A PREDICTION MODEL FOR DAYLIGHTING ILLUMINANCE FOR OFFICE BUILDINGS

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ABSTRACT

A PREDICTION MODEL FOR DAYLIGHTING ILLUMINANCE FOR OFFICE BUILDINGS

Daylight is a primary light source for the office buildings where a comfortable and an efficient working environment should be provided mostly during day time. Evidence that daylight is desirable can be found in research as well as in observations of human behavior and the arrangement of office space. A prediction model was then developed to determine daylight illuminance for the office buildings by using Artificial Neural Networks (ANNs). A field study was performed to collect illuminance data for four months in the subject building of the Faculty of Architecture in İzmir Institute of technology. The study then involved the weather data obtained from the local Weather Station and building parameters from the architectural drawings. A three-layer ANNs model of feed-forward type was constructed by utilizing these parameters. Input variables were date, hour, outdoor temperature, solar radiation, humidity, UV Index, UV dose, distance to windows, number of windows, orientation of rooms, floor identification, room dimensions and point identification. Illuminance was used as the output variable. The first 80 of the data sets were used for training and the remaining 20 for testing the model. Microsoft Excel Solver used simplex optimization method for the optimal weights. Results showed that the prediction power of the model was almost 97.8%. Thus the model was successful within the sample measurements. NeuroSolutions Software performed the sensitivity analysis of the model. On the top of daylight consideration, this model can supply beneficial inputs in designing stage and in daylighting performance assessment of buildings by making predictions and comparisons. Investigation about this subject can be able to support the office buildings' having intended daylighting comfort conditions.

ÖZET

OFİS BİNALARINDA GÜNIŞIĞI AYDINLIK DEĞERLERİ İÇİN BİR TAHMİN MODELİ

Günışığı, çoğunlukla gündüz konforlu ve verimli çalışma ortamı sağlanması gereken ofis binaları için temel ışık kaynağıdır. Günışığının istenilmesinin kanıtı araştırmayla birlikte insan davranışı ve ofis mekanının düzenlenmesinin gözleminde bulunabilir. Bu yüzden Yapay Sinir Ağları'nı (YSA) kullanarak ofis binaları için günışığı aydınlık değerlerini belirleyen bir tahmin modeli geliştirilmiştir. İzmir Yüksek Teknoloji Enstitüsü'nde Mimarlık Fakültesi'nin konu olan binasında aydınlık verisi toplamak için dört ay boyunca bir saha çalışması gerçekleştirilmiştir. Bu çalışma daha sonra yerel hava durumu istasyonundan elde edilen hava durumu verileri ve binanın parametreleri ile ilişkilendirilmiştir. Bu parametrelerden yararlanılarak ileri-besleme türünde üç katmanlı YSA modeli kurulmuştur. Girdi verileri; tarih, saat, dış sıcaklık, güneş radyasyonu (ışınımı), nem, UV indeksi, UV dozu, pencerelere uzaklık, pencere sayısı, odaların yönelimi, kat tanımı, oda boyutları ve nokta tanımıdır. Aydınlık ise çıktı verisi olarak kullanılmıştır. Veri takımının ilk 80 tanesi modeli eğitmek için, kalan 20 tanesi de modeli denemek için kullanılmıştır. En uygun yükler için Microsoft Excel Solver (çözücü) tek yönlü (basit) optimizasyon (eniyileme) yöntemini kullanmıştır. Sonuçlar modelin tahmin gücünün hemen hemen % 97.8 olduğunu göstermiştir. Böylece model örnek ölçümler dahilinde başarılı olmuştur. Modelin hassaslık analizi NeuroSolutions yazılımı yardımıyla gerçekleştirilmiştir. Bu model günışığının önemi konusunda, tasarım aşamasında ve binaların günışığı veriminin değerlendirilmesinde tahminler ve karşılaştırmalar yaparak yararlı girdiler sağlayabilir. Bu konudaki araştırma, ofis binalarının istenilen günışığı konfor koşullarına sahip olmasını destekleyebilir.

To My Beloved Family

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LIST OF ABBREVIATIONS

ANNs - Artificial Neural Networks

ANSI - American National Standards

AS - American System

cd - candela

CIBSE - Chartered Institution of Building Services Engineers

CIE - Commission Internationale De L'Eclairage
International Commission on Illumination
Internationale Beleuchtungs Kommission

cp - candlepower

DOE - The US Department of Energy

fc - footcandle

IEA - International Energy Agency

IESNA - Illuminating Engineering Society of North America

IPE - Illuminance Percentage Error

İYTE - İzmir Institute of Technology

lm - lumen

lx – lux

NN – Neural Network

PVB - Poly Vinyl Butyral

RF - reflectance factor

SI - System International

UV - Ultraviolet

WHO - World Health Organization

ZEB - Zero Energy Buildings

CHAPTER 1

INTRODUCTION

In this chapter is presented first, the initial idea and framework of the study. Arguments are explained in relation to previous studies who worked on similar subjects. Objectives are mentioned as primary and secondary objectives. The procedure of the study is explained in the next part, and finally the contents of the study were briefly explained under disposition.

1.1. Argument

Daylight is the primary source of light (Fontoynont 2002, Ruck 2006). The use of daylight is one of the most important factors to be taken into consideration for building design (Li, et al. 2006). It has an important role in office buildings which are mostly used in day time. The main purpose of office lighting is to provide a comfortable and an efficient working environment.

Appropriate daylighting supported (supplemented) by artificial lighting systems satisfies the visual and psychological comfort conditions. In that case, its presence enhances human visual response, increases motivation and leads to high user performance and worker productivity (Manav 2007, Fontoynont 2002). In addition, properly designed daylighting reduces energy consumption and balances heating and cooling loads of buildings as well as supports human health and activities (Miyazaki 2005, Leslie 2003).

Adequate indoor illuminance is then a basic factor in daylight design and research for buildings. Several daylighting performance research for lighting control systems are based on indoor daylight illuminance and work plane illuminance and daylight design in buildings are based on distribution of daylight levels (Atif and Galasiu 2003, Thanachareonkit, et al. 2005). It is also necessary to estimate the amount of daylight and its distribution inside the buildings in order to evaluate visual comfort and energy efficiency. To design good day-lit buildings, several design tools have been offered, i.e., guidelines, manual calculation formula, computer software programs and models to determine the illuminance of daylight at certain points (Leslie 2003). Since a large variety of daylighting design have been applied over the years, prediction and determination of illuminance levels are necessary as a key stage in daylight design process as well as in daylighting performance assessment of buildings.

Daylighting predictions effect mostly in designing stage. Predicting the illumination level has been done in different ways. The most specific ones can be classified in three groups; model studies, analytical formulas and computer simulations (Egan 1983, Moore 1993, Lechner 2001, Park and Athienitis 2003). Scale models still represent a standard method for the assessment of the daylighting performance of buildings in spite of the capability of computer modeling for daylighting design (Thanachareonkit, et al. 2005). Although there are some disadvantages of the scale model technique which are the high cost of the model and the labor and adequate time to construct and test it (Moore 1993), designers still benefit from scale model method both to predict and evaluate the appearance of interior and to measure illuminance. Another disadvantage is to find accurate equipment and either to wait for suitable weather for outdoor testing or requiring artificial sky simulator (Lechner 2001). Since physical models require close matches of both geometry and building details, certain guidelines should be followed. All building surfaces must be constructed with correct reflectance. All window details including glazing transmittance should be applied as much as possible. The scale and measurement locations should be chosen correctly. All unwanted light penetration should be avoided (Littlefair 2002, Baker 1993). However, several studies showed that discrepancies would occur between buildings and their scale models related to these guidelines mentioned above. As a result of this, the physical model overvalued the daylighting performance of the building (Thanachareonkit, et al. 2005). This example declares a doubt about how the models are reliable.

Analytical formula is another method, even a traditional one, used to estimate daylight in buildings. Serra (1998) mentions that calculations provide designers with knowledge of interior conditions in relation to exterior ones.

Due to the variation in sky conditions, daylight factor which is expressed as the ratio of interior horizontal illuminance to exterior horizontal illuminance is a very known and simple calculation formula. Such parameters included in the side lighting calculation are window dimensions, distance from window wall, glass area and wall reflectance. Others for top lighting calculation are such as sky factors, coefficient of utilization, glass area and floor area (Moore 1993). Lumen method, on the other hand, offered by the Illuminating Engineering Society of North America (IESNA) includes a detailed calculation process with the inclusion of sky contributed and ground contributed coefficient of utilizations (Rea 2000). Detailed information, calculation examples and related studies are available in literature (Egan 2002, Moore 1993, Rea 2000).

Computer lighting simulations, on the other hand, have been commonly used for illuminance calculations and interior visualization. Such programs are Radiance, Superlite, Adeline, Beem, LightCAD, Luxicon and Lumen Micro (Littlefair 2002, IEA 2000). Although a high number of computer-based tools have been applied for daylighting design and studies, they vary according to two basic illuminance calculation methods which are radiosity and ray-tracing techniques. Radiosity algorithm based on modeling simple surfaces including perfectly diffused elements. While ray-tracing technique dealt with complex surfaces with specular reflections (IEA 2000). Designers can match right systems of lighting together with also heating-cooling systems to their buildings. But the users still have difficulties to guess the range of errors to be expected when using these programs (Maamari, et al. 2006). There are weaknesses of existing daylighting design software programs by surveying occupants’ satisfaction. Thus, there is a need for more holistic performance indicators and design selection procedures to judge the quality and quantity of daylight in a building (Reinhart and Fitz 2006).

In this study, however, an intelligence method, Artificial Neural Network (ANN) was developed as a tool to predict daylight illuminance in office buildings. This is a recently developed alternative technique in the modeling of several research processes for various fields. For example, ANN has been applied in many engineering fields, such as in the field of mechanical engineering, civil engineering, building science, and construction management. Despite these studies in engineering fields, there wasn’t so many real evidence in literature for ANN models’ recent use in the field of architecture. Thus, this study offered this new methodology in the field of architecture.

In view of the recent research and knowledge, an investigation was constructed for the office building of the Faculty of Architecture in İzmir Institute of Technology (İYTE) to predict daylight illuminance in offices. The illuminance from the sky is not constant, and the variations in daylight can be quite large depending on season, location or latitude, and cloudiness (IEA 2000). Measurements in the field study can provide detailed performance information under real sun and sky conditions. A model which can be capable of producing outputs similar to the real values was evaluated using the data obtained from the field study and the weather data which was supplied from Weather Station in the Department of Mechanical Engineering in Izmir Institute of Technology.

The developed model provides a practical method to predict the illumination levels obtained from daylighting. The model can be used in different buildings by changing the parameters according to new cases. This can be used in the designing stage of the office building and also be used to improve the building's daylighting performance that affects heating, cooling loads and energy savings. Investigation about this subject can support the office buildings' having intended illumination comfort conditions.

1.2. Objectives

Objectives of this study were formulated under the purpose of developing a computer based model that may become a design assist tool to determine illuminance levels and light distributions. There were two main objectives defined; one being the primary and the other being the secondary.

The three primary objectives were:

a. to develop an ANN (Artificial Neural Network) which can be capable of predicting the daylight illuminance in office buildings; and
b. to offer a new methodology as an alternative to the existing illuminance calculation and prediction techniques; and
c. to evoke and awareness among researchers about the utilization of ANN model in daylighting evaluation studies in the field of architecture.

The secondary objectives of the study were:

a. to discover daylighting issues in office buildings;
b. to perform field measurements in order to construct and investigate the performance of the model;

c. to determine building parameters and weather parameters related to daylighting illuminance;
d. to determine each parameter’s effect on daylighting illuminance; and
e. to explore the model’s applicability in architecture.

1.3. Procedure

The thesis has tried to reach a conclusion by evaluating a computer based model under the light of field measurements and the other data used in the model. Prior to doing so the study was carried out five phases:

In the first, a general survey of several daylighting studies was conducted. Physical facilities of the office building and nature of the data were obtained and presented.

In the second, a field study was planned in the office building that belongs to the Faculty of Architecture in Izmir Institute of Technology to measure daylight illumination levels in the rooms by a luxmeter.

In the third, after the survey, the collected data was combined with the weather data obtained from Weather Station in the Department of Mechanical Engineering in Izmir Institute of Technology. All data was recorded and arranged according to each measurement day.

In the fourth, the ANN model was constructed to predict illuminance by utilizing these data as inputs and outputs. An Excel spreadsheet which is described at Hegazy and Ayed’s study (1998) was used in the model construction. A spreadsheet simulation of a three-layer neural network of feed-forward type with one output node was employed to develop this prediction model.

In the fifth, the model was subjected to sensitivity analysis to determine the relationship between the input and output variables. The analysis was carried out by the assistance of the NeuroSolutions Software by NeuroDimensions Inc.

1.4. Disposition

This report is composed of five chapters, of which the first one is the ‘Introduction.’ In this chapter importance of daylighting utilization is covered first and then methods of daylight illumination calculation and prediction are explained briefly. Finally, a computer based model which is developed to predict the daylight illuminance levels in office buildings is proposed as an alternative methodology.

In the second chapter, which is the ‘Literature Survey,’ general aspects of daylighting characteristics and benefits are identified at first hand. Then, design principles of daylighting are clarified. Following this are given the building variables which affect daylighting. In the next part, importance of daylighting in office buildings was emphasized. According to their daylighting design some selected office buildings are presented at the following of this part. Finally modeling techniques for daylighting prediction and evaluation are explained.

