompasses a portion of the energy field, and specific energy sources (such as shaft work) are entropy-free. Similarly, exergy covers just a fraction of the energy field since processes (such as air under ambient conditions) involve both energy and exergy. Since most thermodynamic processes (such as those involving steam in a power plant) have energy, entropy, and exergy, they occur at the intersection of these three fields [1].

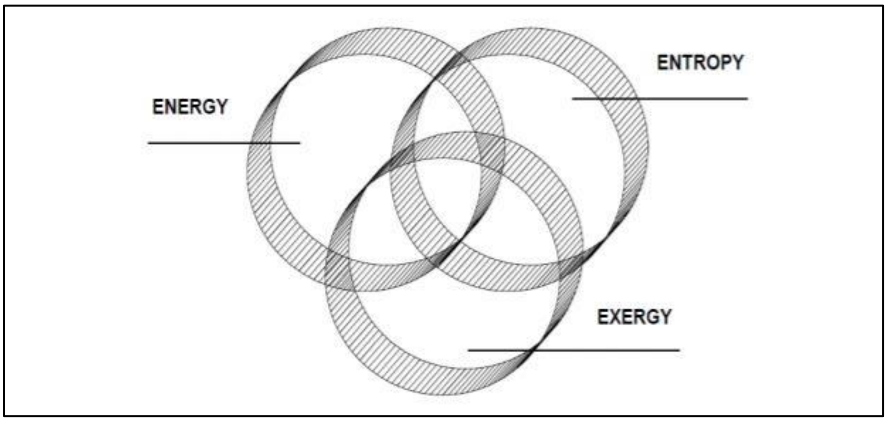


Figure 1.1 The intersection between energy, exergy, and entropy [1].

There are many forms of energy available. Thermodynamics is significant in studying energy transfers and transformations in materials, systems, and machines. This field of science has far-reaching ramifications, some of which cover the entire human enterprise. Our capacity to extract energy and use it for social needs has increased throughout modern history, and the Industrial Revolution was fueled by discovering how to process energy on a wide scale and transform heat into work. In nature, work can be entirely turned into heat, but heat cannot be wholly converted into work without using a machine (e.g., a cyclic engine) [3] Motors optimize the conversion of heat into work.

Energy is motion, or the power of moving, and is derived from the Greek words "en" (in or inward) and "ergon" (force or work). There are several different energy types; energy; energy is a scalar quantity by nature and cannot be measured directly. The actual value of the energy of a system is difficult to calculate, but the energy shift is relatively easy to assess [4].

Newton developed the idea of energy in physics when he assumed kinetic and potential energy. However, it was not until the mid-19th century that the development of energy as a unifying physical concept was adopted and considered one of the most significant scientific accomplishments of all time. Thanks to these developments, the definition of energy is so familiar to us today that we grasp it intuitively; still, we find it difficult to define precisely.

There are countless examples of energy use in human experiences. The sun is the primary power provider of the earth. It emits a wide variety of electromagnetic radiations that travel across space. Energy is also linked to the material structure and released through chemical and atomic reactions. Throughout history, the growth of civilizations, in essence, has been attributed to the exploration and productive application of resources to satisfy societies needs [3].

Within the context of the human body, energy production and exchange are the primary everyday functions. The human body, a biological machine, works as a heat motor and is considered a thermodynamically open system foods or your body's chemical energy transforms to other energy sources such as heat and work. Energy and mass are provided from external sources for essential functions in the human body (food and liquid), interacting with environmental energy generated in the body. This transition and interaction process is necessary for thermal sensation or thermal comfort [5].

In 1956, Rant coined the term "exergy," which is derived from the Greek "ex" (for "from, out of, or outside") and "ergon" (for "work, force, or organized motion"). Accordingly, available energy, availability, assergy, and technological ability to do work comprise other terms and expressions used to describe exergy, whose efficiency is examined based on the Second Law of Thermodynamics. Put differently, exergy is a thermodynamic ratio representing the conversion potential and limit of an energy carrier to complete theoretical work under ambient conditions at a given pressure and temperature [6].

As is well understood, living species need energy in heat and function in thermodynamics terms to maintain their existence. As endothermic species, humans generate metabolic heat, shared in various physiologically-driven processes with the atmosphere to achieve a steady apparent body temperature. The human body and its surroundings sustain a thermal equilibrium that maintains its internal temperature at about 37°C. Any changes in the atmosphere can affect if this heat is excessive, insufficient, or necessary [2]. The heat exchanges occur outside the human body by conduction, convection, radiation, and sudden evaporation. Additionally, the human body has a significant impact on the experiment's outcome in terms of temperature regulation.

Apart from this, by the evaporation catabolic and energy metabolism, the human body generates heat and normally absorbs heat by evaporation and distribution of liquids [7]. Therefore, heat loss must balance heat generation and energy transfer into the human body. The primary environmental variables that influences the human reaction to thermal equilibrium are this body's thermoregulation system, ambient air temperature, radiation temperature, relative and absolute humidity, and air movement [8].

In line with these assessments, energy analytics is the standard approach for measuring energy utilization in applying products and transferring and converting energy, physique, or chemical refining, often as well as the performance of the first law of thermodynamics-based energy balances and the energy efficiency assessment. This equilibrium is used to assess and reduce emissions of waste exergy, such as heat losses. However, energy balance on its own does not include details on energy or materials destruction during a process, nor does it measure the utility or efficiency of the different energy and material flows that pass into a system and leave the system as waste or goods.

The analytical exergy approach overcomes the first law of thermodynamics limitations since the exergy principle is based primarily on the first and second laws of thermodynamics. The energy depletion positions in the process can be clearly determined by exergy analyses for further contribution to activity or technologies. The exergy analysis can also quantify the waste stream's heat content. An exergy review primarily aims at defining meaningful (exergy) efficiencies and the causes of exergy losses and accurate magnitudes [3]. Energy is a conservative commodity under the First Law of Thermodynamics law. On the other hand, according to the Second Law, in this context, entropy production or irreversibility makes exergy non-conservative [9].

The exergy method of study overcomes the limitations associated with the First Law of Thermodynamics, which defines exergy and the Second Law. exergy analysis demonstrates where energy loss happens in a process, leading to better operation or technology. Additionally, such comments can help determine the heat content of a waste stream. In all, exergy research has the primary goal of identifying meaningful (exergy) efficiencies and the causes and accurate magnitudes of exergy losses [1].

Exergy is a measure of how easily energy can be converted into other types of energy. Additionally, it measures a system's deviation from thermodynamic equilibrium with its surroundings. Finally, it represents the maximum ability of power to do practical work as the system approaches balance, during which irreversibility increases entropy at the expense of exergy. Exergy represents the excess of energy expended in physical activity. Not convertible or accessible and cannot be converted into work [3].

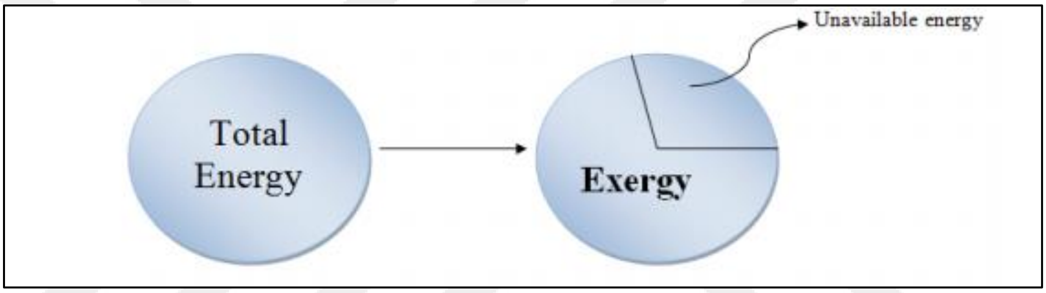


Figure 1.2 Representation of Energy, energy, and exergy in heat transfer.

In this sense, to avoid confusion with traditional energy-based thermal system analysis and design methods, it is essential to distinguish between exergy and energy.

Table 1.1 Comparisons of energy and exergy [4].

Energy	Exergy
It is known to be the capacity to generate motion or the ability to produce it.	It is known to be work or the opportunity to create it.
It is solely dependent on matter or energy flow properties and is unaffected by environmental factors.	Dependent on the properties of a matter or energy flow and the surrounding atmosphere.
According to Einstein's	Under being in total equilibrium with the world,

equation, when in equilibrium with the environment, it has values other than zero (including mc2).	the dead state equals zero.
The First Law of Thermodynamics regulates all processes.	The Second Law of Thermodynamics governs reversible systems. In fundamental or irreversible processes, it is partly or destroyed.
The Second Law of Thermodynamics applies (including reversible ones).	According to the Second Law of Thermodynamics, reaction products are not limited.
In a phase, it permanently conserves, so it cannot be destroyed or created.	It is still conserved in a reversible phase, whereas it constantly consumes in an irreversible process.
Neither can it be neither destroyed nor made. However, energy is still conserved, which cannot be generated or consumed in a balanced state.	It cannot be generated or destroyed in a reversible process, but it is often destroyed (consumed) in an irreversible process. exergy is still conserved in a reversible process, but it decreases in an irreversible process, such as existing systems. As a result, exergy never balances out in actual operations.
It can take several different forms (kinetic energy, potential energy, function, and heat) and be calculated accordingly.	It is calculated in terms of work or capacity to generate employment, and it comes in various forms (e.g., kinetic exergy, potential exergy, work, thermal exergy).
It is only a quantity measurement.	Due to entropy, it is a measure of quantity and consistency.

Given the above definitions, exergy can be classified into the following categories:

Kinetic Exergy: - resulting from a velocity difference between the mass flow under consideration and the environment, while kinetic energy is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity [10].

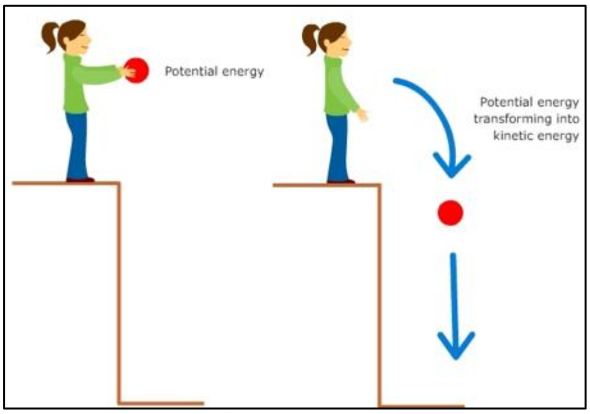


Figure 1.3 Kinetic energy concept is very similar to kinetic exergy concept.

Potential Exergy: - correlates with a value of the considered mass flows in a force field (such as the earth's gravitational field) evaluated with the environment's potential [10].

Physical Exergy: is equal to the product of mechanical and thermal exergy.

Thermal Exergy: is a function of the temperature differential between the flow under consideration and the ambient environment.

Mechanical Exergy: arises from a pressure difference between the considered transition and the surrounding area**.**

Chemical Exergy is associated with mass flowing at the reference temperature and pressure due to molecular structure and concentration variations.

Reactive Exergy: The capacity of a consideration material that is not part of the atmosphere to react with the environment's components.

Non-reactive Exergy: refers to substances available in the reference set but vary in concentration.

Nuclear Exergy: associated with a nuclear fission reaction. Exergy is used for qualitative and quantitative studies of several disciplines of chemical, biochemical, mechanical, environmental, and industrial processes.

The actual thermal conditions in the human body can rarely be characterized as healthy. Depending on time and location, differing temperatures, moisture, airspeed, and other thermometric parameters influence the body's thermal behavior. For this reason, the factors mentioned above should be carefully considered. Under transient conditions, a human body exergy equilibrium model was developed to account for this phenomenon [11]. Human health, competitiveness, and well-being are affected by a thermal atmosphere. Therefore, when it comes to a house's indoor environment, the development and installation of heating, air-conditioning, and ventilation systems require the determination of such criteria to preserve health and well-being [11].

In this respect, over seventy indices have been proposed for thermal comfort or discomfort to address the effect of thermal surroundings on humans throughout the past century. MacPherson and Epstein came up with a concise outline and taxonomy on the issue [12][13]. In general, the Indices are categorized into three major groups based on:

- Estimation of physical causes.

- Physiological pressure.

- Estimation of physical causes.

All factors considered, living in a pleasant indoor environment improves one's sense of thermal ease, well-being, and efficiency. Building energy use is intricately connected to the indoor environment. Given the number of resources expended in Heating, Ventilation, and Air Conditioning (HVAC) systems, an example may be given of this in the United States (European Union) and China of elsewhere, and it is essential to measure the building occupants' thermal comfort requirements for indoor space conditioning and to understand better the perceptual mechanisms that underpin such comfort requirements [14].

Since even the most basic indoor environment should provide conditions whereby thermal comfort is achieved, the human body's thermal balance significantly impacts thermal comfort with its environment.

Thermal comfort is linked to the human body's thermal equilibrium with its surroundings. Traditional human thermal analysis approaches are based on the First Law of Thermodynamics, focusing on the body's energy balance to establish heat flow between the body and the environment [15]. In addition, exergy analysis has recently been extended to measure heat transfer between the person and its atmosphere, using the methods described by the various thermal comfort models [15].

One must know that thermal comfort is characterized as a state in which the behavior has no urge to correct the environment. Consequently, human physical and mental productivity rises in this happy state. However, individual, psychological, social, and organizational factors influence occupant thermal sensation. Even in the same setting, an occupant can feel differently [16], despite sensors showing the same results regardless of where measurements are taken. Indeed, due to a combination of many factors that influence human perception, people staying in very similar spaces, subject to the same environment, and belonging to the same community may have very different opinions on thermal comfort. As a result, the subjects' diagnosis is an essential criterion for overall assessing studies parameters [17].

Experts traditionally regard thermal discomfort as a subjective phenomenon, whereas thermal sensation is an objective sensation. Satisfaction with the thermal environment is a dynamic emotional response to several interconnected and intangible variables [18].

The optimal human thermal model must meet a few specific requirements for analytical purposes. In all, three conditions matter for optimum thermal comfort: heat equilibrium, skin temperature, and sweat rate, all to be within the comfort range. The human body generates heat, transfers heat to the environment, and loses heat by the diffusion and evaporation of body fluids [9].

One can separate the human body into two subsystems for thermodynamic modeling: the core and the shell, as seen in Figure 1. The core is one subsystem whose temperature is kept approximately constant at 37°C, almost independently of fluctuations in surrounding temperature and humidity; on the other hand, the shell is a subsystem whose temperature is highly reliant on these changes [3].

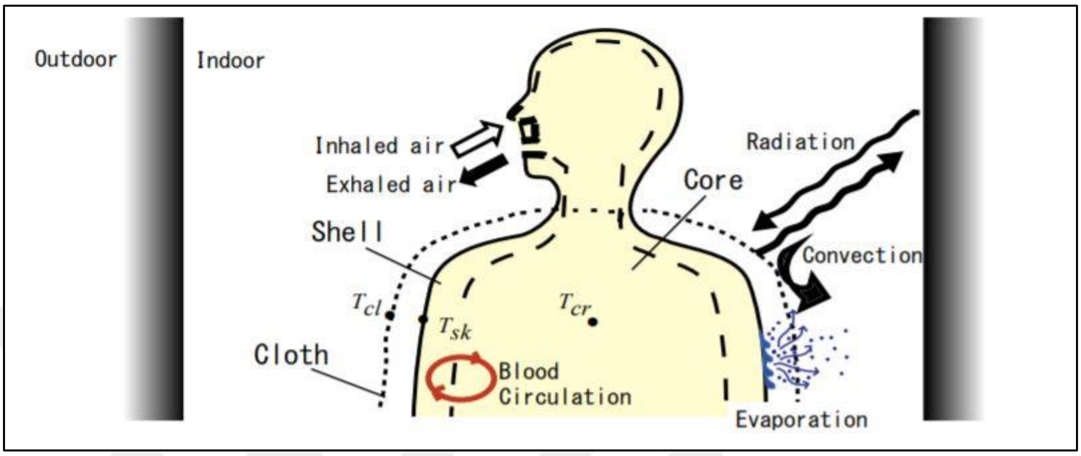


Figure 1.4 Modeling the human body on two subsystems: the core and the shell [3].

The human body works to control the body's entropy by processes such as metabolism to maintain a steady body core temperature. Secret parameters (body mass, skin surface, movement, clothing value, etc.) influence this capacity, expressed as thermal comfort [19]. Thermal comfort is determined by personal, environmental, and physiological factors. The environmental factors in this regard comprise[15]:

- Air temperature;

- Mean radiant temperature;

- Relative air velocity;

And

- Relative humidity.

Concerning the physiological aspect, the variables are:

- Skin temperature;

- Core or internal temperature;

- Sweat rate;

and

- Skin wetness.

Finally, the two personal variables are clothing thermal resistance and heat generation expressed as metabolic rate.

Exergy is defined by the second law of thermodynamics absorbed in the human body because of heat and mass transfer or conversion. The rate of exergy damage is determined by the human thermoregulation mechanism and environmental conditions [2]. Exergy research is used to evaluate the consistency of energy transfer processes in the human body and create thermal comfort metrics based on exergy consumption rate and exergy performance principles [20]. The minimum exergy intake of the human body equals the comparatively maximal productive function done by the human body. In other words, the human body's creation of minimal exergy intake offers optimal or maximum human efficiency [21].

The equation for the human body's exergy balance is as follows [22]:

$$M\left(1-\frac{To}{Tcr}\right)dt$$

$$+Vin\left[\left\{Cpa\left(\frac{Ma}{RTra}\right)(P-Pvr)+Cpv\left(\frac{Mw}{RTra}\right)Pvr\right\}\left\{(Tra-To)-To\,ln\frac{Tra}{To}\right\}\right.$$

$$\left.+\frac{To}{Tra}\left\{(P-Pvr)\,ln\frac{P-Pvr}{P-Pvo}+Pvr\,ln\frac{Pvr}{Pvo}\right\}\right]dt$$

$$+Vw_{corePw\left[Cpw\left\{(Tcr-To)-To\,ln\frac{Tcr}{To}\right\}+\frac{R}{Mw}To\,ln\frac{Pvs(To)}{Pvo}\right]dt}$$

$$+V\,w_{shell}Pw\left[Cpw\left\{(Tsk-To)-To\,ln\frac{Tsk}{To}\right\}\right.$$

$$\left.+\frac{R}{Mw}To\left\{ln\frac{Pvs\,(To)}{Pvo}+\frac{P-Pvr}{Pvr}ln\frac{P-Pvr}{P-Pvo}\right\}\right]dt$$

$$+feff\;fct\sum a\;pj\varepsilon\;cl\;hrb\frac{(Tj-To)}{(Tj+T)}\;dt-\delta SgTo$$

$$=Qcore\left(1-\frac{To}{Tcr}\right)dTcr+Qshell\left(1-\frac{To}{Tsk}\right)dTsk$$

$$+Vout\left[\left\{Cpa\left(\frac{Ma}{RTcr}\right)\big(P-Pvs(Tcr)\big)\right.\right.$$

$$\left.+Cpv\left(\frac{Mw}{RTcr}\right)Pvs(Tcr)\right\}\left\{(Tcr-To)-To\,ln\frac{Tcr}{To}\right\}$$

$$+\frac{To}{Tcr}\left\{\big(P-Pvs(Tcr)\big)\,ln\frac{P-Pvs(Tcr)}{P-Pvo}\right.$$

$$\left.\left.+Pvs(Tcr)\,ln\frac{Pvs\,(Tcr)}{Pvo}\right\}\right]dt$$

$$+Vw_{shell}Pw\left[Cpv\left\{(Tcl-To)-To\,ln\frac{Tcl}{To}\right\}\right.$$

$$\left.+\frac{R}{Mw}To\left\{ln\frac{Pvr}{Pvo}+\frac{P-Pvr}{Pvr}ln\frac{P-Pvr}{P-Pvo}\right\}\right]dt$$

$$+feff\;fcl\;\varepsilon cl\;hrb\frac{(Tcl-To)2}{(Tcl+To)}dt+fcl\;hccl(Tcl$$

$$-Tra)\left(1-\frac{To}{Tcl}\right)dt$$

Where;

M	Metabolic energy generation rate, W/m^2
Tcr	Body-core temperature, K
TO	Outdoor air temperature as environmental temperature for exergy calculation, K
t	Time, s
dt	t’s infinitesimal increment, s
Vin	Volumetric rate of inhaled air, (m^3/s)/m^2
Cpa	Specific heat capacity of dry air (= 1,005), J/(kg K)
Ma	The molar mass of dry air (=28.97), g/mol
R	Gas constant (= 8.314), J/(mol K)
Tra	Room air temperature, K
P	Atmospheric air pressure (101,325), Pa
Pvr	Water-vapour pressure in the room space, Pa
Cpv	Specific heat capacity of water vapor (= 1,846), J/(kg K)
Mw	The molar mass of water molecules (= 18.02), g/mol
Pvo	Water-vapour pressure in the outdoor air, Pa
ρvo	Density of liquid water (= 1,000), kg/m^3
$Vw - core$	Volumetric rate of liquid water generated in the body core, which turns into water vapor and is exhaled through the nose and the mouth, (m^3/s)/m^2
Cpw	Specific heat capacity of liquid water (= 4,186), J/(kg K)
$Pvs(To)$	Saturated water-vapor pressure at outdoor air temperature, Pa
Vw_shell	Volumetric rate of liquid water generated in the body shell as sweat, (m^3/s)/m^2
$feff$	The ratio of the effective area of the human body for radiant-heat exchange to the surface area of the human body with clothing (= 0.696 ~ 0.725)

Tsk	Skin temperature, K
fcl	The ratio of human body area with clothing to the naked human body area (= 1.05 ~ 1.5); the thicker the cloth is, the larger the value of *fcl* is
apj	Absorption coefficient between the human body surface and a surrounding surface Denoted by j (dimensionless). It can be assumed in most cases to be equal to configuration factor, the ratio of diffuse radiation incident on and absorbed by the human body to the diffuse radiation emitted from surface j
εcl	Emittance of clothing surface (dimensionless). Its value is usually higher than 0.9
hrb	Radiative heat-transfer coefficient of the perfectly black surface, W/(m^2 K)
Tj	The temperature of surface j, K
δSg	An infinitesimal amount of entropy generation during the infinitesimal period of time(*dt*), Ons/m^2
$Qcore$	Heat capacity of the body core, J/(m^2 K)
$dTcr$	Infinitesimal increment of body-core temperature, K
$Qshell$	Heat capacity of the body shell, J/(m^2 K)
$dTsk$	Infinitesimal increment of skin temperature, K
$Vout$	Volumetric rate of exhaled air, (m^3/s)/m^2
$Pvs(Tcr)$	Saturated water-vapor pressure at body-core temperature, Pa
Tcl	Clothing surface temperature, K
$hccl$	Average convective heat-transfer coefficient over clothed body-surface, W/(m^2K)

The Second Law of Thermodynamics has been applied to the human body to determine health, efficiency, and thermal comfort in the last decade. Furthermore, experts have further extended the research on the topic to other living systems to entirely understand life, development, and aging. Therefore, in line with the efforts to conduct comprehensive exergy analyses on the human body, it is essential to have the environmental conditions, such as air temperature and relative humidity, as well as the metabolism associated with an activity level (obtained from literature correlations, or oxygen intake and carbon dioxide production) [23].

CHAPTER 2

LITERATURE REVIEW

All thermal comfort prediction methods commonly used tend to apply energy analyses. However, exergy analyses provide more accurate conditions forecasting with optimum thermal comfort [24]. Additionally, exergy research applied to the human body can evaluate the efficiency of energy transfer processes in the body's various structures, tissues, and even cells [25].

The benefits are numerous. By evaluating the locations, types, and actual magnitudes of waste and loss in systems fueled by non-renewable energy resources such as natural gas, coal, and oil, exergy analysis helps make more efficient use of these resources. Exergy research is also helpful for designing more efficient thermal systems of all kinds and directing efforts to minimize inefficiencies [26]. The relation between thermal comfort and human body exergy balance has shown that against the human body's exergy consumption rate, the thermal environment has an excellent minimum effect in terms of thermal comfort [27]. It is generally accepted in the field of exergy research that a system's working functions, such as heating and cooling, are fueled by exergy, not energy [28].