In the third chapter which is named ‘Material and Method’, the field study and the ANN model construction is explained. Firstly the case office building is described and the materials for the model construction are clarified. Then the methodology of the data compilation and field study are defined. At the end of this chapter the description of ANN model construction methodology is presented.

In the fourth chapter the results and discussions of the study is displayed. The results of constructed the ANN model are given and sensitivity analysis for the model is mentioned by the assistance of the graphics. At the discussions part accuracy of the results are interpreted.

In the last chapter, namely the ‘Conclusion,’ is presented the concluding remarks of survey and model and wider issues are also discussed.

CHAPTER 2

LITERATURE SURVEY

In this chapter, a survey of literature about daylighting that comprises its definition and use in architecture is presented. Characteristics and benefits of daylighting are then clarified. Following sections include its design principles, general concepts and key building variables. Selected examples express several daylighting designs for office buildings. They are represented by photographs and figures. This chapter concludes with modeling for daylighting evaluation methods which include scale models, computer simulation techniques and analytical formula.

2.1. Definition of Daylighting

Daylight is the primary source of light (Fontoynont 2002). That’s why it is today a topic of growing interest to designers and building owners worldwide (Ruck 2006). If daylighting is designed correctly, dynamic interiors to support human health and activities may be configured and energy demand may be reduced. On the other hand if it is done incorrectly vision may be obstructed, extensive energy may be consumed or this high energy may cause uncomfortable environment (Leslie 2003).

Daylighting is dynamic in nature, composed of diffused skylight, reflected light and intense directional sunlight which are always changing in intensity, direction and spectrum as the time and weather change (Leslie 2003). The illuminance from the sky is not constant and the variations in daylight can be quite large. They depend on season, location or latitude, and cloudiness (IEA 2000).

2.2. Characteristics and Benefits of Daylighting

Daylight provides high illuminance and permits excellent color discrimination and color rendering (Leslie 2003). This means that daylight satisfies the condition for good vision (Li, et al. 2006).

Many authors (Fontoynont 2002, Darragh and Miller 2002, Ruck 2006) mention that quality daylighting is a major element of lighting satisfaction. Li et al. (2006) point out that daylight is considered to be the best light source for good color rendering closely matches human visual response.

In a well designed space, Capeluto (2003) states that daylight reduces energy costs, enhances the visual quality, and offers psychological benefits that are hard and expensive to imitate with electrical lighting. Daylighting affects heating and cooling loads of buildings. When lighting controlled is installed in daylighting solar gain and heat gain from artificial lighting may be supplied (Miyazaki, et al. 2005, Li, et al. 2005). Garcia-Hensen et al. (2002) gives an example that solar heating is necessary during winter months for some regions. In such locations, toplight solar passive strategies are applied in spaces without any equator-facing façade to reduce energy consumption in mechanical heating, lighting and ventilating systems.

Atif and Galasiu (2003) clearly indicate that the entire process for good day-lit buildings starts at the design stage. If daylighting is designed correctly, dynamic interiors to support human health and activities can be obtained and energy demand is reduced.

Several research and observations in regard to human behavior and office arrangement give evidence to depict that daylight is desirable. Daylight is also important for its quality, spectral composition, and variability. IEA (2000) analyses of human reactions against their surrounding and suggests that daylight is preferred because it satisfies two basic human requirements. First, people need to see both a task and the space well. Second, people need to experience some environmental stimulation.

In addition, daylighting affects building systems such as mechanical heating and cooling systems and electric circuit systems (Lee and Selkowitz 2006). Li et al. (2006) argue that energy savings from daylighting schemes provide low electric lighting demand. They reduce peak electrical demands, cooling energy consumption and the potential for a smaller heating, ventilation and air conditioning plant. According to these reasons utilization of daylight becomes a design approach which has great energy saving potential. Studies about the use of daylight in building design have a prior role in the field of architecture. For example, field measurements were taken for open plan offices and results showed that by the use of daylight, daily energy savings for electric lighting ranged from 1.1 to 1.7 kWh (Li, et al. 2005). In the view of these studies, the US building sector's energy consumption is expected to increase by 35% between now and 2025. The US Department of Energy's (DOE) Energy Efficiency and Renewable Energy Building Technologies (BT) overall program aims to achieve net ''zero energy buildings'' (ZEB) by 2025. In these buildings the right mix of innovative technologies are combined with proper design, controls integration, and on-site renewable energy supply systems to achieve net zero energy use (Lee and Selkowitz 2006).

2.3. Design Principles of Daylighting

Atif and Galasiu (2003) clearly declare that the entire process for good day-lit buildings starts at the design stage. Several design criterions for daylighting in buildings have been cited in literature. Leslie (2003) states that the typical daylight zone is about 5m deep from the window wall or the top floor of a building with skylights. Most of the floor area used by occupants should be placed in the daylight zone. Spaces in a building may be ranked according to their need for daylight. The building should be planned after this process. Brown and De Kay (2001) also agree on these criteria that activities which need high lighting levels should be placed near the windows while activities which don't need much light should be placed far away from the window line. In addition to this, Leslie (2003) argues that critical visual tasks should be located near the building's perimeter. Another zoning rule is to locate rooms, which require high amount of light, on upper floors. Since more light is available on such areas, especially for buildings in dense urban areas. Spaces where occupants use in short times or rarely use (circulation spaces and resting spaces) however should be placed in such areas where amount of perimeter light accesses low (Brown and De Kay 2001).

Moore (1993) and Leslie (2003) mention that the multistory buildings should be elongated along east-west axis. Such orientation is necessary to maximize north apertures on façade for daylight access and avoid excessive solar heat gain in summer.

Other criterion is related with surface finishing materials (their color and reflectancea). Leslie (2003) and Brown and De Kay (2001) argue that surface color is important since daylight is reflected on that surface. Surfaces which are light-colored reduce the luminance contrast between the windows and surrounding surfaces and increase the amount of light reflected into the space. Lechner (2001) ranks the surfaces according to their importance in the process of lighting reflectance. The descending order is; ceiling, back wall, side walls, floor and small pieces of furniture. Ceiling surfaces are the least important areas to reflect light, while floor surface are the most effective areas where light mostly reflects. Brown and De Kay (2001) show approximate reflectances for these surfaces in Table 2.1 and surface finishing reflectances according to their color in Table 2.2.

Table 2.1. Recommended reflectances for surfaces
(Source: Brown and De Kay 2001)

Surface	Recommended Reflectance (%)
Ceilings	70-80
Walls	40-80
Floors	20-40

Table 2.2. Recommended values for surface finishing reflectances according to color
(Source: Brown and De Kay 2001)

Color	Reflectance (%)
white	80-90
pale yellow & rose	80
pale beige & lilac	70
pale blue & green	70-75
mustard yellow	35
medium brown	25
medium blue & green	20-30
black	10

Windows dimensioning is another design criterion for daylighting. Windows should be placed higher on the wall so that the light may penetrate through the interior space. When it is possible, daylight should be admitted from more than one side of a space. By the assistance of this criteria infirmity may be increased and the brightness within the room may be balanced (Leslie 2003). In addition, Brandi et al. (2001) argue that a number of smaller daylight openings are more favorable than one large opening.

Leslie (2003) states that controlling direct sun light should be controlled in daylighting design. There are several horizontal elements which are used to reflect direct sun. They are called window blinds. Non-specular surfaces also distribute and diffuse the light to the inside.

The layout of furniture and equipments in a room should be carefully arranged. If this type of design criterion is not done properly; the visual environment may become uncomfortable. For example, workstations and computer screens should be located perpendicular to the windows so that visual discomfort and reflected glare is reduced (Leslie 2003).

2.3.1. Concepts of Daylighting

Light is defined as portion of the electromagnetic spectrum. Human eye is visually sensitive to light (Lechner 2001). The source of daylight is skylight. Moore (1993) identifies skylight as diffuse light from the sky dome. It is the result of the refraction and reflection of sunlight as it passes through the atmosphere.

Illuminance is the light energy that arrives at a surface at a certain rate (Lou 1996). Lechner (2001) states that illumination is measured with footcandle meters which are also known as illuminance meters or photometers.

Illuminance is also equal to the number of lumens falling on each square foot of a surface. The unit of illumination is the footcandle which can be explained in the following form:

$$\text{Footcandles} = \frac{\text{Lumens}}{\text{Square feet of area}} \quad \text{or} \quad \text{fc} = \frac{lm}{ft^2} \tag{2.1}$$

Lou (1996) expresses luminous intensity as the amount of light emitted by the source, travelling in a given direction. Intensity of illumination is measured using the unit candela (cd) which has replaced the older term candlepower (cp).

In lighting terminology, both the System International (SI) and the American System (AS) use lumen as the unit of luminous flux and candela as the unit of luminous intensity. Lux is the SI unit for illumination and is approximately equal to one-tenth of a footcandle or 1 footcandle is equal to approximately 10 lux. And also the power with which light is emitted from a light source is also measured in lumens (Lechner 2001). These comparison of AS and SI lighting units are shown in Table 2.3.

Table 2.3. Comparison of American Standard (AS) and System International (SI) lighting units (Source: Lechner 2001)

Property	(AS)	(SI)	Conversion Factor
Supply of light	Lumen (lm)	Lumen (lm)	
Illuminance	Footcandle (fc)	Lux (lx)	1fc ≈ $^{1}_{1}$10 lx*
Luminous intensity (candlepower)	Candela (cd)	Candela (cd)	
Luminance	cd / ft^2	cd / m^2	1 cd / ft2 = 0.09 cd / m^2

*The approximation of 10 lux per footcandle is more than sufficient for most purposes (actually 1 fc = 10.764 lux)

Lechner (2001) compares the brightness and luminance as follow. The brightness of an object refers to the perception of a human observer. On the other hand the object’s luminance refers to the objective measurement of a light meter. In addition to this, Lou (1996) states that the reflected light which appears on a surface as seen by the eye is luminance.

Light falling on an object can be transmitted, absorbed, or reflected. The reflectance factor (RF) indicates how much of the light falling on a surface is reflected. The transmittance factor describes the amount of light that is transmitted as compared to the incident light (Lechner 2001). In addition to these Moore (1993) describes daylight penetration as the distance into the room that daylight reaches along the task plane at a predetermined illuminance level.

Lou (1996) points out that the effects of light are not always comfortable for human vision. If an extreme amount reflects off a smooth surface and is angled directly toward the eye, the abusive quality of glare is produced. Lechner (2001) argues and adds that glare can be called ‘‘visual noise’’ that interferes with visual performance.

There exist other concepts in daylighting about angles. Each location on the earth has a sun position dependent on hour and season because the earth rotates around the sun and around its own axis. The sun position is defined by solar altitude and solar azimuth (Figure 2.1, Figure 2.2). Solar altitude is defined as the angle between the centre of the sun and the horizon, according to latitude, season and hour. Solar azimuth is the horizontal angle between the reference direction North and the vertical circle through the centre of the sun (0^o–260^o), again according to latitude, season and hour (Daniels 2003).

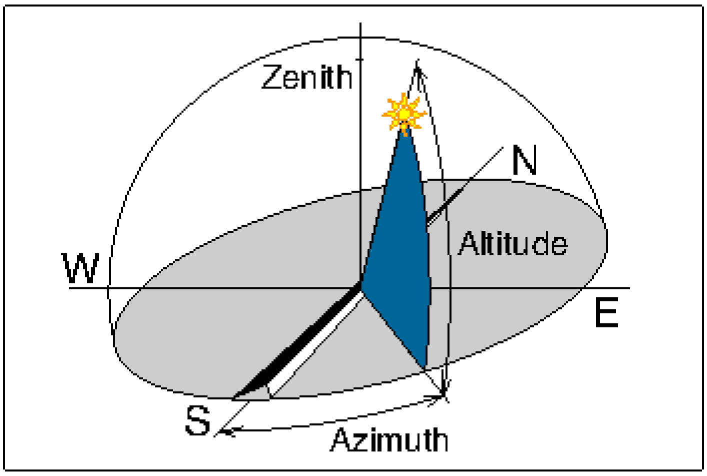


Figure 2.1. Diagram of solar azimuth and solar altitude angles

(Source: LEARN, London Metropolitan University 2008)

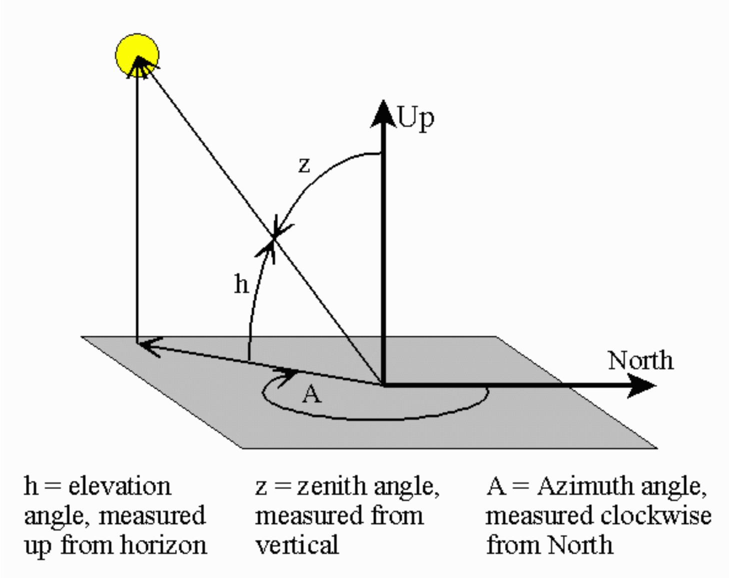


Figure 2.2. Drawing of zenith angle and azimuth angle

(Source: National Oceanic & Atmospheric Administration 2008)

The daylight factor is a concept of daylighting which is used for calculation. Lechner (2001) states that the ratio of the indoor illumination to outdoor illumination on an overcast day is called daylight factor. This is an indication for the effectiveness of a design in to bring daylight indoors is called daylight factor.