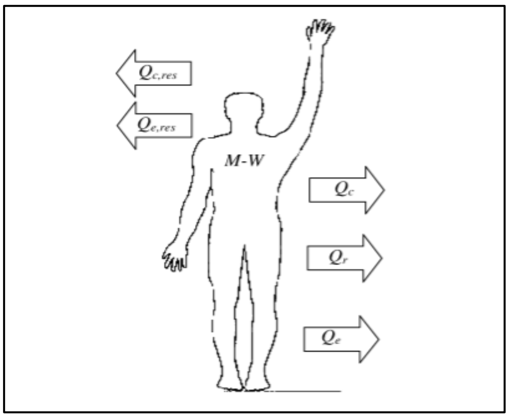


Figure 2.1 Human heat balance [27].

According to Shukuya et al., the exergy principle can be used to calculate the energy required to run a device, and any thermodynamic system functions as an "exergy entropy" mechanism, in which exergy is supplied and consumed. In contrast, entropy is produced and discarded into the environment. This principle was first used to analyze the exergy balance of the human body. Using the “exergy-entropy” process as a guide, one can calculate the human body's exergy balancing equation using the "exergy-entropy" process as a guide and then use the ambient temperature for exergy measurement [29].

Turhan and Akkurt investigated the link between thermal comfort and human body exergy utilization in a temperate climate zone. As a test case, the Izmir Institute of Technology's site in Izmir/Turkey was equipped with a primary office building. In order to acquire the tenant's Thermal Sensation Votes, an online survey was used in conjunction with a mobile app to collect responses. Sensor data was used to determine thermal comfort and exergy balance in the building. There is a difference in the expected mean values for summer, and winter Thermal Sensation Votes under the provided conditions, with the latter being higher. Thermal-sensing votes were projected to be warm, but the predicted mean votes were nil. The HBexC rate computation offered better estimates of optimal thermal comfort environment features for a specific example study [19].

The human body's exergy balancing equation was defined, and some numerical results were given by Iwamatsu et al. A warm radiant exergy is essential during the winter, whereas cold radiant exergy is essential during the summer. Summer and winter have the lowest rates of exergy intake by the human body [30].

A new exergetic model developed by Prek et al., based on exergy analysis of thermal comfort analysis, can be used to anticipate human reactions to changes in temperature. Since the Second Law of Thermodynamics can be used using a two-node model, it was selected since it is straightforward to compute and implement. As demonstrated by the exergy studies, there is a direct link between human exergy uptake and environmental conditions. In addition, steady-state data reveal that exergy consumption by the human body is linked to the PMV value [31].

Exergy rates are almost non-existent, according to Schellen et al., and the energy contribution via heat and mass fluxes is critical instead. Temperature and relative humidity impact the human body's exergy activity. Lower relative humidity and higher temperatures are better for the human body's efficiency [32].

Albuquerque-Neto et al. generated two physiological parameters: thermal device frames and breathing machine frames, to determine the rate of exergy loss in the human body throughout physical activity. In addition, the rates of lung and tissue loss during exercise were recorded. According to their findings, tissues that have been subjected to physical exercise perform better, whereas lung function is less efficient. Prek (2005) estimated that more than 60% of the population's air system was destroyed in this manner [33].

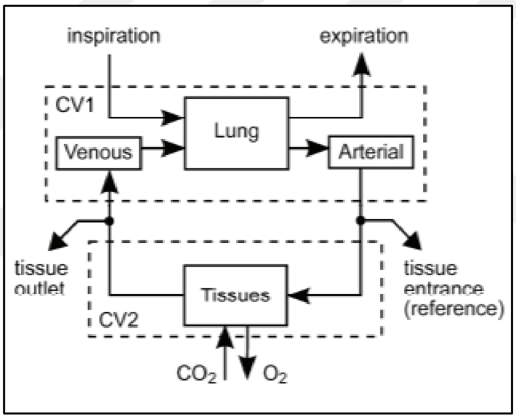


Figure 2.2 Control volume definition [33].

Henriques et al. used an exergy study to determine how much energy individuals can waste while exercising at sea level and high elevations at various acclimatization levels. It is possible to measure the volume of a person's lungs and other bodily functions using these two methods. According to the research, respiratory efficiency was worse at higher latitudes and during physical activity. As a result of this improvement in exergy efficiency, it appears that the respiratory system is primarily responsible for the physical stress experienced at high elevations. At this point, the acclimatization period impacted the respiratory system more significantly [34].

Butala conducted an experiment in which the destruction of each thermal and mass transfer mechanism was measured separately based on the type of exergy and its appropriate indoor reference condition, rather than an overall input-output body correlation. Exergy destruction was influenced by a variety of environmental factors that were studied in depth. An additional benefit of this approach is that the combination of indoor factors that minimize human exergy destruction may be defined. The findings also suggest that human exergy degradation may be linked to human thermal comfort [2].

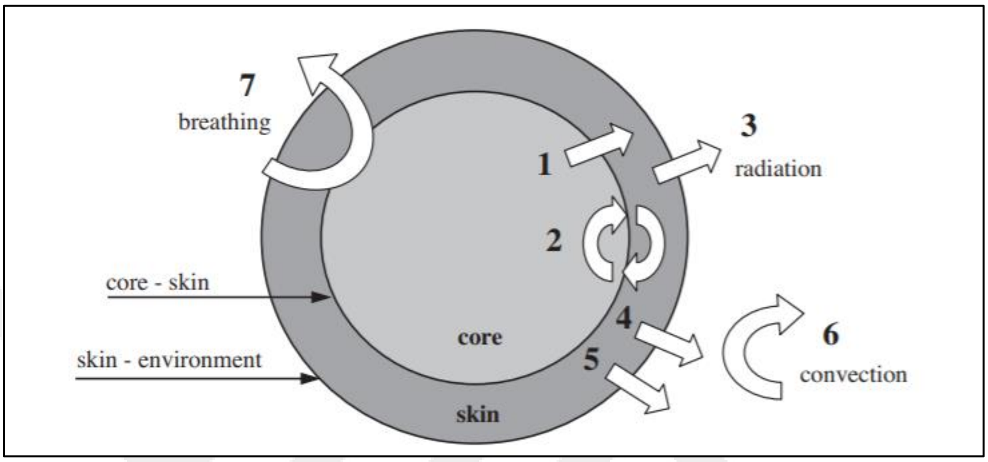


Figure 2.3 Heat and mass flow in two-node human body model [2]

1 – conduction between core and skin compartment, 2 – blood flow between core and skin compartment, 3 – thermal radiation, 4 – sensible heat transfer at the skin surface, 5 – water perfusion and sweating (latent heat), 6 – convective heat and mass transfer, 7 – breathing.

Butala used an exergy-based survey to examine how the human body interacts with its environment. Exergy loss due to convection, radiation, evaporation, and respiration can be measured and expressed in exergy transmission rate. This value replaces the exergy loss in the heat balance equation in Fanger's modified thermal comfort model. The results show statistically that exergy loss should replace thermal energy loads in the basic Fanger model. To put it another way, this results up in a particular level of thermal comfort [15].

According to Tokunaga and colleagues, human body energy and exergy balance are different. In essence, a portion of the exergy is necessary. Wet exergy, found in liquid water, is caused by sweat secreted in the exergy balancing equation, especially in the summer. The intake of exergy is reduced slightly in the naturally ventilated space. On the other hand, the first 10 minutes in the engineered air-conditioned room are much higher and decrease. The difference in skin surface in the dynamically air-conditioned room was more pronounced than in the naturally ventilated environment. Therefore, the total exergy intake was more efficient in the mechanically air-conditioned environment. Traditional mechanical cooling systems use an enormous amount of exergy, both in terms of energy and in the form of exergy generated by the user's own body [35].

Rabi et al. showed a minimal irreversibility rate for different combinations of ambient air and medium radiant temperature. Further research has shown that the mechanisms of heat transfer influenced by both clothing’s – convective and radioactive heat transfers – have a more significant impact on overall irreversibility than the other heat transfer processes. Because convection may transfer more heat than thermo-radiation, exergy losses are more minor among these two methods. In the future, thermostat convection may be a preferred method of heat loss [36].

This study by Xiaozhou Wu et al. reported a tremendous difference in skin surface temperature in the dynamically ventilated room. Additional findings show that mechanically air-conditioned areas had higher adequate total exergy intake than vented areas. Much exergy is used in conventional mechanical cooling systems. This exergy is not simply from energy but also from human exergy. By the second thermodynamic maxim, the most efficient use of the human body is associated with the least amount of physical activity. Temperatures that seem "lightly cold" to the human body are ideal for this phenomenon [37].

During the summer months in Izmir, Turkey, Caliskan et al. researched human energy and exergy. The findings show that the metabolism and rate of exergy heavily influence the human body's energy output. Metabolism has a far higher kilowatt-hour output than exercise (1,661 W/m^2), despite the latter's relatively low output. This is when the body experiences its greatest loss of energy (70.59 %). Radiation, convection, and conduction all play a role in heat transfer, as convection. However, the human body loses the greatest exergy because of the moisture in the exhaled air (6,393 percent) because the body uses so much of the exergy (90.786 %). Thermal comfort is also examined in the study. 0.028 of the predefined Mean Vote (PMV) rate ensures a soothing effect on the human body. Moreover, the number of thermally dissatisfied people has been predicted to be less than 5.017 % [7].

This study shows that computer calculations reveal the relationship between the exergy used within the body and the interior ambient thermal variables, such as air temperature and humidity, to produce a thermally neutral situation at PMV*=0. This study was carried out by Komizo et al. Temperatures at 18°C and 25°C in the room air of the door provide the lowest activity consumption rate for the human body at 1.0 meters and 0.9 clothing. Therefore, thermal comfort and low human body consumption levels can be achieved by using radiant warm exergy rather than warm connective exergy to create a temperature difference [38].

Human body exergy was studied by Mady et al. to identify the connection between exergy destruction rate and exergy productivity with aging conditions and environmental factors. The study then created a behavior model for a person in a stable mental state. While analyzing these results, the effects of aging and the environment on exergy degradation and productivity are considered. Finally, exergy degradation rates in the human body and exergy performance due to aging and the atmosphere's circumstances are examined using a complete model of the human thermal system [20].

Shukuya describes an exergetic approach leading to exergy-free heating and cooling systems in future structures. However, an in-depth awareness of the surrounding environment is necessary for the definition of exergy to establish the amount of energy that must be used to meet exergy needs [38].

According to Krainer and colleagues, the human body's HBExC ratio and PMV index change between typical laboratory settings and LowEx systems. To determine the most efficient thermal convenience device, the PMV index does not provide much information. All of the results from the HBExC provide detailed data regarding the impact of individual features and experimental settings on the various sections of HBExC. In previous studies on average test individuals, HBExC levels in comfort surroundings were lower. For individual users, the results of simulations suggest that adequate settings are not necessarily less pleasant (PMV closer to 0) and that specific features substantially impact all HBExC elements [39].

According to research, temperatures can be reduced by as much as 99.7 % when thermal insulation is used in building envelope systems. Allows "soft" radiant exergy in building envelope systems in temperate and cold climates. Additionally, it permits "cool" radiant energy to be produced rather than "warm" radiant energy in hot/dry and humid areas. The amount of exergy that the human body expends on thermal insulation reduces regardless of temperature. 5.4 % in a temperate climate, 35.9 % in a cold environment, 10.1 % in a warm/drought climate, and 0.6 percent in hot/dry moist conditions were attributable to decreased thermal insulation. The human body's thermal insulation abilities are unsurpassed [40].

According to Shukuya, the absorption of exergy must be coupled with entropy generation to maintain the desired exergy level, whether it is "hot" or "cool." This means that the entropy generated inside the area must be regularly discharged to the outside environment. Therefore, the objective is to find a design method for a device that uses the least amount of exergy supply while obtaining the necessary energy from the nearby outside ecosystem and making intelligent use of it to maintain a specific level of health in built-in settings while addressing this issue [41].

Using an exergy-based approach, Butela investigated the relationship between thermal comfort and the atmosphere. The two-node thermal model is improved by using the Second Law of Thermodynamics to calculate exergy loss. Differs with average PMV and systematic analysis between thermal comfort and exergy degradation. This number is different from the PMV. Exergy analysis, it turns out, has several advantages: Exergy destruction is a standard unit of measurement and expression for heat and mass transport. The exergy destruction is frequently determined using location factors (indoors). Thermal exergy destruction is a single-value pseudo-property that encompasses all relevant characteristics that affect thermal comfort [42].

The exergetic aspect of day lighting and the luminous and thermal comfort aspects are discussed in the work by Maki. They computed the exergy consumption for lighting and cooling in a classroom with and without electric lighting. It is observed that the use of daylighting eliminates the chemical exergy contribution to the power plant by 89 percent. Furthermore, according to a questionnaire study of students' perceptions of stimuli and warmth in the classroom, the cut-off of fluorescent tubes caused no luminous pain when daylighting was used. Furthermore, it improved their thermal comfort [43].

This study is making an effort to evaluate a LowEx system (a heating and cooling system that uses the least amount of energy possible to create healing and comfort conditions for individual users). An experimental burn patient model room was used to compare the LowEx gadget to the regular one. Energy consumption was calculated using thermal comfort settings for three people (burn patient, healthcare worker, and visitor). Both systems used a simulation to create realistic burn patient settings for testing. By lowering the quantity of human body exergy intake (HBExC), which is valid for thermoregulation, reduced evaporation, radiation, and convection, the LowEx technique can be demonstrated to create optimum settings for burn patients [44].

Following Shukuya's work on thermal comfort and the built structures, it is vital to supply occupants with "warm" or "cool" radiant exergy from the inside surfaces of building envelope systems, both in summer and winter, according to Shukuya's findings. According to a new study, the thermal efficiency of window systems affects the availability of "warm" and "cold" radiant exergies. Radiant exergy is almost ten to twenty times more "warm" when windows are adequately insulated and the interior solar control system is in place during the winter. On the other hand, the interior shading equipment reduces "warm" light exergy emission against the inside atmosphere by over 80% in the summer, allowing the specified environmental space to be occupied [45].

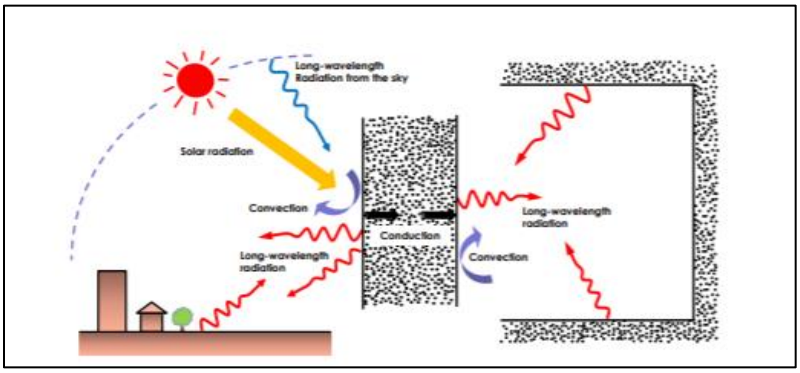


Figure 2.4 Thermal exergy transfer within an external wall by long-wavelength radiation, convection, and conduction [46].

Using the exergy concept to evaluate the human body as a heat transmitter, Guo et al. found that the body maintains a consistent core and skin temperature through physiological reactions, such as trembling, sweating, and breathing, to ensure proper heat dissipation. A numerical and analytical analysis of terms for measuring metabolism, radiation, evaporation, and convection exergy alterations in the human body was performed to illustrate the essential assumptions employed in existing human body exergy models. As a result, exergy from metabolism is overestimated; radiation exergy is underestimated; and convective exergy deficits are overestimated, with certain limitations [46].

Last but not least, Isawa presented his findings on the relevance of his estimations of human body exergy equilibrium to the measurement of human comfort indoors. He investigated the integrated exergy intake of variously sized enclosures constructed of wood, metal, and concrete using formulae for human body exergy equilibrium. Result: a lower combined exergy intake for better thermal comfort. According to the author, a timber enclosure offers more thermal comfort over concrete or metal constructions sans insulation and an energy source in Shizuoka, Japan's typical winter and intermediate season circumstances [29].

According to the study's conclusions, researchers should be aware of the potential for errors in their calculations and assumptions. To accurately predict the human body exergy consumption in indoor situations, architects, engineers, and researchers can use the ANN model and the findings of this study.

CHAPTER 3

METHODOLOGY

In this chapter, we mainly discuss the work we have achieved throw out our thesis, which was the best thermal comfort condition for an occupant in a specific building chosen, which we will discuss and explain in this chapter.

3.1 Case Building

The case building was an office building at Atilim University in Ankara, Turkey (39.81°N 32.72°E), designated as a CSB type climate zone by the Köppen-Geiger Climate Classification. Figure 3.1 depicts the case building's location chosen for this study. It is worth noting that the average temperature of Ankara during the winter (January, February, and December) and summer (June, July, and August) seasons is 0.7°C to 2.6°C and 20.3°C to 23.7°C, respectively.

The case building has a depth of 4.7 meters, a width of 3.25 meters, and a height of 2.8 meters. In addition, the case building has one wide window in the south direction (window to wall ratio of 3.6). Figure 3.2 shows a comprehensive architectural drawing of the case building [47].

Figure 3.1 The Location of the Case Building.

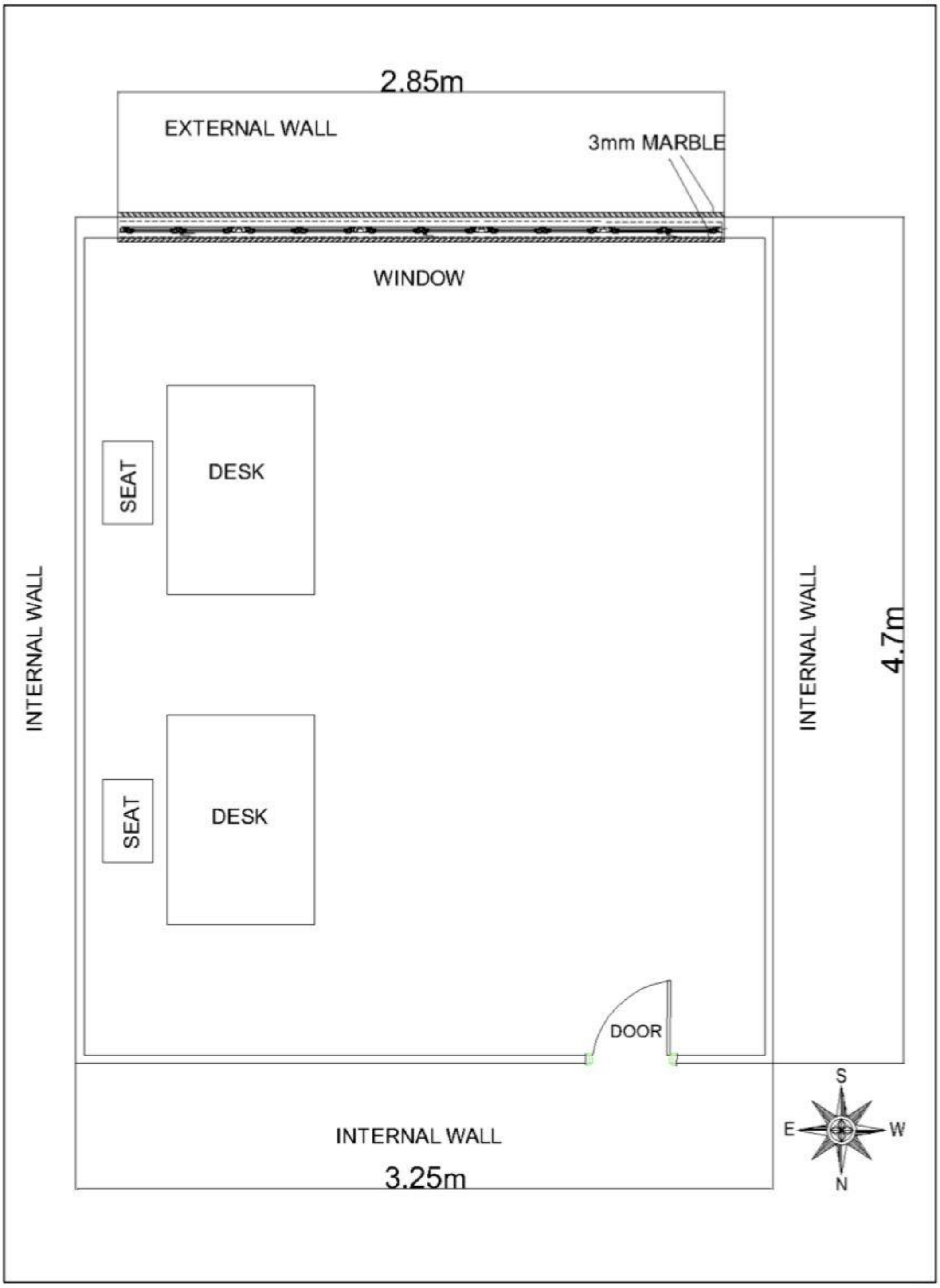


Figure 3.2 The Architectural Drawing of the Case Building [47].

3.2 Data Collection

An occupant inside the case building used an infrared thermometer - EXTECH 42530, shown in Figure 3.5, to measure the wall and indoor air temperatures. The temperature data was taken at 10-minute intervals between 09:00 and 17:00 between July 6, 2020, and April 19, 2021. Table 3.1 lists the parameters for infrared thermometers, whereas Figure 5.17 depicts a data gathering diagram. A developed globe thermometer was used to measure the globe's temperature and, thus, Mean Radiant Temperatures. It is worth noting that the globe thermometer is developed by The measurement processes were the same as the reference [47]. The temperatures of six walls were calculated from five different sites, as shown in Figures 3.6 and 3.7. It should be mentioned that while taking the wall temperatures, the drapes were closed to prevent short-wave radiations. In addition, to avoid any disruptions in the MRT, MRT values were calculated with a developed globe thermometer by Mehmet Furkan ÖZBEY [47]. Figure 3.8 shows the globe thermometer used by Mehmet Furkan Özbey [47]. The room's radiator was turned off during the measurements. Furthermore, because the radiator is made of a different material than the wall, the radiator's temperature was measured simultaneously with the wall's temperature using an infrared thermometer.

Figure 3.3 Infrared Thermometer (EXTECH 45230).

Table 3.2 The Specifications of Infrared Thermometer.

Specifications	Range / Details
Range	-50°C to 538°C
Accuracy	±2%
Resolution	0.1°C
Emissivity (ε)	0.95
Dimensions	211x89x38mm
Weight	200g

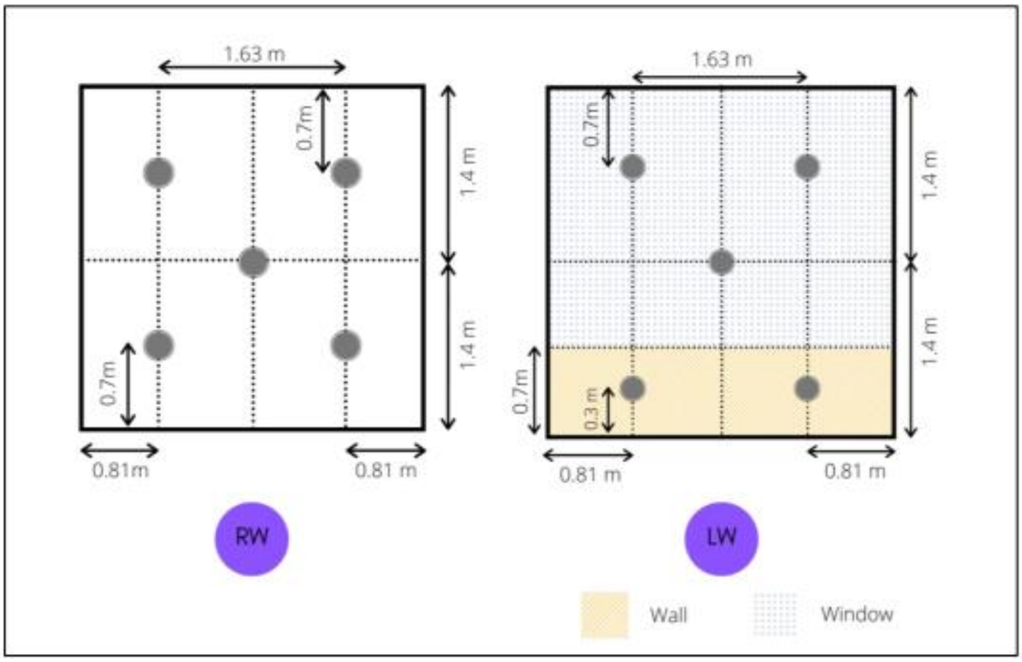


Figure 3.4 The Locations of Taken Temperatures for Left and Right Walls [47].