2.3.2. Shape and Layout of Building

The shape (form) of the building determines how much the floor area will have access to daylighting (Lechner 2001). As generally supposed to be in multistory buildings a 15-foot perimeter zone can be fully daylit and another 15 feet beyond that can be partially daylit.

In Figure 2.3, 16 percent of the square plan building is not daylit, 33 percent is only daylit partially and at the other 51 percent of the plan there is a full daylight zone (Lechner 2001).

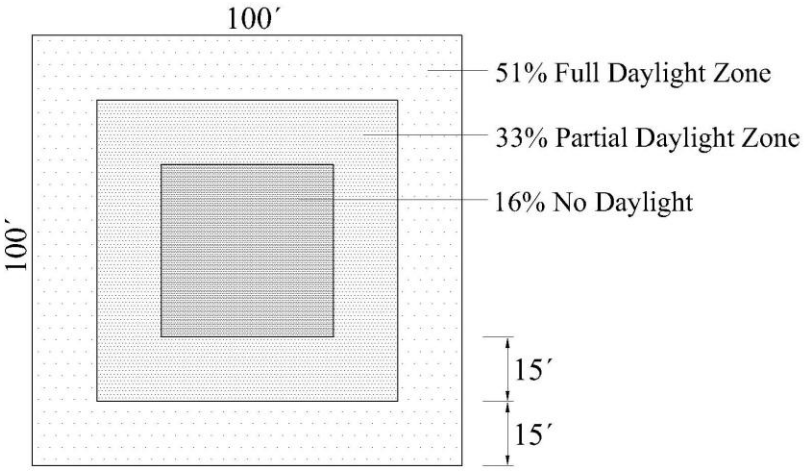


Figure 2.3. The square plan multistory building
(Source: Lechner 2001)

The rectangular plan multistory building in Figure 2.4 there is 41 percent which is partially daylit and 59 percent of the plan is fully daylight. This plan type can eliminate core area which receives no daylight, while there is still a large area that is only partially daylit (Lechner 2001). In the building plan in the Figure 2.5 there is an atrium at the center which is able to have all of the adjacent area daylit (Lechner 2001).

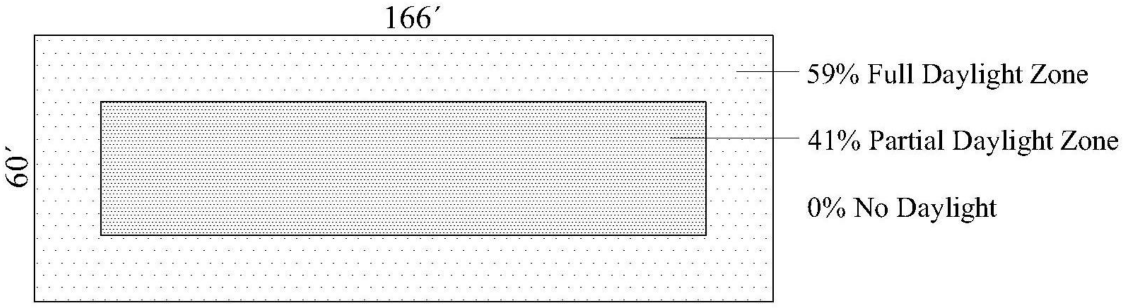


Figure 2.4. The rectangular plan multistory building
(Source: Lechner 2001)

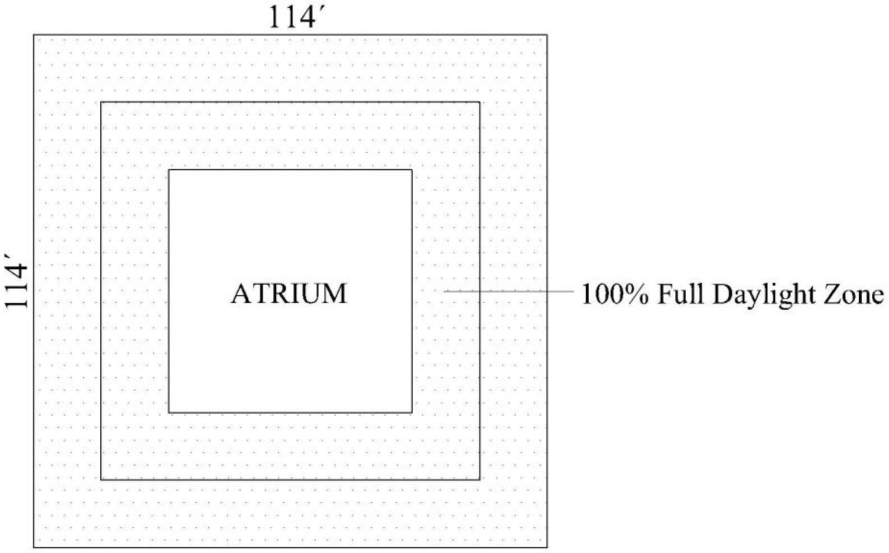


Figure 2.5. The square plan multistory building with atrium
(Source: Lechner 2001)

Serra (1998) expresses that the shape and proportions of a building are determinants for the collection of natural light. They depend on the location of the opening. As a rule, irregular or elongated spaces with light entering at the end have a rather irregular light distribution.

Lechner (2001) states that open space planning is very advantageous for the light penetration to the interior. There may be glass partitions which supply acoustical privacy without blocking the light in such places.

2.3.3. Type of Building

Constraints on different building types over the years have affected typical building shapes and their design schemes over the years to serve their standard use. One of them is the availability of daylight. Several floor organizations have been developed to respond several building requirements. As an example, various ways of organizing space in office buildings is shown at the bottom of Figure 2.6. There is a cellular design and an open plan design that demands different daylighting strategies. A conventional window however may be adequate to distribute daylight to a shallow office room. Thus more complex design strategies may be necessary to bring daylight into deep (IEA 2000).

There are some examples of the churches are shown in top row of the Figure 2.6. First one is Pantheon which has a circular plan and a portico of three ranks of huge columns. There is a dome as a floor to cover the building. The dome has a central opening called the Great Eye which opens to the sky. The second plan belongs to the Roman Hall Church. It has rectangular plan and vertical openings on the side walls for daylight penetration. Third one is a Gothic Basilica. Daylighting is provided by the openings on the side walls. Last one of these rows is the chapel of Notre Dame du Haut in Ronchamp. It has thick walls with the upturned roof which is supported on columns embedded within the walls. The lighting of interior space is supplied by the clerestory windows and wall openings.

The middle row of the Figure 2.6 presents some schools. First school in this row has rectangular planning. It has a linear atrium lying through the plan of the building. The second school is in Hamburg. It has a cross-like plan with an atrium in the middle of the building. The plan of the third school is in such a form that resembles to a nucleus. In this type of planning daylight penetration into the building interior may be increased. The last drawing of this figure shows a school which has a courtyard. The interior spaces of this building can use daylighting not only coming from the side walls (that are placed at the perimeter of the building), but they also utilize the light reaching to the courtyard.

The bottom row of Figure 2.6 shows various ways of organizing space in office buildings. There is a cellular plan in the first column of the row. In this plan type rooms of the office use the daylight coming from the side walls. Natural light gathered in the room can only be used by that room’s occupants. On the other hand in open plan office shown next to this example, daylight can also reach to deeper sides of the interior space. In the following plan the offices are grouped. This plan increases the sides of the building which utilize more daylight. Combination offices are planned in the last drawing of this row. The right side wall of the building is composed of glass to increase daylight penetration.

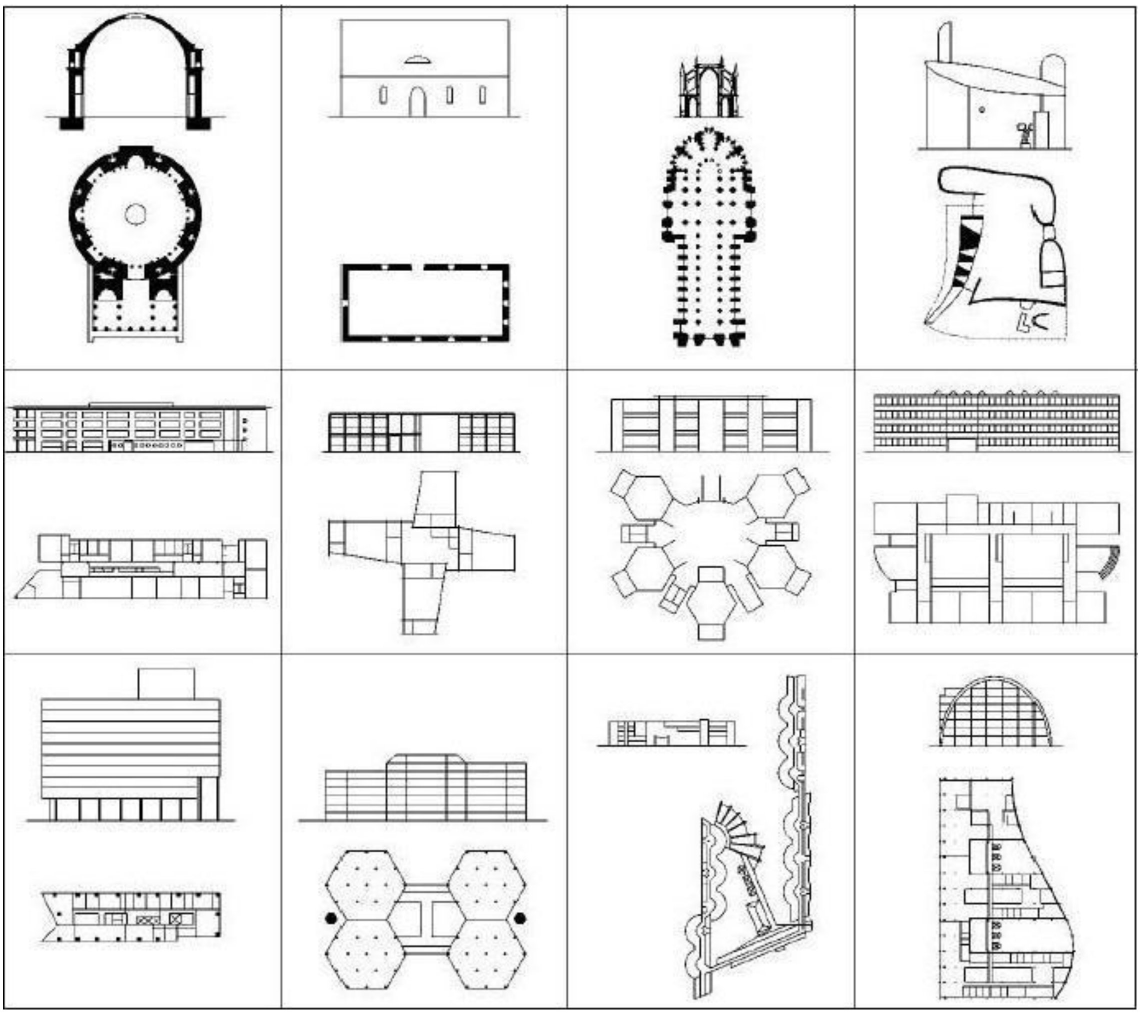


Figure 2.6. Daylighting design schemes for various building types

(Source: IEA 2000)

2.4. Key Building Variables Affecting Daylighting

The performance of a daylighting strategy for rooms depends on certain situations. IEA (2000) expresses this under three titles which are daylight availability on the building envelope, physical and geometrical properties of window(s) and physical and geometrical properties of the space. In building design there are several variables which effect daylight design. These are building area and orientation, glass type, shading and optical systems, windows dimensioning, external obstruction and climatic conditions.

2.4.1. Building Area and Orientation

Building daylight availability is supported by some variables. One of these variables is orientation. Phillips (2000) states that orientation has a direct effect in daylighting design. The optimum natural lighting solution for the building’s function is achieved by setting the building on its site and its relationship to the sun.

IEA (2000) states that each orientation will require different design strategies. In addition to this, Lechner (2001) recommends that south-facing glazing should be used when winter solar heat is desirable. While north-facing glazing is used when winter heat is not desirable. On the other hand the designer should avoid east and west glazing in order to eliminate summer overheating or severe glare.

Moore (1993) expresses that in small buildings energy performance is controlled by the building envelope so daylighting becomes less important. In order to design such buildings properly, southern exposure for passive solar heat gain must be balanced against minimizing perimeter area to reduce heat loss. This differs in large buildings because of greater internal loads. Heat loss is less important, but the need for exposure to relatively uniform lighting levels predominates. Moore (1993) indicates that southern and northern exposures are commonly the most desirable ones so east and west exposures may be minimized while both east and west orientations afford only half-day exposure to sunlight.

Phillips (2004) clarifies that each architectural program (an office, school, church, etc.) has its own specific needs for orientation. The function of buildings specifies orientation requirements. It is essential that the building orientation and the interior layout take most advantage of the daylight available. Phillips (2004) explains an example about residential buildings in northern hemisphere. The sun rises in the east and sets in the west. In these buildings the rooms (kitchen, morning room or even bedrooms) which may benefit from mostly early morning light should be placed on the east side. On the other hand the rooms (living room) which are usually used in the afternoon or evening should be faced south or west.

2.4.2. Glass Type

The transparency of daylighting systems is a major issue since a primary function of windows is to provide occupants' view to the outside (IEA 2000). There may be a combination of glass and daylighting systems for utilizing natural light. Daylighting systems can provide solar shading, glare control, and the redirection of light. In addition to these, they can increase the amount of daylight penetrated in rooms and decrease cooling loads. There are different types of glasses which are used for in windows and openings. These are categorized as follow.

Clear glazings are single sheet, double or triple glazed or alternatively a 'thick' glass. The thickness of the glass decreases the daylight penetrating through inside. Clear glass however allows high transmission of daylight while it but also allows high transmission of solar radiation (Phillips 2004).

Tinted glass is produced in two ways. The first one is to modify clear glass which can produce different radiant heat transmission characteristics. The second way is to coat glass with microscopically thin layers of metallic oxides. These coatings reflect the heat away (Phillips 2004).

Patterned glass is the semi-molten glass. This technique is used to diffuse sheets for various purposes, however it is rarely used for windows because their capacity for light transmission is modified (Phillips 2004).

Boccaccini (2007) expresses that wired glass which is the oldest type of safety glass has a metallic mesh combined into plate glass. Phillips (2004) explains that it is made by sandwiching a wire mesh within the thickness of the glass. This glass type is generally used for security (Phillips 2004). Boccaccini (2007) points out that recently it is primarily used due to its fire resistance ability.

Laminated glasses are composed of laminated sheets of plastic between sheets of glass (Phillips 2004). Aguilar (2005) mentions that the most common polymeric interlayer is plasticized poly vinyl butyral (PVB). It absorbs mechanical energy which is the impact of projectiles. By this way shattering of glass is get under control (Aguilar 2005). Ivanov (2006) describes the PVB-material as a rubber like elastomer. When a crash happens, it keeps the pieces of broken glass plates within the frame of the glass unit. According to Phillips (2004), laminating method reduces the transmission of daylight. These glasses are used for security purpose and for spaces where there is a need to control the access of ultraviolet (UV) lights. Aguilar (2005) states that laminated glasses also reduce noise and supply thermal insulation. When it is compared with clear sheet glass it has another advantage. It blocks the UV radiation. As a result laminated glass avoids damages caused by UV radiation on human skin (Aguilar 2005).

Glass blocks are used to get daylight into the buildings. The walls made of glass blocks have thermal characteristics due to hollow nature of the blocks. Special openings will be required to provide a view (Phillips 2004).

High-tech glazing contains a number of glazing types. One of them is the photovoltaics. This type of glass is designed to generate electricity from solar radiation and then it may be used in the building to reduce the energy required for the artificial lighting. The photochromic glasses respond directly to an environmental stimulus (temperature or light). They resemble to the special sunglasses which alter their transmission factor depending upon the brightness of the ambient light (Phillips 2004). Alternatively one of the specific topics in daylighting is electrochromic glazing (Lee, et al. 2006). The electrochromic glasses designed to respond indirectly by the application of an electrical current which alters their visual and thermal characteristics (Phillips 2004). This type of glass can adjust the transmission of radiation over a wide range without changing the distribution of daylight (IEA 2000). Zinzi (2006) supports this definition that electrochromic windows act as active components which can modulate the solar light flux input in order to gain energy saving. For near-term products Lee and Tavil (2007) state that switchable electrochromic windows work depending on a nanometer-thick switchable coating on glass to reversibly change tint. They also provide a better visual environment and a sensible cut of glare problem.

2.4.3. Shading and Optical Systems

The function of a system to protect from glare inevitably affects the view to the outside on account of sun shading and the redirection of daylight (IEA 2000). The construction material of a daylighting system may not necessarily be transparent itself in order to provide a view through outside; the subjective impression of visual contact to the outside is most important. Kischkoweit-Lopin (2002) further argues that the primary subject of shading system design is to block direct sun and admit diffuse light. Several shading systems have been developed to increase the use of daylight.

Kischkoweit-Lopin (2002) categorizes these systems into two groups which are explained below as:

a) Shading systems which use diffuse skylight block direct sunlight but they are transparent for diffuse skylight.

b) Shading systems which use direct sunlight diffuse sunlight or redirect sunlight onto the ceiling or above eye height.

The optical systems are defined as the daylighting systems without shading. Kischkoweit- Lopin (2002) points out that these systems have been designed to redirect daylight to areas further from the window or skylight primarily. They may or may not block direct sunlight.

These various systems are used to benefit from daylight. The system and building however should be matched correctly not to cause overheating or glare problems (Kischkoweit-Lopin 2002). A complete daylighting system involves a variety of architectural elements which are used to capture and control natural light, if that control could effectively and reliably displace electric lighting usage in a building consequently, this day-lit building could save energy (Sabry and Faggal 2005). In addition to this, Ochoa and Capeluto (2006) point out that integral glazing/shading systems help to achieve improved overall energy performance and enhanced lighting levels which have visually comfortable uniformity. Uncontrolled penetration of solar radiation can increase the thermal loads during summer by producing an extra load to air-conditioning systems.

2.4.4. Windows Dimensioning

The window is determined as an opening in a wall or side of a building (Phillips 2004). It allows light and air in the interior. The window design determines the distribution of daylight to a space because daylighting is one of the main functions of windows (IEA 2000).

Daylight which enters through from the window openings provides light to let pass to the interior and connects the outside to the inside (Li, et al. 2006). The authors (IEA, 2000) support this argument that glazed areas are an interface between exterior and interior. According to Mueller (2005) the façade of the building has to provide a high quality performance in order to create a high quality illumination. It is an important issue for visual tasks and biological (circadian) effects of the user. Reduction of the electricity consumption for artificial illumination is also a result of this consideration.

Phillips (2004) acknowledges that windows are broadly classified into two main types. First one is the window in the side walls of a building and the second one is the opening into the roof, generally known as rooflights.

Windows involve a number of design considerations. One of them is the size and position of windows, window frames, and other elements of the facade design is considered to be designed in relation to the eye level of building occupants (IEA 2000). IEA (2000) argue and point out that in daylighting design the placement and sizing of windows have a significant role because they have a decisive effect on the potential daylight and thermal performance of adjacent spaces.

Phillips (2004) states that the horizontal window which is placed high in the wall may penetrate daylight well into the space. Lechner (2001) argues and adds that for excellent daylighting the designers may use high windows, clerestories or skylights although they may use low windows to view outside. The mounting height of the window may be increased daylight penetration into an indoor space. In Figure 2.7 Lechner (2001) shows a window of a room which has a normal height. The curve in the figure represents how the daylight penetration in the room changes. When the window is placed in a higher place on the wall like in the Figure 2.8 room may be daylighted much more.

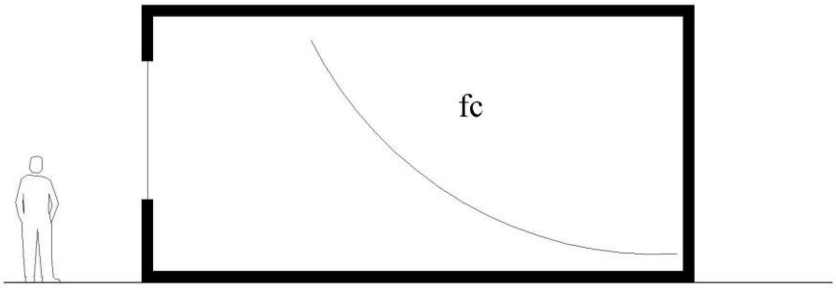


Figure 2.7. Daylight penetration of a normal heighted window in a room
(Source: Lechner 2001)

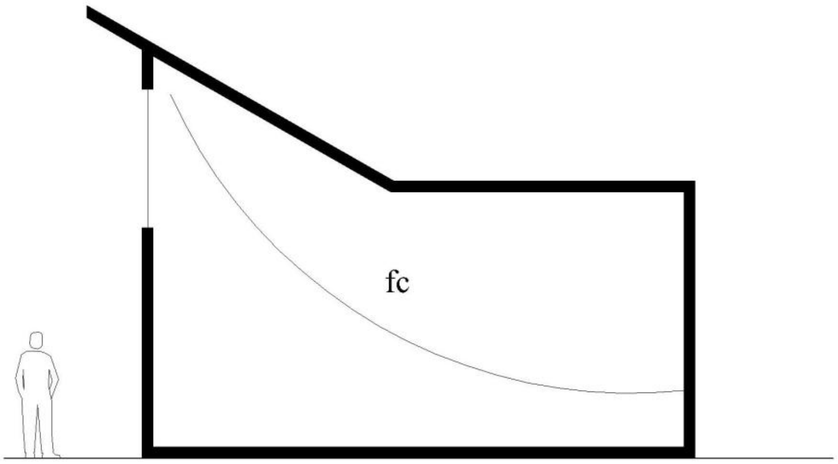


Figure 2.8. Daylight penetration of a high placed window in a room
(Source: Lechner 2001)

The useful depth of the indoor space which is illuminated by daylight is limited to about 1½ times the height of the top of the window (Lechner 2001). In addition to this Egan (1983) points out that illumination levels at the end of the room (with unilateral window opening) opposite the window is reduced as room depth (D) is increased. Illuminance at the end of the rooms changes from high to low while room depths are increased in Figure 2.9.

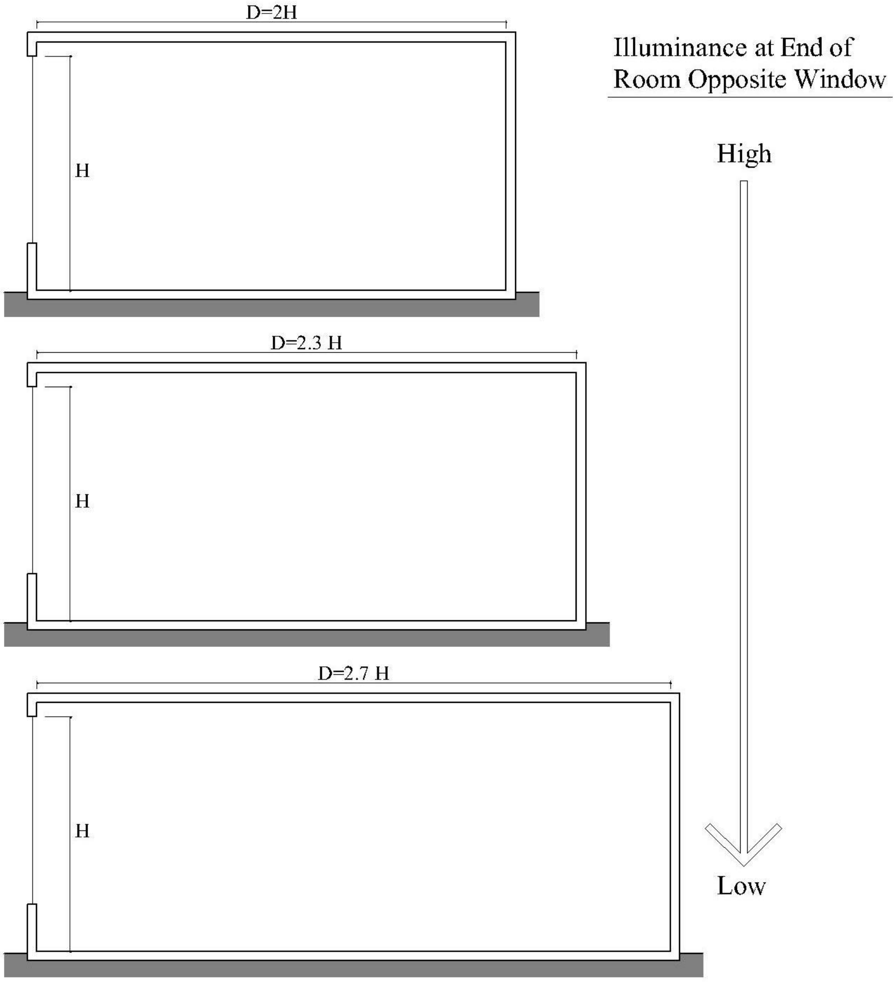


Figure 2.9. Illumination changes according to room depths
(Source: Egan 1983)

Windows are arranged horizontally rather than vertically and if they are spread out rather than concentrated, daylight will be more uniformly distributed in a space. The windows on each wall can illuminate the adjacent wall and by this way the contrast between each window and its surrounding wall may be reduced. As a result of this, the distribution of natural light may be better and glare can be reduced by placing windows on more than one wall. Lechner (2001) presents two illustrations in Figure 2.10 and Figure 2.11 which show how light is distributed in a room. In Figure 2.10 there is an unilateral lighted room which has one window opening. There is a bilateral lighted room which has two window openings in the other figure (Figure 2.11). Lechner (2001) states that light distribution can be improved by admitting daylight from more than one point. Contours of equal illumination in these room plans represent how the distribution of daylight changes.