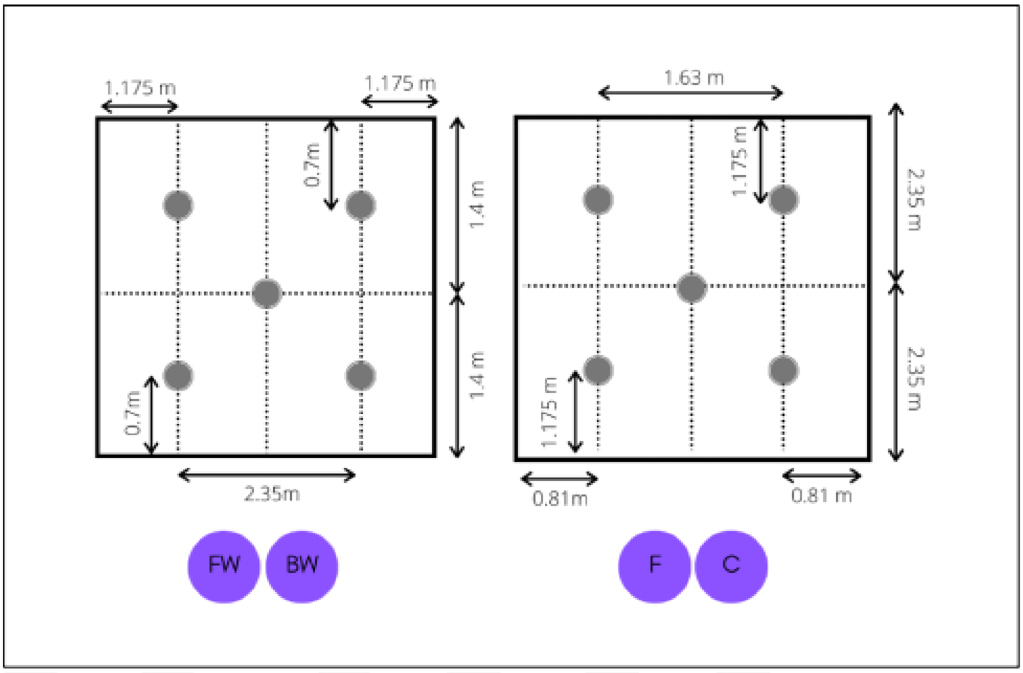


Figure 3.5 The Locations of Taken Temperatures for Front Wall, Back Wall, Ceiling and Floor [47].

Figure 3.6 The developed globe thermometer [47]

3.3 Method to calculate exergy balance

The typical form of exergy balance is given in Eq. (1) [19] for the human body shown in Fig. 4. , and Table 3.4 describes the terms in Eq. (1). It is worth noting that these equations and terms are taken from the reference [19].

$$Xin - Xout - Xcons = Xst \qquad (1)$$

The exergy balance of the human body is estimated for given environmental variables under steady-state settings, assuming that heat storage is insignificant. Then, Eq. (1) is translated to Eq. (2) using the terms in Table 3.3, and the HBexC (Xcons) rate can be computed using this equation.

Shukuya et al. established a novel thermal comfort approach that relies on the First and Second Laws of Thermodynamics. The process utilizes the outdoor temperature (T_o) and relative humidity (RH_o) as well as the interior environmental factors to determine the human body exergy consumption (HBexC). Only a few thermal comfort variable combinations give a least HBexC rate and PMV = 0 (thermal neutrality).

$$Xcons = Xin,met + Xin,inh + Xin,w,cr + Xin,w,sh + Xin,abs - Xout,exh - Xout,sw - Xout,dis - Xout,c \qquad (2)$$

Table 3.2 Exergy balance for the human body system [15].

Terms	Notations in Fig 4	Terms	Explanations
X_{in}	(1)	$X_{in\ met}$	Exergy generated by metabolism
	(2)	$X_{in,\ inh}$	Exergy contained in the inhaled humid air
	(3)	$X_{in,\ w,\ cr}$	Exergy contained in the liquid water generated in the body core by metabolism
	(4)	$X_{in,\ w,\ sh}$	Exergy is included in the sum of liquid water generated in the shell by metabolism (sweat)
	(5)	$X_{in,\ abs}$	Radiant Exergy absorbed through the surface (skin and clothing)
X_{out}	(6)	$X_{out,\ exh}$	Exergy contained in the exhaled humid air
	(7)	$X_{out,\ sw}$	Exergy contained in the moist air leaving the body surface (evaporated water from the sweat)
	(8)	$X_{out,\ dis}$	Radiant Exergy discharged through the surface (skin and clothing)
	(9)	$X_{out,\ c}$	Exergy is transferred by convection from the surface to the surrounding air
X_{cons}	(10)	X_{cons}	Exergy consumed by the human body
X_{st}	(11)	$X_{st,\ cr}$	Exergy stored in the core
	(12)	$X_{st,\ sk}$	Exergy stored in the skin

After getting the required data, we used Python for our next stage. It is an object-oriented, dynamically semantic, interpreted high-level programming language. We used Python to create our ANN (artificial neural network) to obtain the output data. The python programming language was chosen because it increases productivity. Since there is no compilation step, the edit-test-debug cycle was speedy. A segmentation fault will never occur in a Python script due to a bug or incorrect input. Python scripts are therefore very easy to troubleshoot [48].

Complex numerical and symbolic computations can be performed at incredible speeds by modern computers. However, they fall far short of human brains in conducting perceptual functions like language and image identification. Human brains accomplish things in a parallel processing manner, whereas computers steps towards achieving input data and follow instructions successively. An artificial neural network is created when artificial intelligence is designed based on a biological neural network (ANN). The architecture of biological neurons, such as those found in the brain, served as inspiration for the design of the artificial neural network. Intertwined neurons make up the vast majority of the brain's cells. A neuron is a cell that responds to an input signal by performing a simple task. However, a system of neurons can accomplish complicated tasks like speech and image recognition with incredible speed and precision when they are attached together. Artificial neural networks (ANNs) are especially well-suited to solving nonlinear problems and finding the approximate principles that regulate their accurate solutions [49].

The ANN is a network of nodes, similar to neurons, which are interconnected. The character of each node, the structure of the network, and the rules for learning are all essential components of a neural network. How signals are processed by a node, such as how many inputs and outputs it has, how each one is weighed and how it is activated are all determined by the node character. The structure of a network's nodes is determined by its topology. The initialization and re-adjustment of weights are controlled by learning rules. The fuzzy rules that connect different types of data are found by ANNs as they work. This implies that if they get certain data in one process, they will concentrate on certain rules. If they get different and updated data, ANNs will change their rules to match, integrating the old data with the new, and they do this without any outside help [50].

The data under their management is always being updated, which creates a dynamic system. The rules of the system are automatically changed by the ANNs as the problem in question changes over time. Here, we go from an early classification to one that is much more detailed and precise.

The ANN alone takes care of this one, and it uses the new cases as data. And ANN consists of three essential layers, as shown in the Figure 3.7 ANN layers

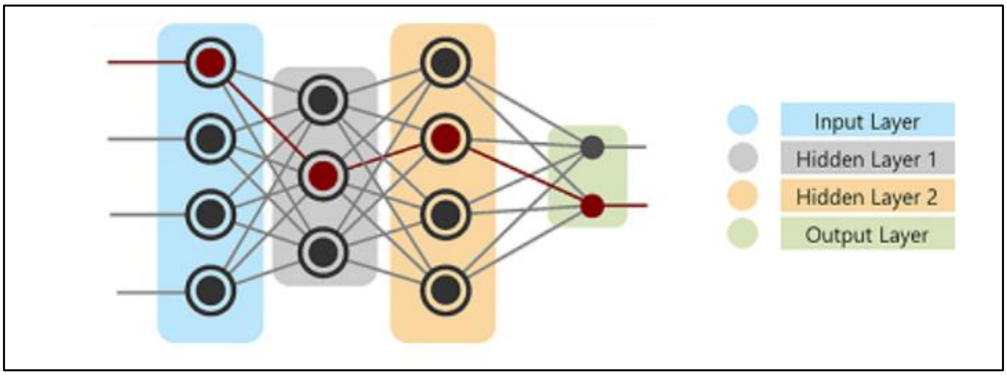


Figure 3.7 ANN layers [51].

Input Layer(s): As the name suggests, this layer accepts all the inputs provided by the programmer [51].

Hidden layer (s): The term "Hidden layers" refers to the group of layers that exist between the input and output layers. Here, calculations are made, and the outcome is generated.

Output Layer(s): The inputs go through a series of transformations via the hidden layer, resulting in the output delivered via this layer.

For instance, in the figure below, it would sound right to choose an ANN to determine how the input is transformed into the output only if the process occurring inside the black box is extremely complex. Otherwise, it would be prudent to employ alternative methods.

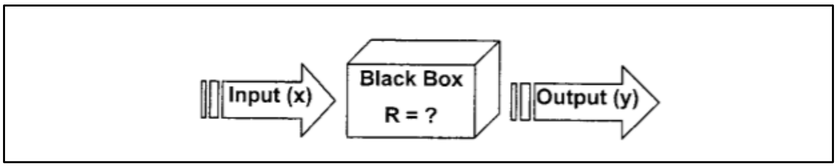
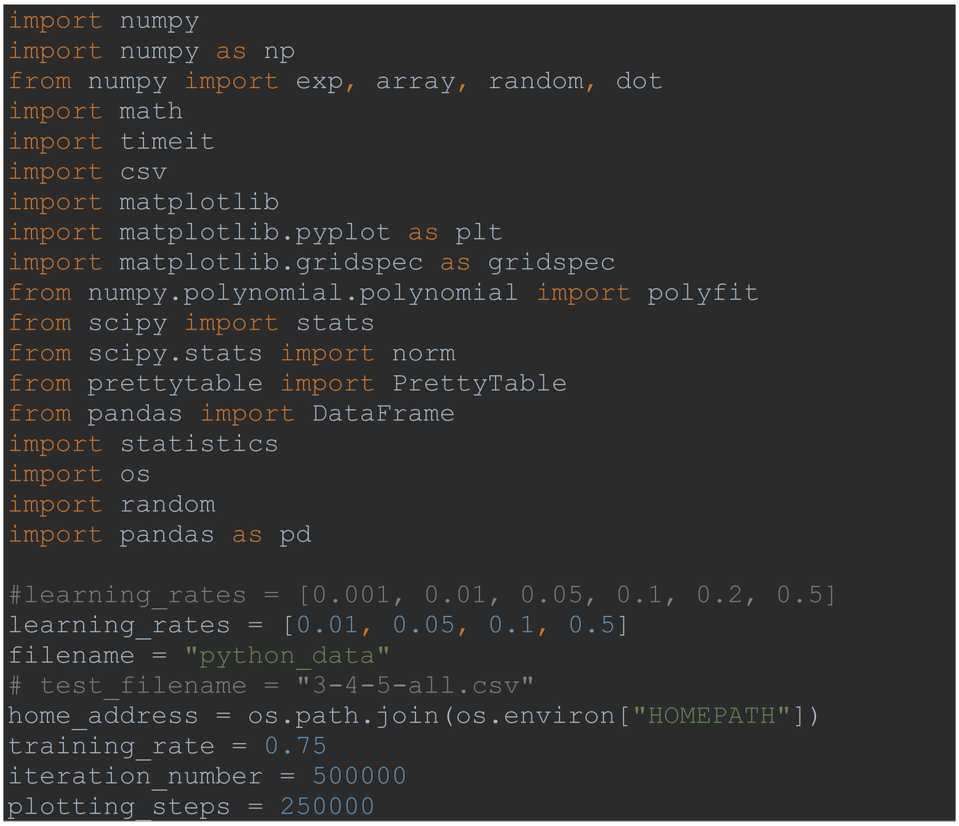


Figure 3.8 A black box is a system for which we don’t know the internal rules but only the observed input and output [50].

A mechanical engineering student collected the parameters we used during this work (MEHMET FURKAN ÖZBEY) supervised his research by Assist. Prof. Dr. Cihan Turhan.

The data included a date, PMV, air velocity, AMV, CLO, OT, O_2 concentration, T_i, T_o, RH_i, RH_o, MRT, HBExC rate (W/m^2), T_{cloth}, T_{skin}, Exhalation and Sweat, Warm Radiant (out), Warm convection (out), Cool radiant(in), Breath air (in). We worked on 133 parameters. Our model will use the sigmoid function because it has a threshold value from zero to one as there can be. Back propagation will be used to optimize the random outcomes. In other words, the entire input-to-output process is fed forward. two outputs, either zero or one. The code that we used during our work was written and generated by Asst. Prof. Dr. Bahram Lotfi Sadigh and Asst. Prof. Dr. Cihan Turhan [52]. However, the writer of this thesis re-arranged the code for the human body exergy consumption case.



```python
import numpy
import numpy as np
from numpy import exp, array, random, dot
import math
import timeit
import csv
import matplotlib
import matplotlib.pyplot as plt
import matplotlib.gridspec as gridspec
from numpy.polynomial.polynomial import polyfit
from scipy import stats
from scipy.stats import norm
from prettytable import PrettyTable
from pandas import DataFrame
import statistics
import os
import random
import pandas as pd

#learning_rates = [0.001, 0.01, 0.05, 0.1, 0.2, 0.5]
learning_rates = [0.01, 0.05, 0.1, 0.5]
filename = "python_data"
# test_filename = "3-4-5-all.csv"
home_address = os.path.join(os.environ["HOMEPATH"])
training_rate = 0.75
iteration_number = 500000
plotting_steps = 250000
```

Figure 3.9 Part of the Python code that was used in this thesis.

We used 75% of data as training, 5% of the data as cross-validation and 20% as run after alternated some parts of the code to get the code to generate the best result that makes the human body comfortable and increases its efficiency throw out all the time that he is in the building.

The model's learning rate determines adaptation time. Given the minor changes made to each update's weights, lesser learning rates necessitate more training epochs, whereas more excellent learning rates necessitate fewer training phases. The learning rates used in the Python codding were [0.01, 0.05, 0.1, 0.5].

Iteration is a method of separating a block of instructions in a computer program for a set number of repeats. It is claimed that that set of statements is iterated; a computer scientist may refer to that block of statements as iteration. In the study, iteration numbers were changed between every 250000 steps, and in total, we used 500000 iteration numbers.

CHAPTER 4

RESULTS AND DISCUSSIONS

Four input parameters, namely, OT, T_O, RH_I, and T_{SKIN}, were used to develop an ANN model for the existing educational facility. As a result of this experiment, the HBExC of the occupant was calculated as an output in Atilim University, Ankara, Turkey's Engineering Faculty, and was compiled the data from a single office. In total, 133 data were included in the ANN model, with 99 being used for training and cross-validation and the remaining 34 being used for testing. We applied iteration number of 500000 iteration we got results shown in the table 4.1. The model used feed-forward back propagation algorithm variation Levenberg–Marquardt (LM), and no bias terms were used. HBExC performance values were determined using a variety of network architectures that had double, triple, and quadrilateral hidden layers and different numbers of neurons in the hidden layers. Table 4.1 shows the best learning algorithm and the number of neurons best suited for the HBExC. After we obtained our results, we applied a cross validation to the optimal output data. Cross validation is defined as the ability to test predictive models by splitting the original data set into two groups: one group to train the model, and the other group to check how well it works. We applied a 10-fold cross-validation; the original data is split into 10 equal-sized parts. One of the 10 subsamples is kept for testing the model, and the other 10 subsamples are used as training data. In the next step, the cross-validation procedure is iterated 10 times (the folds), with each of the 10 subsamples being used only once as validation data. In the next step, the 10 results from the folds can be averaged (or combined) to get a single figure. All observations are used for both training and validation, but only one observation is used for validation at a time. This method is better because each observation is used only once for validation [52].

Table 4.1 Statistical data obtained using different structures for the HBExC of buildings.

Learning algorithm	**Number of Neurons**	**Training sets**			**Testing sets**			**Duration time**
		MSE	R^2	MAPE	MSE	R^2	MAPE	
LM	4-4-1	0.011762755	0.845	1.924031879	0.116349435	0.381	2.81	31.9283932
LM	4-8-1	0.010089931	0.916	2.208851456	0.033207978	0.434	3.45	36.1543896
LM	4-4-4-1	0.003827658	0.95	1.296917249	0.081769826	0.562	3.82	49.3512709
LM	4-4-8-1	0.002467435	0.967	1.152742296	0.142610619	0.566	4.35	55.9145949
LM	**4-8-8-1**	**0.00284281**	**0.974**	**0.936817408**	**0.006689363**	**0.917**	**1.98**	**59.2813826**
LM	4-8-4-1	0.00328765	0.972	1.030794477	0.081402866	0.615	4.84	53.0982768

It is not easy to fully avoid overfitting, an occurrence in which increasing the complexity of a model (or adding more parameters) results in fitting noise fluctuations in the training data that are useless for predicting new data. There are, even so, several established techniques for minimizing overfitting. In our research, we used a technique called 10-fold cross validation. Cross validation will allow the development of a model that performs well on both unseen and training data. We performed a cross validation on the best value in Table 4.1 and obtained the result shown in Table 4.2.

Table 5.2 Statistical data obtained using different structures for the HBExC of buildings 10-fold cross validation results.

Validation Results Sets	**Number of Neurons**	**Training sets**			**Testing sets**			**Duration time**
		MSE	R^2	MAPE	MSE	R^2	MAPE	
1	4-8-8-1	0.002562	0.978	0.944546	0.035548	0.411	2.50	59.1289511
2	4-8-8-2	0.001461	0.986	0.809179	0.038809	0.574	2.82	58.9040087
3	4-8-8-3	0.002767	0.976	1.019303	0.026398	0.528	2.69	58.8072948
4	4-8-8-4	0.003217	0.954	0.976447	0.173185	0.654	4.07	154.3303238
5	4-8-8-5	0.003078	0.973	1.057809	0.032047	0.581	3.03	187.027281
6	4-8-8-6	0.001292	0.988	0.830466	0.027262	0.683	2.85	57.1010792
7	4-8-8-7	0.002435	0.98	0.892419	0.047843	0.751	3.78	57.9774599
8	4-8-8-8	0.002722	0.977	1.014458	0.027001	0.752	2.77	57.9961656
9	4-8-8-9	0.002335	0.98	0.890449	0.115326	0.725	5.07	57.0331372
10	4-8-8-10	0.003111	0.972	0.915203	0.03228	0.787	2.81	59.4376027

For example, as shown in table 4.1, the first case that started working on consisted of one hidden layer. The neurons number was 4-4-1 with a learning rate between (0.01-0.5). Therefore, we can get the maximum R^2 = 38%, the lowest MSE of $1.1163\text{x}10^{-5}$, and the MAPE of 2.81 with duration number 31.92.

The difference between the predicted and actual values of the dependent variable is shown in Figure 4.1 to illustrate how accurate the model's predictions are. For a well-fitting model, a good model will suggest that the average residual value should be zero and the points should be distributed symmetrically across the horizontal axis, which is not the case in this figure. While figure 4.2 illustrates the optimal relationship between the x- and y-axis coordinates of the data points plotted on the graph as a scatter plot. A line graph representing the ideal relationship between the x- and y-axis coordinates of the data points plotted on the graph. The best fit line is shown in figure 4.2 by reducing the distances between the data points and the intended line. Figure 4.3 explains the histogram is a graph whish shows the frequency distributions. It should be a bell shape distributed around the zero for an optimal case.

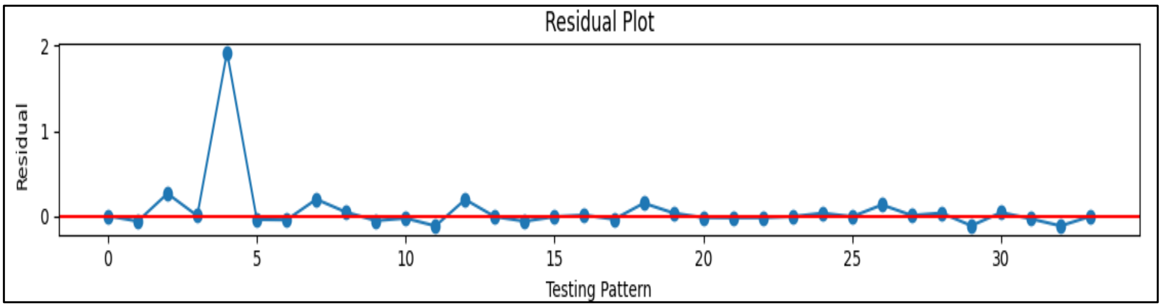


Figure 4.1 Test results and their comparisons for 4-4-1 model with the simulated values.

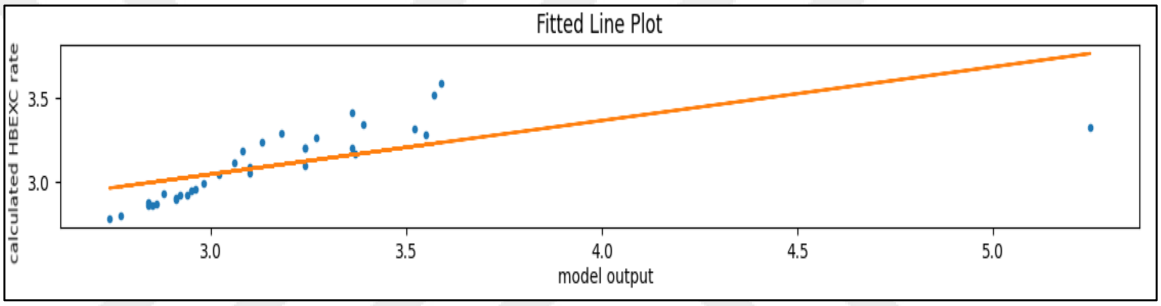


Figure 4.2 The statistical evaluation of ANN and simulation results for the testing for 4-4-1 model.

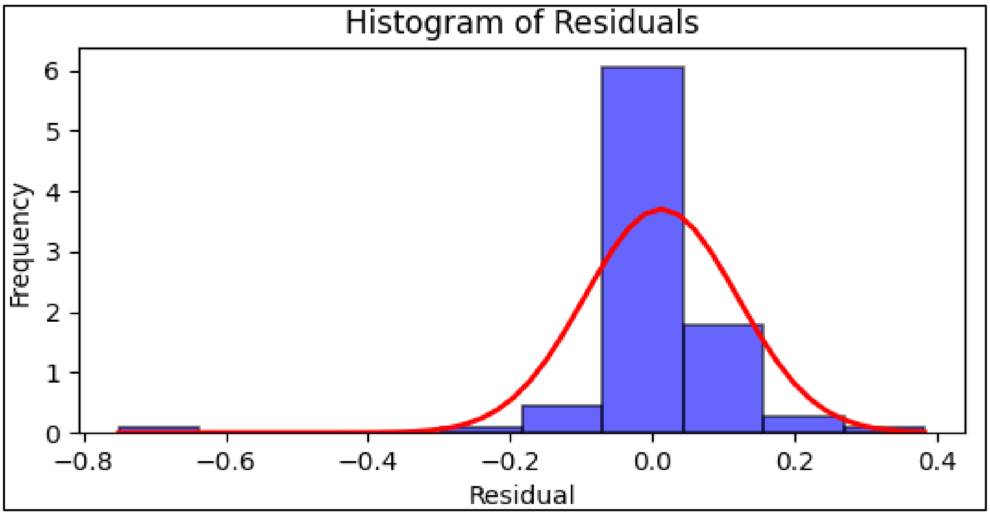


Figure 4.3 The histogram of residuals of ANN for the training set for 4-4-1 model.