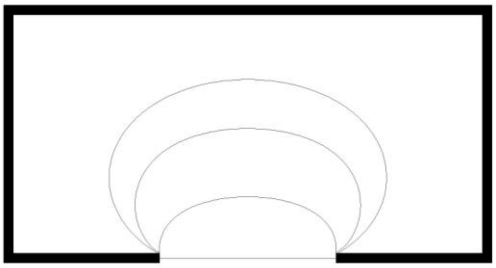


Figure 2.10. Contours of equal illumination in an unilateral lighted room plan
(Source: Lechner 2001)

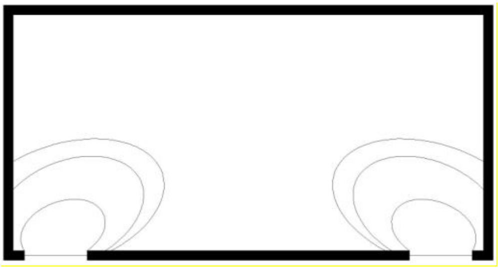


Figure 2.11. Contours of equal illumination in a bilateral lighted room plan
(Source: Lechner 2001)

In summer windows should be shaded from excess sunlight. Overhangs which shade the light before it enters may be used on south windows for seasonal control (Lechner 2001).

There have been also clerestories which are specialized examples of windows (Phillips 2004). They are applied mainly in tall buildings. This situation is highly associated with their existence at high levels. Clerestories are used to get daylight further into the interior and also they assist to light the roof structure.

2.4.5. External Obstruction

IEA (2000) claim that new buildings' obstruction of daylight for existing buildings must be considered by designers in order to select daylighting strategies. Nearby buildings may reduce access of daylight and reflect sunlight which causes glare at the street level. Li et al. (2006) argue with these expressions and point out that the shading effects due to nearby obstructions strongly affect daylighting of the building. In addition to this, the direct sunlight blockage due to nearby buildings may not be as difficult as generally supposed to be. But extreme obstructions can block the performance and effectiveness of a daylighting scheme. The results of Capeluto's study (2003) indicate that in urban sites illuminance levels and daylight distribution on floor height is significantly different because of the nearby buildings. If the designer does not pay special consideration on window size and location, internal partitions and organization these differences occur.

2.4.6. Climatic Conditions

The availability of natural light is determined by the latitude of the building site and the conditions immediately surrounding the building (Ochoa and Capeluto 2006). One of these conditions is climate. Daylighting strategies are also affected by climate. IEA (2000) clarify that the identification of seasonal, prevailing climate conditions, particularly ambient temperatures and sunshine probability, are basic climatic parameters in daylight design.

Brown and De Kay (2001) explain that daylighting conditions may be estimated by plotting the average number of clear, cloudy and partly cloudy days as a percentage of the total days in the month. They classify sky conditions as overcast, clear or partly cloudy. In overcast sky the light is diffuse and relatively even over the sky dome. Egan (1983) explains the overcast sky as the sky which has 100% cloud cover, completely occluding view of the sun. The other types are clear sky has 30% cloud cover and partly cloudy sky which is constantly changing sky in a range from 30 to 70 % cloud cover. In addition Brown and De Kay (2001) point out that the illumination from a clear sky varies with the position of the sun, the season and the amount of water vapor in the atmosphere.

2.5. Daylighting in Office Buildings

The main purpose of office lighting is to provide a comfortable and an efficient working environment. Manav (2007) states that the presence of visual and psychological comfort conditions ensures user well-being and increase motivation. Park and Athienitis (2003) also agree on this subject and add that it will lead to a higher performance and improved productivity as well as reduces adverse environmental impacts. Recent work at the Lighting Research Center claims a physiological mechanism that explains why daylight seems to improve performance. Leslie (2003) reports the experimental work that suppression melatonin (the hormone responsible for regulating the body’s internal clock or circadian rhythm) is influenced by exposure to light levels typical of daylight which are an order of magnitude above normal electric lighting levels in buildings. This effect of daylight is more important in the work places as offices which are used in daytime. The lighting quality in an indoor space also affects comfort, well-being and health of the occupants. Quality daylighting is a major element of lighting satisfaction according to a report published by the National Bureau of Standards (Darrah and Miller 2002).

Building occupants prefer natural light and an outside view. In a well designed space, daylight reduces energy costs, enhances the visual quality and offers psychological benefits which are hard and expensive to imitate with electrical lighting (Capeluto 2003). Leslie (2003) supports the benefit of daylighting about energy costs and further argues that energy is saved by dimming down electric lights which are not needed because of daylight. As a result of saving energy, power plant emission that causes acid rain, air pollution and global warming may also be reduced.

Galasiu and Veitch (2006) refer to Escuyer and Fontoynont who adopted a semi-directed interview method to survey French participants’. It is about preferences toward their working environment, office lighting control system, lighting remote control, and office blinds. A survey reveals that people who are working on computers prefer light levels in a range from 100 to 300 lux. On the other hand people who are working less time on computers, prefer light levels in a range from 300 to 600 lux.

Nicol et al. (2006) made measurements of illuminance on work surfaces in five European countries. They reported in conclusion they found that the mean desktop illuminance is practically independent of the sky-type and it varies little with outdoor illuminance.

2.5.1. Spaces Daylightened in Office Buildings

ANSI (American National Standards) / IESNA (Illuminating Engineering Society of North America) (1993) classifies the office plans in two groups; open plan offices and private offices (cellular plan).

In open plan offices where accommodate workers are in a common space, there can be many different kind of seeing tasks and activities. To determine appropriate illuminances, specific task locations should mainly be identified and luminance contrasts should extensively be considered (ANSI/IESNA 1993).

Private offices are supposed to be relatively small spaces bordered with floor to ceiling partitions in general and each office serves for only one occupant. The control of overhead brightness may be less important in terms of direct and reflected glare than for large spaces.

Office buildings also include public areas. They are generally; entrance and elevator or escalator lobbies, corridors and stairways. Lighting considerations should include safety requirements and luminance differences between adjacent areas because many people move through these areas. Entrance lobbies give first impression in office buildings. There is a safe transition from exterior to the interior which is provided by lighting. Corridors are important transition space where illumination should provide at least one fifth the illuminance level of adjacent areas. The stair treads should be well illuminated (ANSI/IESNA 1993).

Public areas may be designed in the atriums of office buildings. Atrium brings natural light into the core of a building and connect the surrounding spaces with the outside (Calcagni and Paroncini 2004, Littlefair 2002). Littlefair states that the atrium may become the focal point of trade and human activities, increasing the qualitative value of the indoor spaces. There are some design criterions of atrium design. They are; the orientation to the sun, the shape of the atrium, the transmittance of the atrium roof, the reflectivity of the atrium surfaces and the penetration of daylight into adjoining spaces (Calcagni and Paroncini 2004). Lechner (2001) expresses that atriums can be illuminated by skylights, clerestories or window walls. There can also be courtyards for utilizing daylight in office buildings. Moore (1993) identifies the courtyard as an enclosed or semi enclosed outdoor area completely surrounded by a building. In addition to these Table 2.4 represents recommended illumination levels according to type of activities in office buildings.

Table 2.4. Guidelines for illumination levels
(Source: Lechner 2001)

Approximate Type of Activity	Footcandles
1. General lighting throughout space	
a. Public spaces with dark surroundings	3
b. Simple orientation for short, temporary visits	8
c. Working spaces where visual tasks are only occasionally performed	15
2. Illumination on task	
a. Performance of visual tasks of high contrast or large size	30
b. Performance visual tasks of medium contrast or small size	75
c. Performance of visual tasks of low contrast and very small size over a prolonged period	150

‘‘Because of the variability of actual conditions, the final design illumination values will often be 50 percent larger or smaller than these guideline values. Precise values are not appropriate because of the large tolerance of human vision and because the quality of the light determines whether more or less light is required. These values can be reduced by 25 percent if the quality of the lighting is very high and they should be increased 35 percent if the average age is over forty. This table is adapted from IESNA tables for recommended illumination levels’’ (Lechner 2001).

2.6. Selected Studies for Daylighting in Office Buildings

Daylighting is vital for office buildings which are used mostly in day time. Selected examples which express several daylighting designs for office buildings are presented below in this section.

Sukkertoppen is an 18,000 m^2 multimedia centre which was developed through the renovation of an old sugar refinery factory in 1992. It was renovated by Højgaard and Schultz for The Employees' Capital Pension Fund. The centre consists of 84m long new building, 13m deep office building which is located to the south of the old two and three storey brick structure on an east-west axis. There is an atrium which is four storeys high in the centre of the buildings. The main design consideration for the new building is to maintain daylight penetration through the lower floors by designing such central atrium. In order to gain more daylight inside the building the windows faced to the atrium. In addition, the façade of this building is painted white to increase reflected daylight passage into the old building. The Figure 2.12 shows the atrium of the centre which connects the renovated sugar refinery (at the left side) with the new office building (at the right side).

Figure 2.12. The glazed atrium in Sukkertoppen
(Source: Fontoynont 1999)

In the Figure 2.13 a section of the buildings and the atrium are shown. The luminous flux (Klm) and the daylight factor curves in the monitored rooms are shown (‘‘the flux values given for a standard overcast sky providing 10,000 lux’’) (Fontoynont 1999).

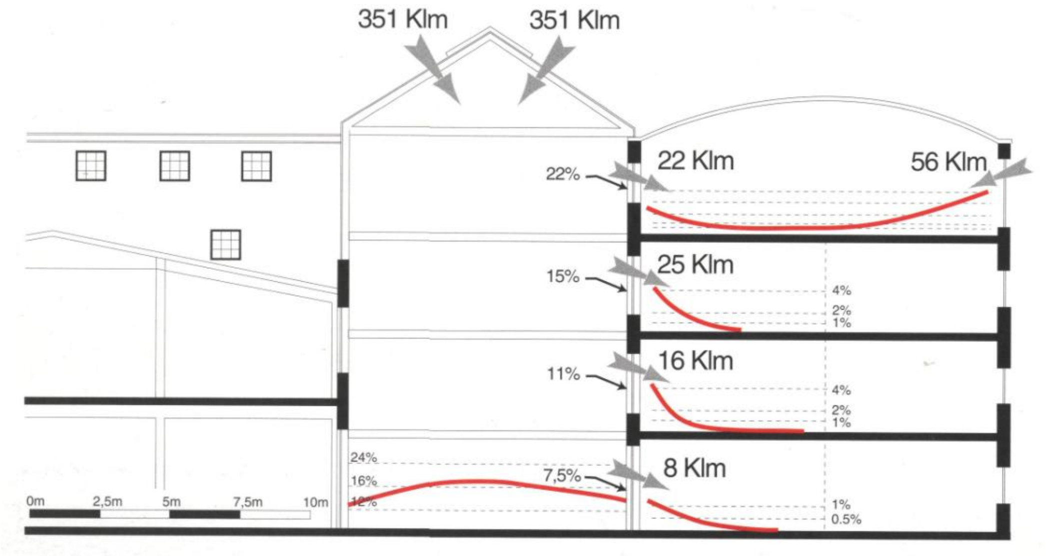


Figure 2.13. The section of the buildings and atrium

(Source: Fontoynont 1999)

Another specific office building is Domino Haus whose total area is 6,800m^2. It is designed by Riehle and Partner and houses an architect’s office, a number of small investments and law firms. The building has four storeys on the north side, while it has three storeys on the south side. There is a central atrium (Figure 2.14) around which the offices are located.

Figure 2.14. Atrium of the Domino Haus

(Sorce: Fontoynont 1999)

In the offices spaces movable partitions are constructed not to obstruct the daylight penetration. It also provides the flexibility in the use of office areas. Such a design concept is a complementary strategy to the atrium concept to increase the amount of light entering deep into the spaces. ‘‘Daylight factor variations on work planes and vertical daylight factors in the atrium and on the roof monitors’’ is shown on the section of the building in the Figure 2.15 (Fontoynont 1999).

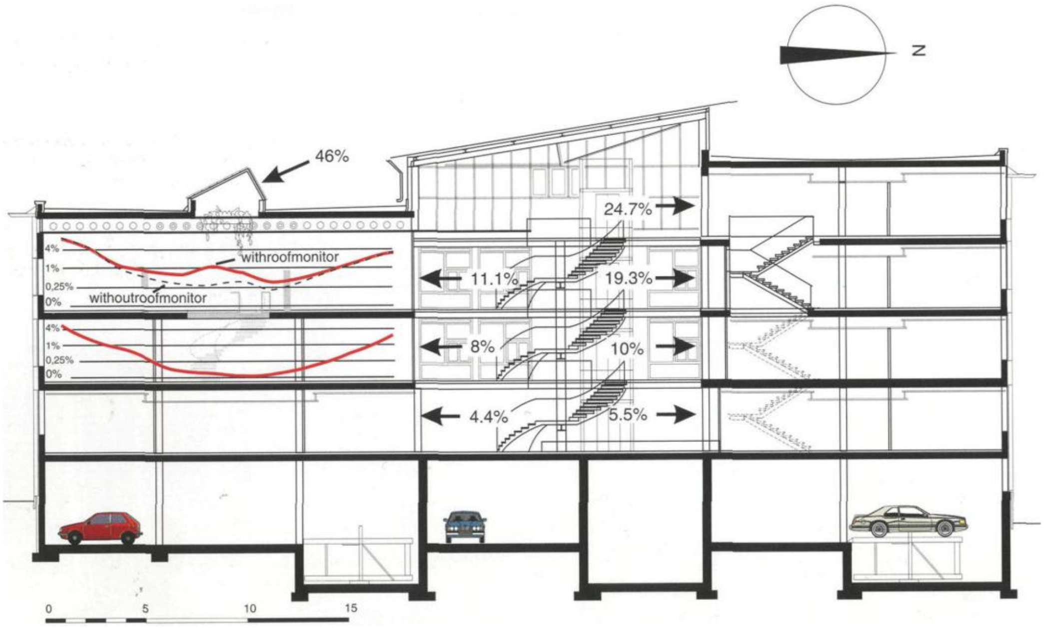


Figure 2.15. Section of the Domino Haus

(Source: Fontoynont 1999)

Three roof monitors are fixed at the centre of the ceiling in the southern building block. The monitors distribute daylight on the upper floor with the advantage of floor opening (Figure 2.15). For example, the red line on the section represents the light level with roof monitor; while the dashed line shows the situation without roof monitor. On the other hand windows on the exterior façade are equipped with external blinds which are used to block the incoming sunlight and to avoid glare problems (Fontoynont 1999).