In the same case the neurons number was 4-8-1 with learning rates between (0.01-0.5); we can get the maximum R^2 = 43% and the lowest MSE of 3. $32x10^{-5}$ and MAPE of 3.45 with duration time 36.15.

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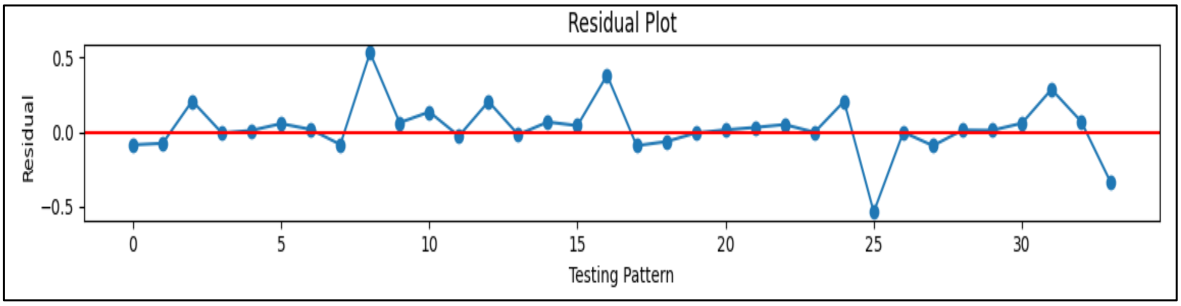

Figure 4.4 Test results and comparisons for 4-8-1 model with the simulated values.

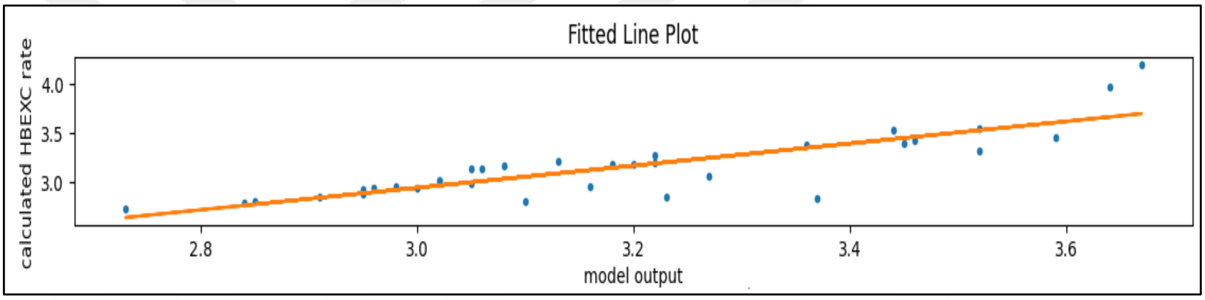

Figure 4.5. The statistical evaluation of ANN and simulation results for the testing for 4-8-1 model.

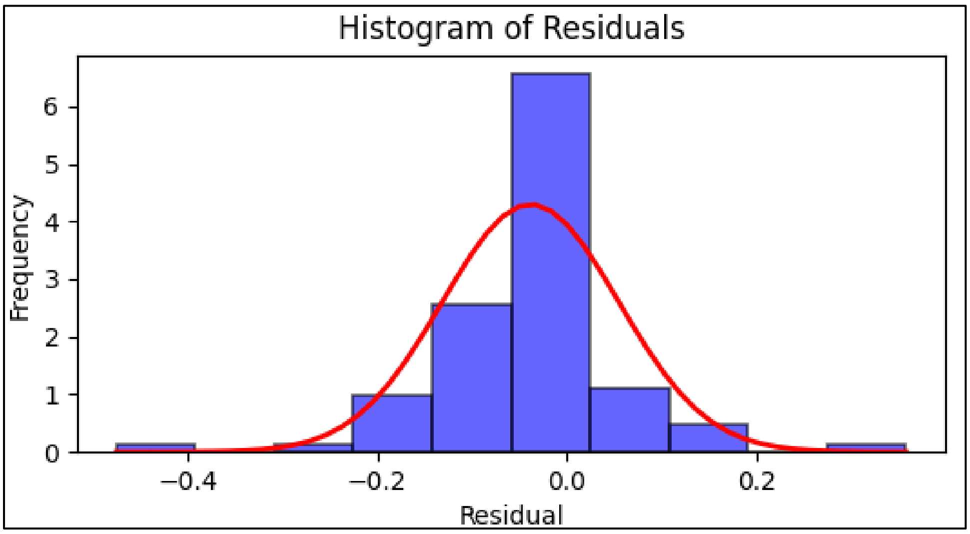

Figure 4.6 The histogram of residuals of ANN for the training set for 4-8-1 model .

In the second case, we used two hidden layers neurons number 4-4-4-1, with learning rate from (0.01-0.5) we can get the maximum R^2 = 56.2% and the lowest MSE of 8.17×10^{-5} and MAPE 3.82 with duration time 49.35.

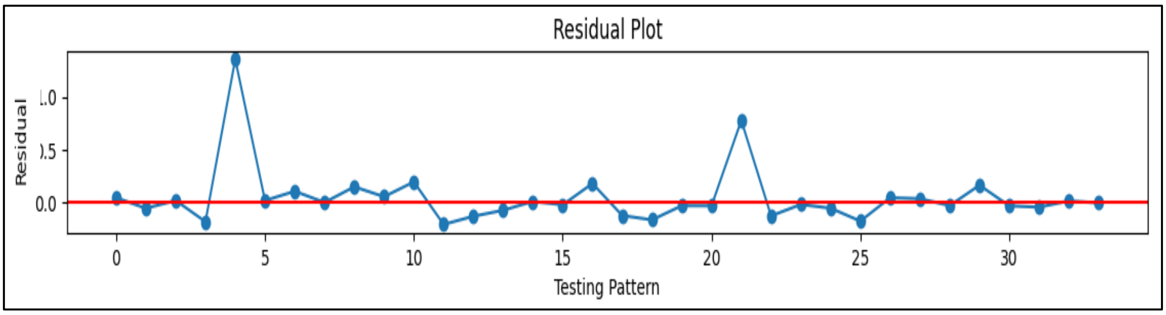

Figure 4.7 Test results and their comparisons for 4-4-4-1 model with the simulated values.

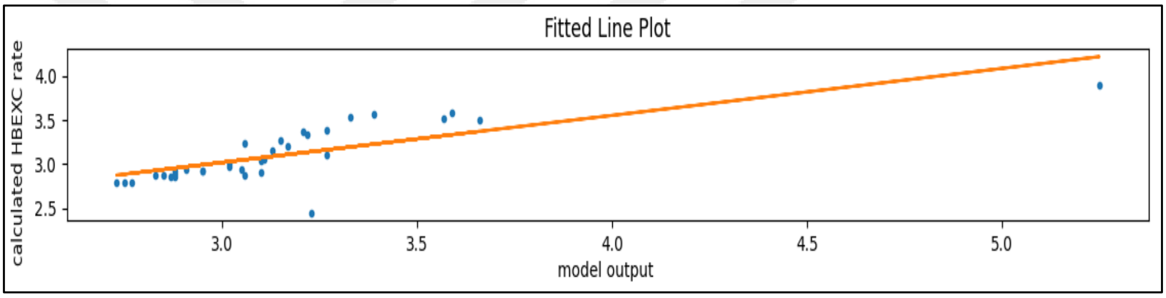

Figure 4.8 The statistical evaluation of ANN and simulation results for the testing for 4-4-4-1 model.

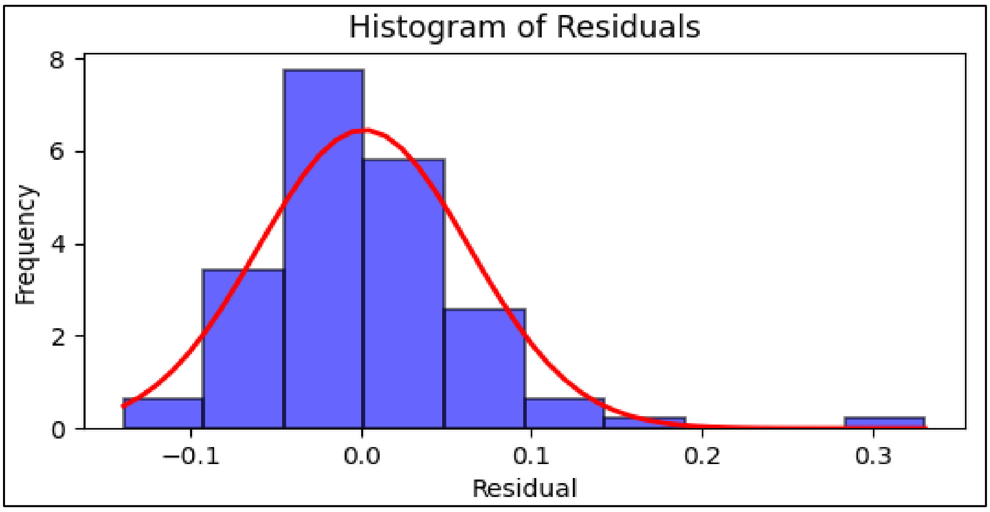

Figure 4.9 The histogram of residuals of ANN for the training set for 4-4-4-1 model.

To illustrate the R^2 value close to 1, two hidden layers were used, and the number of neurons 4-4-8-1 the learning rate from (0.01-0.5) we can get the maximum R^2 = 56.6% and the lowest MSE 1.426.17x10^{-4} and MAPE 4.35 with duration time 55.91.

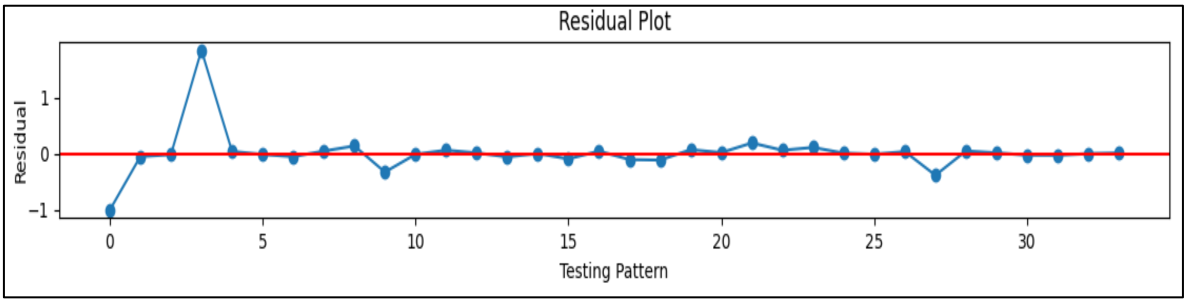

Figure 4.10 Test results and their comparisons for 4-4-8-1 model with the simulated values.

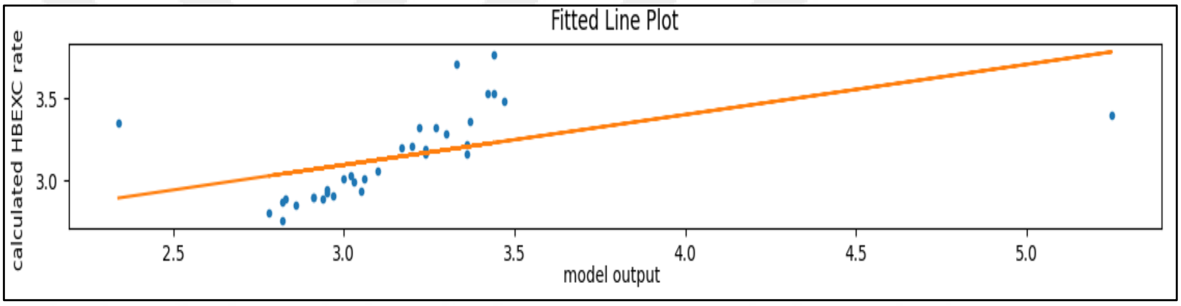

Figure 4.11 The statistical evaluation of ANN and simulation results for the testing for 4-4-8-1 model.

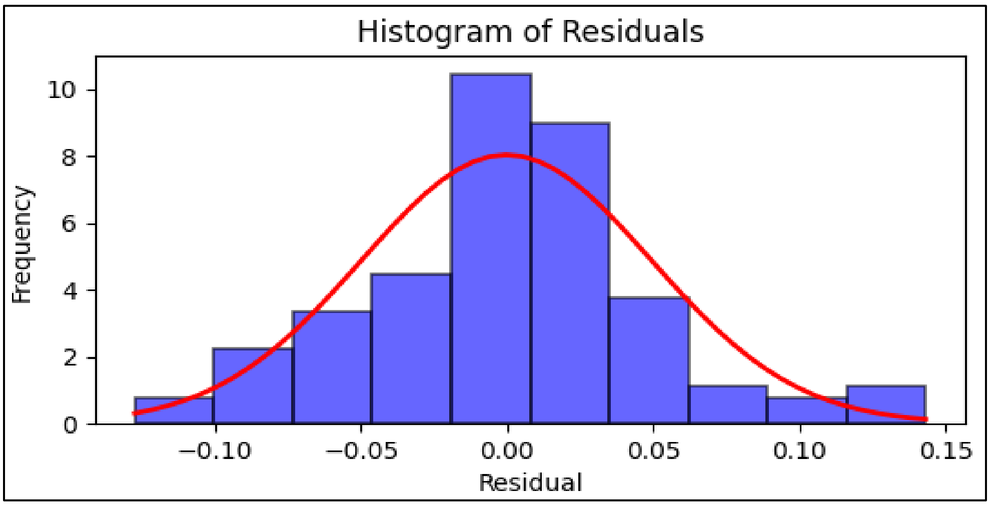

Figure 4.12 The histogram of residuals of ANN for the training set for 4-4-8-1 model.

In the similar position, we start with neurons number 4-8-4-1 learning rate from (0.01-0.5) we got the maximum R^2= 61% and lowest MSE=8.14x10^{-5} and MAPE 4.84 with duration time 53.09.

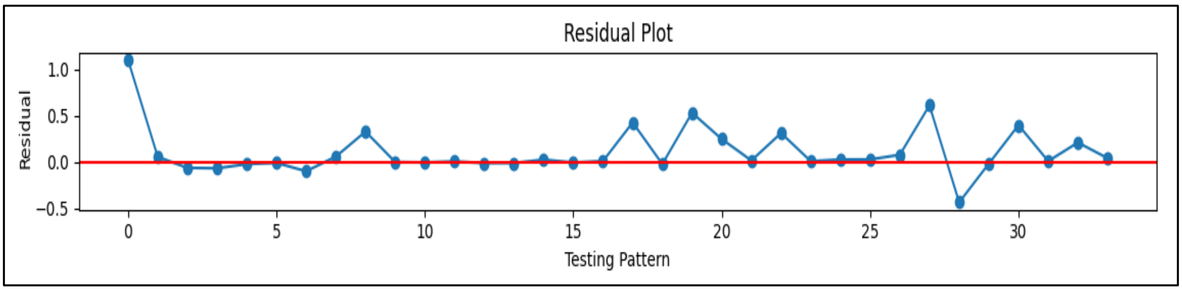

Figure 4.13 Test results and their comparisons for 4-8-4-1model with the simulated values.

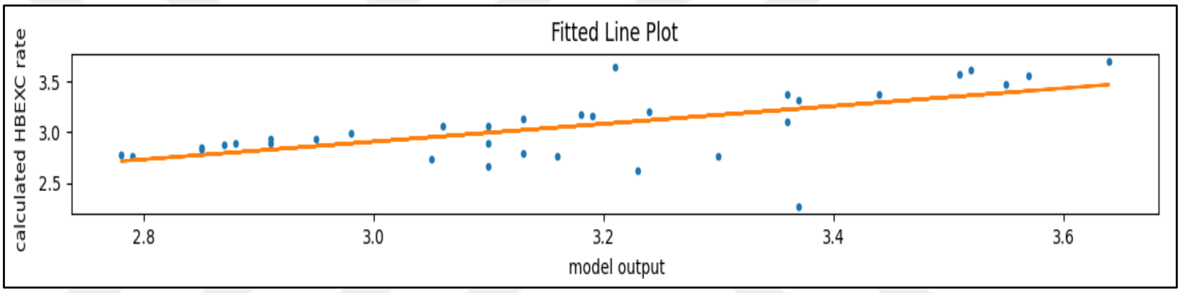

Figure 4.14 The statistical evaluation of ANN and simulation results for the testing for 4-8-4-1 model.

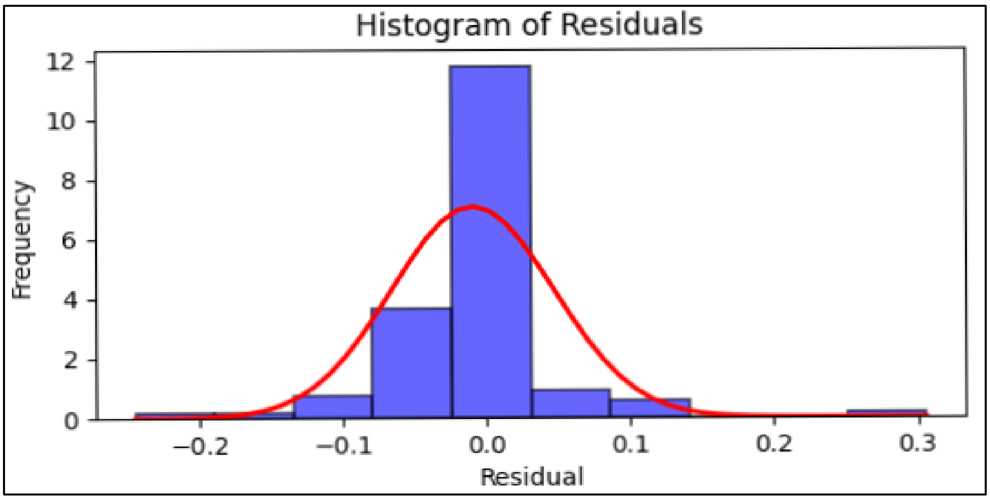

Figure 4.15 The histogram of residuals of ANN for the training set for 4-8-4-1 model.

Also, in the third case, three hidden layers were used, and neurons number 4-8-8-1 learning rates from (0.01-0.5) we can get the maximum R^2 = 91% and lowest MSE $6.6x10^{-5}$ and MAPE 1.98 with duration time 59.2.

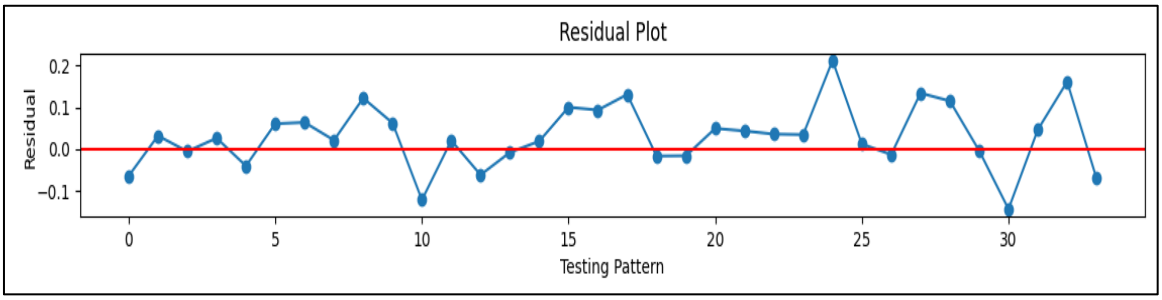

Figure 4.16 Test results and their comparisons for 4-8-8-1 model with the simulated values.

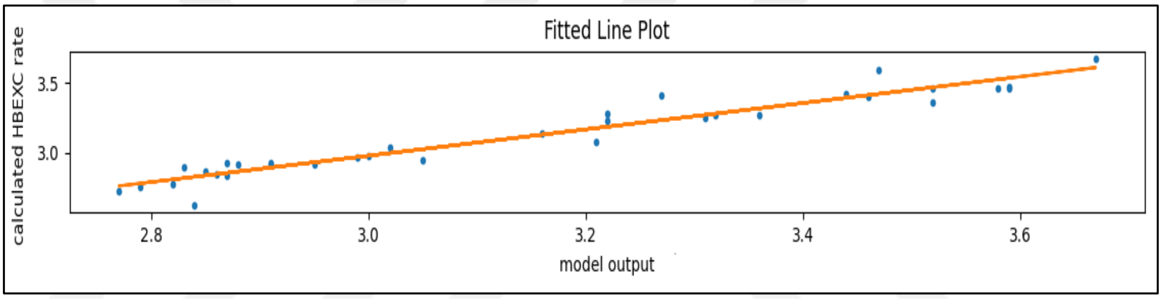

Figure 4.17 The statistical evaluation of ANN and simulation results for the testing for 4-8-8-1 model.

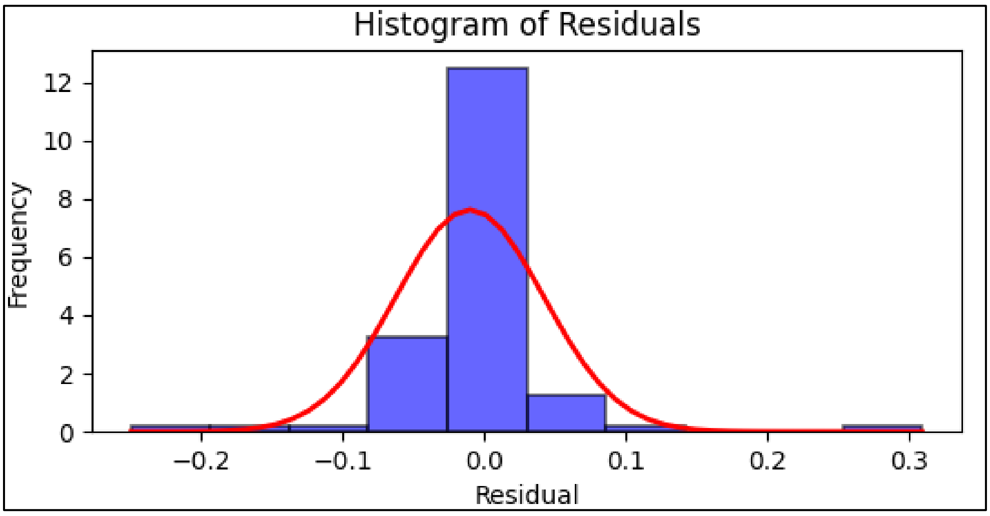

Figure 4.18 The histogram of residuals of ANN for the training set for 4-8-8-1 model.

CHAPTER 5

CONCLUSIONS

The research aims to develop an ANN model that can accurately forecast how much exergy a human body uses each day. Atilim University in Ankara, Turkey, a single classroom provided the models' input data using Python software; various input variables were supplied into the model. 99 samples were used for training for the ANN model, and another 34 were used for testing. We applied iteration number of 500000 iteration. The values were determined using a variety of network architectures that had double, triple, and quadrilateral hidden layers and different numbers of neurons in the hidden layers. The LM learning algorithm produced excellent results with five and ten neurons in four hidden layers. With an R^2 of 91.7 %, the ANN model successfully estimated the HBExC of the structures. Then a 10-fold cross validation was applied to the optimal result so that each data point was tested and the runtime is decreased because we repeated the process only ten times when k equals ten.

The output data was obtained during the work was proven to be the best outcome for human body comfort. The study showed that humans had their highest efficiency (in terms of thermal comfort) inside the building during these conditions, which requirement was calculated with the device installed in the room, as we explained in the previous chapters.

According to the study's conclusions, researchers should be aware of the potential for errors in their calculations and assumptions. To accurately predict human body energy consumption in indoor situations, architects, engineers, and researchers can use the findings of this study.

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