The old Berlin Reichstag Building was reconstructed by Foster and Partners. The main aim of this new building is to optimize the use of daylight throughout the building. A cupola (dome) which is placed on the roof, located above the plenary chamber is designed to supply natural light and ventilation. At the core of this dome there is a sculpture light sculptor which rises from the top of the chamber and opens out towards the cupola. It is a reflective cone which is ‘‘a concave faceted cone, covered with a battery of 360 angled mirrors which together form a giant lens (a lens that has a surface consisting of a concentric series of simple lens sections) working like a lighthouse in reverse, directing horizontal light down to the chamber’’ (Figure 2.16). There is a movable sun-shield which blocks solar gain and glare during the day (the process is reversed at the night) is associated with the cone. In the Figure 2.17 the relationship of the plenary chamber, with the dome and light sculptor is illustrated (Phillips 2004).

Figure 2.16. Photograph of the light sculpture and the dome (cupola)
(Source: Phillips 2004)

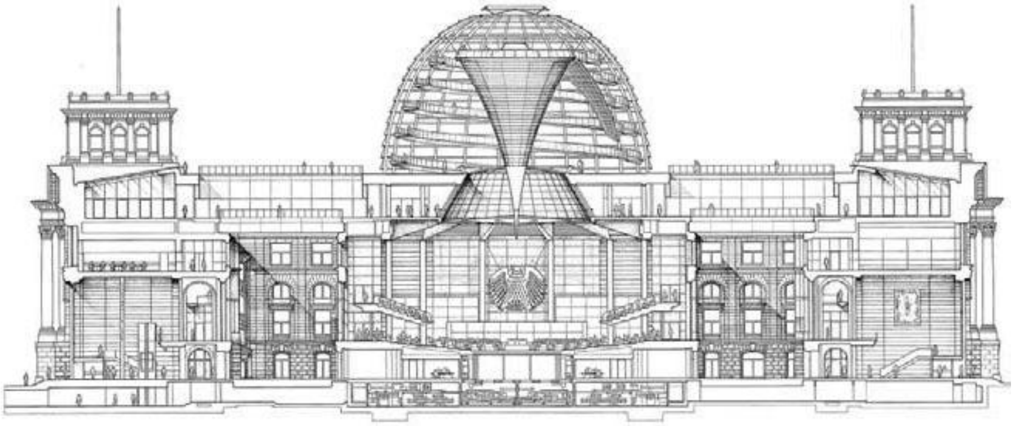


Figure 2.17. Section of the building

(Source: Phillips 2004)

The Arup Campus was built in Solihull by Arup and Partners as an office building for their own use. Its orientation (north-west and south-east) was designed to optimize the use of daylight. The building consists of two parallel pavilions (60m long by 24m deep) which have two storeys. In the building there are mezzanines (clerestory) and floor openings designed for maximizing light penetration to the lower levels. At the exterior of the building protecting roof pods are placed at intervals along the roof line. Daylight penetration to the central areas of the offices is ensured by these pods incorporating skylights. They are shown in the photo in Figure 2.18 and the illustration in Figure 2.19. In Figure 2.20 there is a photograph which shows the daylight penetration to the interior space of one of the office buildings.

Figure 2.18. Arup Campus, office buildings

(Source: Phillips 2004)

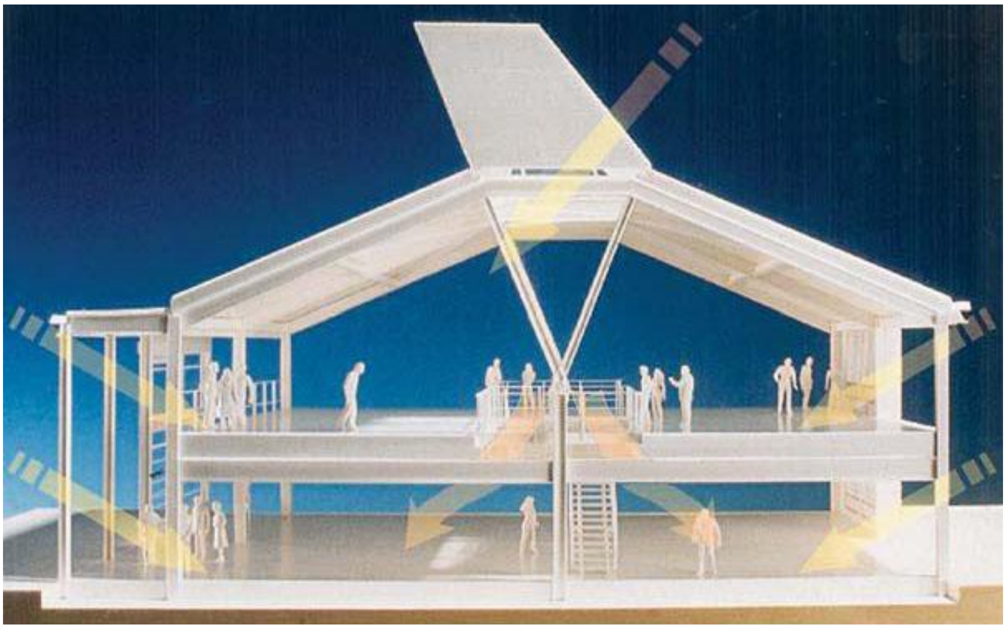


Figure 2.19. Section of the model of an office building

(Source: Phillips 2004)

Figure 2.20. Interior of an office building

(Source: Phillips 2004)

At the north-east and south-west facades the glazings are minimized to avoid glare problems. The occupants at the main elevations are seated close to a window manually operated louvers where personal control may be provided. The louvers which are at south-east façade are shown in Figure 2.21 (Phillips 2004).

Figure 2.21. External hand-operated louvers to the south east elevation
(Source: Phillips 2004)

It is clear in literature that daylighting performance research for lighting control systems based on indoor daylight illuminance and work plane illuminance (Park and Athienitis 2003, Atif and Galasi 2003, Thanachareonkit, et al. 2005) and daylight design in buildings based on distribution of daylight levels (Littlefair 2002). Ruck (2006) states that the investigations and the interest for daylighting is about the indoor environment as well as by international efforts to reduce building energy use. The work of the International Energy Agency (IEA) Task 31 research team was organized into four themes which are namely; user perspectives and requirements, integration and optimization of lighting systems, daylighting design tools and daylight performance tracking network and design support (Ruck 2006). In the article by Leslie (2003) reviews the literature according to daylighting. In the study it is investigated that the design of buildings to use light from the Sun and the reason of daylight utilization for buildings and occupants. The author points out the effects of daylighting on energy consumption of buildings, physiological and biological systems of human beings.

Al-Sallal (2006) investigated the visual environment and the presence of glare inside the studio spaces by an experimental research approach under actual sky using scaled architectural physical models.

In Tzempelikos and Athienitis’s (2006) study they present a simulation-based integrated thermal and daylighting analysis for perimeter office spaces. The study is performed to evaluate ‘‘the impact of façade design alternatives – glazing area and shading properties and control – on the thermal and daylighting performance of office buildings at the early design stage and to provide at this preliminary stage’’. In the study of Saridar and Elkadi (2002) they examine the historical development of façade design according to their daylighting efficiencies. Then they investigate ‘‘the impact of applying recent façade technology on daylighting performance in buildings in eastern Mediterranean.’’ Kıschkoweit-Lopin (2002) presents a research that is an overview of daylighting systems. The author mentions that there have been a huge number of different daylighting systems which allow new and optimized ways of daylighting utilization. The right systems should be chosen to match the requirements of the buildings, otherwise there may some problems such as overheating of rooms and glare may occur.

Galasiu and Veitch (2006) present an overview of literature which are about ‘‘occupant preferences and satisfaction with the luminous environment and control systems in daylit offices.’’ The study supplies knowledge about people responding to daylight and their responding to automated photocontrolled lighting and shading controls. Nicol et al. (2006) investigate the same subject by using the results of field surveys of measurements of desktop illuminance in twenty-six offices in five European countries.

To design good day-lit buildings, several design tools have been offered (guidelines, manual calculation formula, computer software programs and models) to determine the illuminance of daylight at certain points (Leslie 2003). For example; Park and Athienitis (2003) introduce a prediction method (with an interior light sensor) that may be applied for the workplane illuminance in daylighting control systems in their study. There is another study which is about ‘‘the daylighting performance and energy use in heavily obstructed residential buildings is performed by the use of computer simulation techniques’’ (Li, et al. 2006).

Reinhart and Fitz (2006) are also performed a web-base survey on the current use of daylight simulations in building design and presented their findings.

2.7. Modeling for Daylighting Prediction and Evaluation

Daylighting design tools help designers with the qualitative and quantitative elements of daylighting design. IEA (2000) states that they can visualize the luminous environment of a given daylighting design and also predict illuminance levels of the architectural spaces. Design tools have an extremely important role in the decision-making process that characterizes daylighting design. These tools are: Scale models, computer programs and Analytical Formula.

2.7.1. Scale Models

Scale models still represent a standard method for the assessment of the daylighting performance of buildings in spite of the capability of computer (Thanachareonkit, et al. 2005). Moore (1993) further argues that models can provide accurate prediction for interior daylight illumination in buildings. If a daylighting model is tested under identical sky conditions it may give exact data about the real building.

Lechner (2001) and Moore (1993) indicate that the model can reproduce exactly the conditions of the actual building. In addition, this if a few basic requirements are met, even simple and rough models can be used for quantitative results. Moore (1993) also declares that it is easy to make comparisons when we change a single design component.

Moore (1993) states that there may be some disadvantages of the scale model technique. Cost of the model which comprises materials and labor may be high. There should be enough time to construct and test it. Another problem is to find accurate equipment and either to wait for suitable weather for outdoor testing or requiring artificial sky simulator (Lechner 2001).

There are some important considerations for constructing physical models. All fenestrations should be detailed precisely and in appropriate and high amount of light entering (or leaving) to the interior of the model should be avoided (Moore, 1993). Materials should resemble real conditions. A large variety of finishing materials are applied to represent real ones to cover interior surfaces in buildings. Correct reflectances and glazing transmittance should be satisfied by using appropriate materials (Littlefair 2003). For example, the opaque walls should be modeled with opaque materials (Lechner 2001). External objects which reflect or block light entering the windows should be included in the model test. Model ratios change from 1:8 to 1:32. Lechner (2001) suggest using a scale of at least ½ inch = 1 foot if possible. In large model construction a scale of 3/8 inch = 1 foot may be quite well. Moore (1993) states that alternative schemes can be easily tested if the model is constructed modular. In addition, Moore (1993) states that modular construction provides accommodating insert representing the competing configurations. Lechner (2001) points out that view ports may be added on the sides and back to observe or photograph the model. A photometer (light meter) is an useful equipment. It can measure the illumination (footcandles or lux) inside the model.

Daylight model testing can be performed under a real or an artificial sky. Moore (1993) expresses that many daylight researchers prefer an artificial sky which approximates to an ideal overcast sky according to the luminance distribution. Lechner (2001) argues and states that artificial skies are used for the model tests for consistent results, but they may not be useful for most designers. Some of the artificial skies are very expensive and bulky to build and most of them simulate only standard overcast conditions. Thus, Lechner (2001) underlines that the real sky and sun are usually used to test daylighting models.

Moore (1993) points out that accurate and convenient measurement of interior and exterior model illuminance is extremely important. The measurements should be taken with a cosine-corrected and color-corrected photometer. Cosine correction is necessary for measuring illuminance in a plane and color-correction is for a sensitivity match of the human eye.

Phillips (2004) mentions a case study that the model is placed under artificial sky at the Bartlett School of Architecture. ‘‘The artificial sky consists of a hemispherical array of compact fluorescent luminaires, which can be individually programmed and controlled to provide a luminance distribution which matches that of the CIE overcast sky’’(Phillips 2004). There is a photo of the scaled model shown in

Figure 2.22. The measurements of illuminance levels at the specified points in the building is performed by using individual sensors or cells which is shown in Figure 2.23.

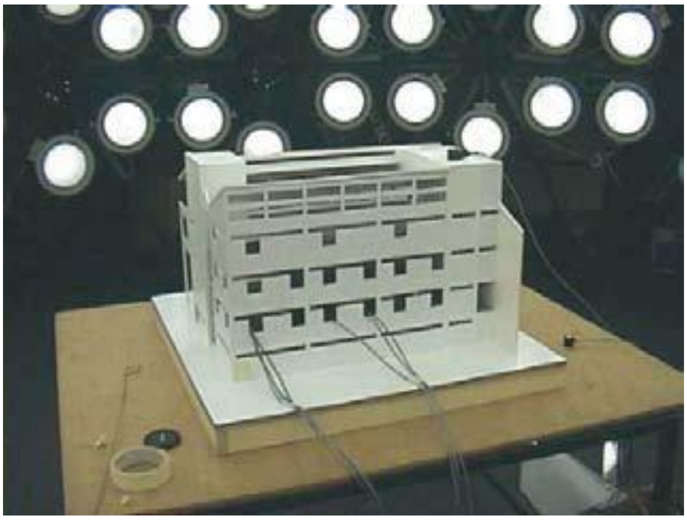


Figure 2.22. Physical 1/50th scale model
(Source: Phillips 2004)

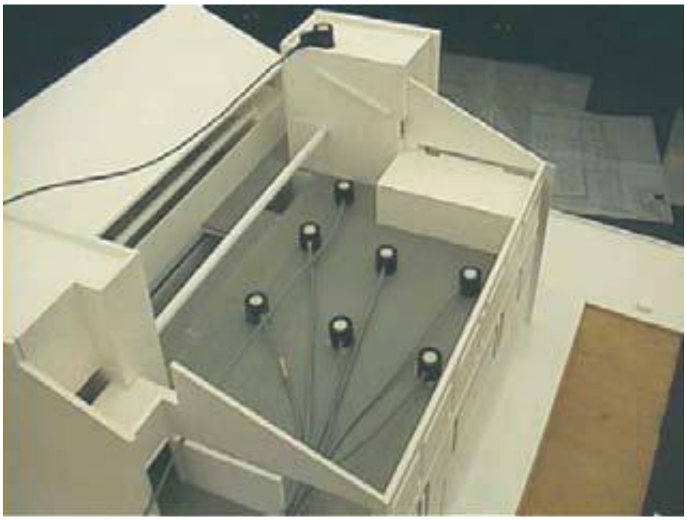


Figure 2.23. Individual sensors or cells positioned within the model
(Source: Phillips 2004)

2.7.2. Computer Programs

In building design process, lighting computer programs have become more crucial over the years. Designers can match right systems of lighting and also heating-cooling to their buildings. But the users still have difficulties to guess the range of errors to be expected when using these programs (Maamari, et al. 2006).

By advancement of computational capability, the optimum window size and types to minimize energy consumption of buildings have been explored and computer simulations have been constructed (Miyazaki, et al. 2005).

Leslie (2003) explains capability of the computer problems by some expressions. The designers may use these programs to apply the daylighting design principles to their buildings. At specified points for specified conditions the programs can determine the illuminance from daylight. Light distribution in a space can be analyzed. Computer programs can also predict annual energy savings under alternative control strategies. In addition to these they can predict the location and time for direct sun. As a result of this ability of the programs designers may evaluate shading devices and planimetric configuration for visual and thermal comfort.

IEA (2000) express that the computer programs have fewer limitations than simple tools. They can address the geometry and the photometry of the modeled architectural space. Image based daylighting computer tools also provide synthetic imaging of modeled space. As a result of these recent surveys reveal that designers increasingly use these tools. In the table 2.5 there is an overview of daylighting computer design tools which are used commonly by the designers (IEA 2000).

There exist some other programs which are used as a design assist tools for daylighting design. They are; 3DStudioMax, Softimage, Maya, Light Wave 3D, Energy Plus, Lightscape, Relux Professional, Skyvision, Delight and OptiCAD.

The computer programs apply two main calculation method; the radiosity technique and the ray-tracing technique (IEA 2000, Bryan and Autif 2002). IEA (2000) states that the radiosity method is used to determine the illuminance and luminance of set of points located at the centers of different surface elements. Bryan and Autif (2002) argue and add that the original surfaces of the space are divided into a mesh of smaller surfaces. The amount of light from each mesh element to every other mesh element is calculated. The ray-tracing (backward ray-tracing) technique determines the visibility of surfaces by tracing imaginary rays of light from a viewer's eye to the objects of a rendered scene (IEA 2000). Bryan and Autif (2002) express that this technique gives more accurate results for surfaces having specular reflections and refractions. Most daylighting and electric lighting calculation programs currently use this ray-tracing technique (IEA 2000).

Table 2.5. Overview of daylighting computer design tools
(Source: IEA 2000)

		IEA ECBCS/SHC ADELINE 3.0	Lawrence Berkeley Lab RADIANCE 2.4	Lawrence Berkeley Lab SUPERLITE 2.0	Electric Power Research Institute BEEM 1.01	Electric Power Research Institute LIGHTCAD 1.0	Cooper Lighting LUXICON 1.1	Lighting Technologies Inc. LUMEN-MICRO 6.0
General Applications	Indoor	x	x	x	x	x	x	x
	Outdoor	x	x				x	
Hardware	Operating System	Windows	UNIX	DOS	DOS	DOS	WINDOWS	DOS
	System Memory Required	32MB	16MB	600K	512K	4M	8M	565K
	Hard Disk Space Required	50-80MB	30MB	1M	500K	3.5M	26M	8M
Type of Analysis	Point-by-Point Illumination	x	x	x			x	x
	Interreflected and Direct Calculations	x	x	x			x	x
	Room Surface Luminance or Exit	x	x	x			x	x
	Avg. Indoor Illuminance (zonal cavity)				x	x	x	x
	Daylighting	x	x	x	x	x	x	x
	Visual Comfort Probability	x	x				x	
	Relative Visual Performance						x	x
	Advanced Statistical Analysis						x	
	Image Synthesis	x	x				x	x
Types of Output	Point-by-Point	x	x	x			x	x
	Iso-Contours	x	x				x	x
	Scaled Output	x	x				x	x
	Templates	x	x					x
	3D Model View	x	x				x	x
Photometric Database	Photometric Graphic Viewer						x	x
	Photometric Format	IESNA Eulumdat	IESNA			IESNA	IESNA, Other	AII&TL-1

2.7.3. Analytical Formula

Serra (1998) mentions that calculations provide designers with knowledge of interior conditions in relation to exterior ones. Because of this, results are expressed as percentages of the exterior level. These calculations are called daylighting factors (DL):

$$DL = 100 \times \frac{E_i \quad \text{interior}}{E_e \quad \text{exterior}} \tag{2.2}$$

where; E_i is the interior illuminances, E_e is the exterior illuminance and DL is the daylight factor.

Daylighting calculation systems are generally supposed to be falling into the following categories; predimensioning methods, point-by-point methods and computer-assisted exact calculation (Serra 1998).

Predimensioning method shows approximately how much light will enter the space. The resulting mean illuminance on a working plane is provided from this calculation method. The disadvantage of the method is that the mean value reached gives little information about the resulting light environment because the distribution of light in an interior space tends to be irregular. The equation of this method is given below (Serra 1998).

$$E_i = \frac{E_e S_{pas} vtu}{S_1} \tag{2.3}$$

where:

E_i = interior illuminance, in lux

E_e = mean exterior illuminance on a horizontal plane, in lux

(Normal figures in the calculations are 10,000 lx per overcast day in winter and 100,000 lx per clear day in summer.)

S_{pas} = total surface area of openings for light to pass through, in m^2

ν= opening factor or solid angle of sky seen from the opening as a proportion of the total solid angle of the sky (2π), over 1 (on a vertical plane, 0.5)

t = transmission factor of the enclosing surface as a whole, over 1 (normally under 0.7)

u = utilization coefficient, or ratio between the flux reaching the lit plane and the flux entering the premises through the opening, over 1 (value of 0.2-0.65)

S_l = surface area of the premises, in m^2

Point-by-point systems determine the light distribution within the premises. The light arriving from the openings at each point in a theoretical network or mesh covering the working plane in question is calculated repetitively. The resulting environment evaluation may be performed by the use of these systems. They may produce graphs of relative illuminance value. Although the systems have these advantages they may fail when they consider the effect of light reflection on the interior walls. The equations of this method are given below (Serra 1998).

$$E = \frac{I \cos \alpha}{d^2} \tag{2.4}$$

where:

E = resulting illuminance, in lux

I = intensity reaching the point, in candelas

α = angle at which the light arrives from the opening

d = distance from the centre of the opening to the point, in m

$$I = LS_o \tag{2.5}$$

where:

L = illuminance of the opening, in cd m^{-2}

S_o = surface area of the opening, in m^2

$$L = \frac{E_o}{\pi} \tag{2.6}$$

where:

E_o = illuminance emerging from the opening

$E_o = E_e v t$

where:

E_e = mean exterior illuminance on a horizontal plane, in lux

v = opening factor or solid angle of sky seen from the opening as a proportion of the total solid angle of the sky (2π), over 1

t = global transmission factor of the enclosing surface, over 1 (Serra 1998)

CHAPTER 3

MATERIAL AND METHOD

This chapter involves two subsections, namely, the material and the method which are associated with the description of the study and evaluation with the Artificial Neural Network (ANN) model. Physical facilities of the office building and nature of the data obtained are presented in material. Method includes the sampling procedure, data collection and concludes with the construction and evaluation of the ANN model carried out in this study.

3.1. Material

The study was carried out in the office building that belongs to the Faculty of Architecture in Izmir Institute of Technology. Materials were private offices of the academic personnel. They are namely, Z1 to Z12 and 101 to 112. Building parameters were gathered by the field survey. They are namely, distance from windows, number of windows, orientation of rooms, floor identification, dimensions of the room, point identification. Others were weather data which were obtained from Weather Station in the Department of Mechanical Engineering in Izmir Institute of Technology. These data were namely, outdoor temperature, solar radiation, humidity, UV index and UV dose.

3.1.1. Case Building: Faculty of Architecture Building Block C in Izmir Institute of Technology

The subject building is associated with the Faculty of Architecture of İzmir Institute of Technology (İYTE) in İzmir, Turkey. This office building is situated in the northern part of the campus on a hilly site (latitude 38° 19’; longitude 26° 37’). Offices are located in a 2-story building (Block C) which is approximately 1072m^2 as the schematical expression of the basic layout is shown in Figure 3.1.

The story height for all rooms is 3.50m. There are a total of 24 rooms occupied by instructors and professors. Each floor contains 12 rooms of which 7 are facing west, 5 are facing east and an atrium located in the centre of the building with a large skylight (17.00 x 3.50m). A circulation corridor connects all rooms to the atrium. The rooms have windows which are placed from the ceiling to the floor of the rooms. All the windows have the width of 1.00m and 3.50m height. According to the Sun's position and the location of the rooms; the rooms (Z01, Z02, Z03, Z04, Z05, 101, 102, 103, 104, 105) which are placed at East of the building have more daylight illumination level at morning hours, while the rooms (Z06, Z07, Z08, Z09, Z10, Z11, Z12, 106, 107, 108, 109, 110, 111, 112) which are placed at West of the building have more daylight illumination level at afternoon hours.

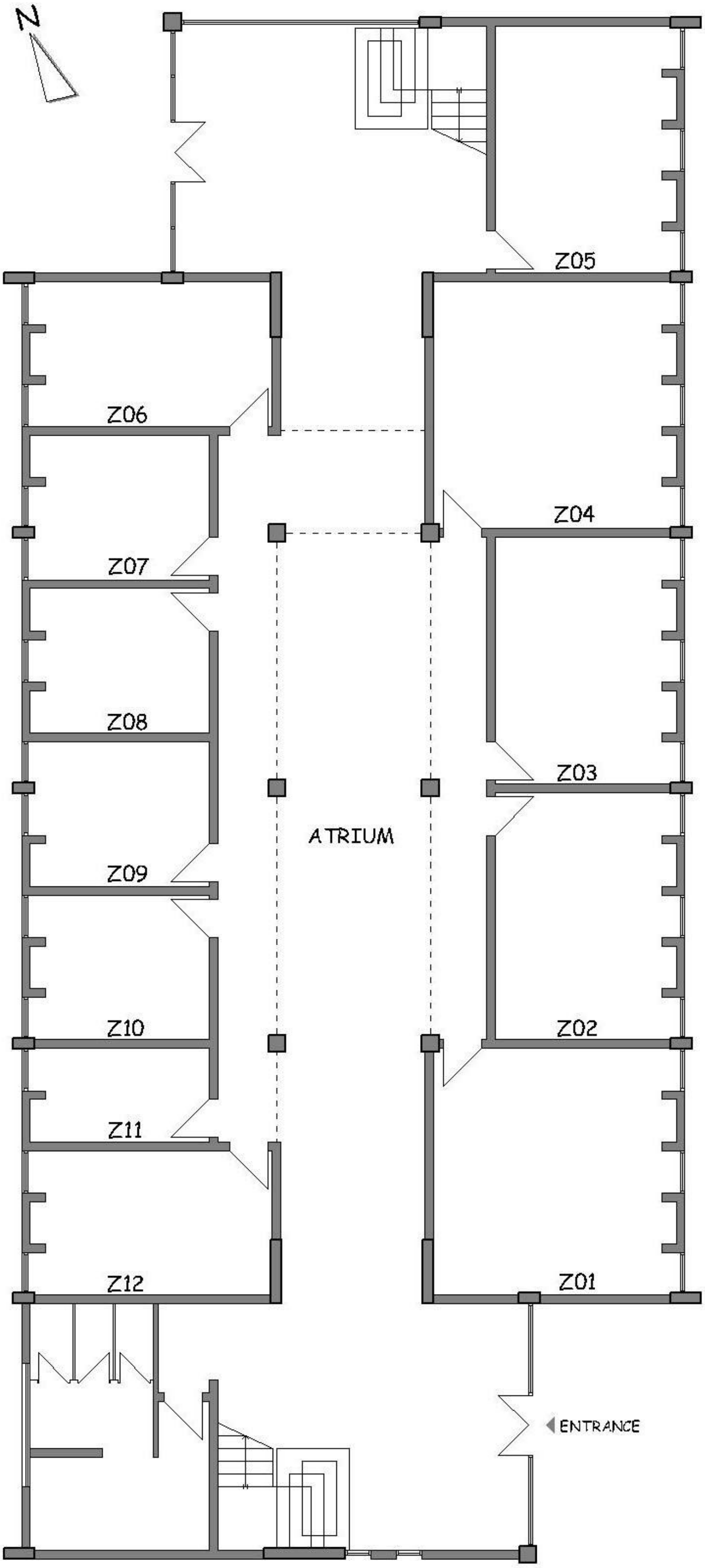


Figure 3.1. A schematic drawing of ground floor plan

3.1.2. Building Parameters and Weather Data

Building parameters consisted of what was designated as a) distance to windows; b) number of windows; c) orientation of rooms; d) floor identification; e) room dimensions; and f) identification point

a) Distance to windows:

As Lechner (2001) explains how the daylight penetration in the room decreases through the inside, the distance between the location of illuminance points and the window line becomes a design parameter. In a room the illumination level is reduced as the distance to the windows in the room is extended. In the case building, there were two types of distance determined in the sample room. The first one was near the wall at which windows were placed. The second type was placed near the exterior wall of the room which was opposite of the wall with windows.

b) Number of windows:

Daylight which enters through from the window openings provides illuminances to the interior. The window design then determines the distribution of daylight to a space. Windows connects the outside to the inside (Li, et al. 2006, IEA 2000). Window size and their position are basic design considerations. Illumination level in a room becomes higher when the number of windows is increased. As the window size of the sample rooms were identical and only their number varies in some offices, number of windows was taken to be a building parameter in this study. In the case building there were three types of rooms according to the number of windows. There are four rooms which have only one window, ten rooms with two windows and another ten rooms with three windows.

c) Orientation of rooms:

Literature (Phillips 2000, IEA 2000, Moore 1993) cites the direct effect of orientation in daylighting design. Glazing in south-façade becomes necessary when winter solar heat is desirable. While glazing in north facade is used when winter heat is not desirable. On the other hand, the function of buildings specifies orientation requirements. As in most buildings the aim is to take most advantage of the daylight available, the interior layout should be in accordance with the building orientation. For example, a room which needs to benefit from mostly early morning light should be placed on the east side, if it is in the northern hemisphere. Therefore, orientation of rooms was taken to be a design parameter in this study. The rooms were categorized according to their location in the building. They are; rooms facing to East and rooms facing to West.

d) Floor identification:

To admit daylight to the interior, the sun rays strike to the building façade. As their incident angle may change and the amount of sun rays receiving to the surface may change, the story height becomes another design parameter (IEA 2000).The upper storeys in a building utilize daylight more than the lower storeys. In the case building, there were two storeys in the case building. The rooms were grouped according to their storey.

e) Room dimensions:

Illumination changes according to room depths. The distribution of daylight which is represented with contours of equal illumination in literature (Lechner 2001, Egan 1983) changes according to room size. Therefore, the illumination level varies due to the room dimensions. In this sense, the ratio of the length of the room to the width of the room was calculated and used as a building parameter in the model construction.

f) Identification point:

In an office room of the case building four points were determined according to their location in the room. The points A1 and A2 were located near the window line and B1 and B2 were located near the interior wall. A1 and B1 were located at the left of the room when we were standing at the position where we turned our face to the wall with windows in the room. Then, A2 and B2 were located at the right of the room. The locations of the points are shown in the Figure 3.5 and Figure 3.6.

Weather data consisted of what was designated as a) outdoor temperature; b) humidity; c) solar radiation; d) UV Index; e) UV dose.

a) Outdoor temperature:

"Temperature represents molecular kinetic energy, which is then consistent with the equation of state and with definitions of pressure as the average force of molecular impacts and density as the total mass of molecules in a volume" (AMS Glossary 2008). Temperature is taken to be a weather parameter which indicates the condition of its occlusion (whether it is a clear day or an overcast day). For example, days with high outdoor temperature would be assumed that there are clear sky conditions. So, the sunlight may vary according to the sky condition.

b) Humidity:

The absorption of solar radiation is supplied by atmospheric gases and water vapor in the atmosphere (IEA 2000). The water vapor in air affects the diffusion and scattering of sunlight through the air as well. The amount of water vapor in atmosphere is called humidity, which is taken to be another weather parameter for this study.

c) Solar radiation:

Solar radiation is the total incident energy which is visible and invisible from the sun (Joshi, et al. 2007). Daylight is defined as the visible global radiation which is the energy in the form of electromagnetic waves or particles (IEA 2000).

d) UV Index:

The Global Solar UV Index (UVI) is described as a simple measure of the UV radiation level at the Earth's surface. UV radiation levels and therefore the values of the index vary throughout the day (WHO 2002).

e) UV dose:

The amount of UV radiation to which a person is exposed. The UV dose depends on the intensity of UV radiation and exposure time.

3.2. Method

Several steps of procedures were followed to accomplish the study by starting with the sampling method and data compilation. Field measurements were carried out to complete relevant data and then the explanation of the Artificial Neural Network (ANN) model as a prediction tool. This section concludes with the steps of the ANN model construction for this study.

3.2.1. Sampling Method and Data Compilation

The data compilation procedure was started with designing the data sheets. They were arranged to record illuminance measurements which were performed at specific points for each sample rooms. The sheet which is shown in Table 3.1 includes; room/space designations, point labeling, actual room dimensions, dates for measurements, time (actual hours for measurements) and measurement readings.

Table 3.1. An example of a record sheet for illuminance measurements

Date			**Time**						
Ground Floor Rooms					**First Floor Rooms**				
Z1	A1	A2	B1	B2	**101**	A1	A2	B1	B2
Z2	A1	A2	B1	B2	**102**	A1	A2	B1	B2
Z3	A1	A2	B1	B2	**103**	A1	A2	B1	B2
Z4	A1	A2	B1	B2	**104**	A1	A2	B1	B2
Z5	A1	A2	B1	B2	**105**	A1	A2	B1	B2
Z6	A1	A2	B1	B2	**106**	A1	A2	B1	B2
Z7	A1	A2	B1	B2	**107**	A1	A2	B1	B2
Z8	A1	A2	B1	B2	**108**	A1	A2	B1	B2
Z9	A1	A2	B1	B2	**109**	A1	A2	B1	B2
Z10	A1	A2	B1	B2	**110**	A1	A2	B1	B2
Z11	A1	A2	B1	B2	**111**	A1	A2	B1	B2
Z12	A1	A2	B1	B2	**112**	A1	A2	B1	B2

The existing first floor drawings were obtained in order to donate the grid spacing for measurement locations (Figure 3.2). The data sheets and the floor drawings then employed in the field survey. The meteorological data which was then utilized for the model application was obtained from the Weather Station in the Department of Mechanical Engineering in İYTE.

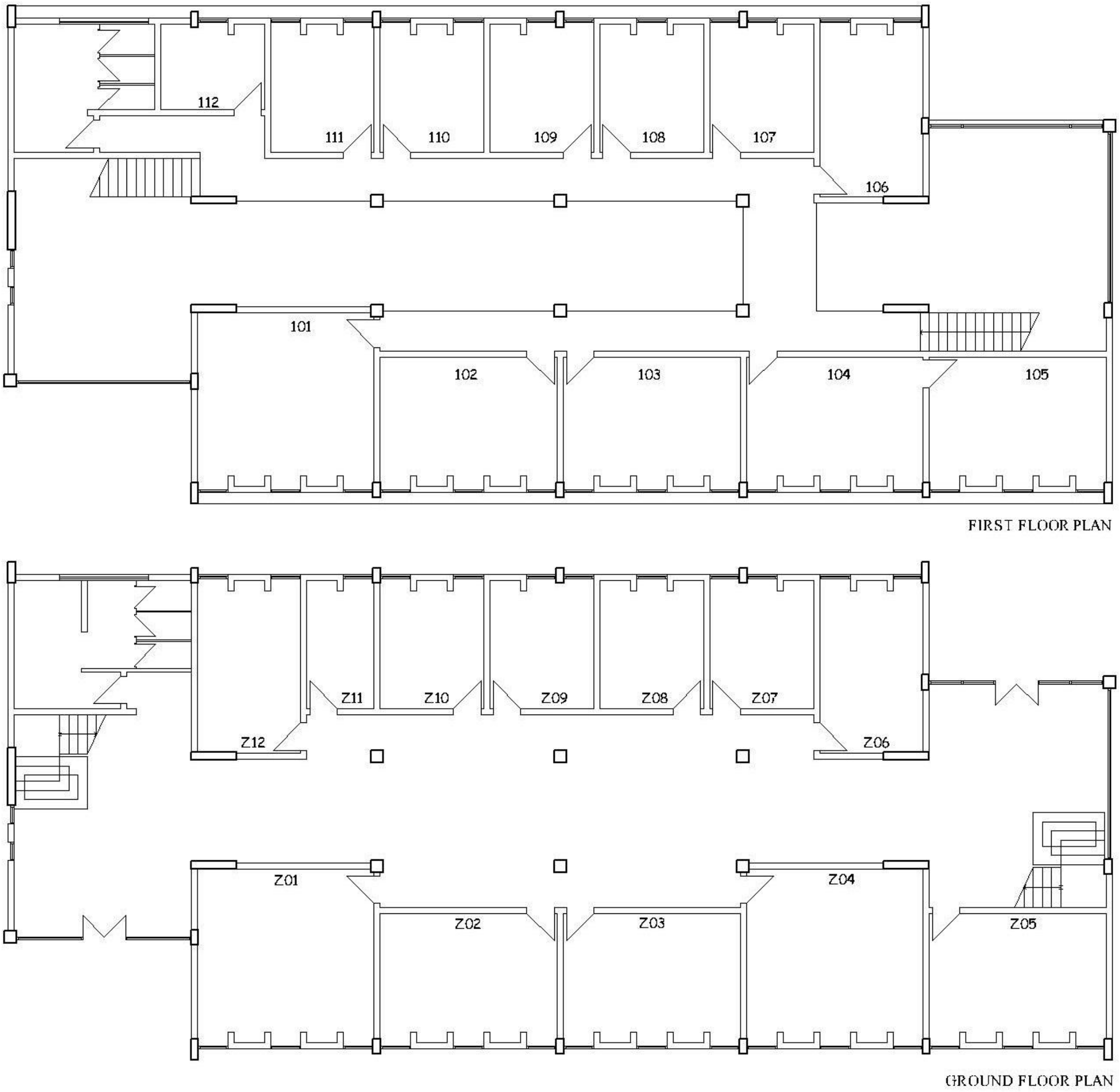


Figure 3.2. Drawings of floor plans belong to the office building

3.2.2. Field Measurements

As the interior daylighting levels change according to the sky conditions at any time, objective measurements of illuminance are not the only and directly indicators for actual building performance because interior illuminance due to daylight changes as a function of sky conditions. The illuminance from the sky is not constant, and the variations in daylight can be quite large. It depends on season, location or latitude, and cloudiness (IEA 2000, Kim and Kim 2003). Measurements in the field study can provide detailed performance information under real sun and sky conditions.

The CIBSE (Chartered Institution of Building Services Engineers) Code for Interior Lighting (CIBSE factfile 1996) recommends that ‘‘an interior, or a representative area, is divided into a number of equal areas which should be as square as possible. The illuminance at the centre of each area is measured and the mean calculated. This gives an estimate of the average illuminance.’’ Measurements are then repeated for various days and are taken by a luxmeter (lightmeter) which is used with a portable stand for the constant height measurements.

The survey was carried out on the ground and first floors of the office building in İYTE in the period between the months of November 2007 and February 2008. The measurements were taken for a total of 21 days for the hours; 09:00 at morning, 12:00 at noon, 15:00 at afternoon. The weather data was obtained for the same days and hours which were presented at Appendix C; Figures C.1-5. The number of measurement points and their locations were determined according to recommendations of the CIBSE Code (1996). The number of points was determined in relation with the Room Index (ratio between room size and height). Türkoğlu and Çalkın (2006) refer to CIBSE No 3 (1996) for the formula (3.1) of room index which is shown below.

$$k = \frac{L \text{x} W}{h \text{ x}(L + W)} \tag{3.1}$$

Where; k is the room index, L is length of the room, W is the width of the room and h is the height of the room.

For example, as the room size for Z01 was 5.70m to 5.80m and the height of the room was 3.50m, the Room Index calculated as 0.82137. Then, according to Table 3.2, the number of measurement points were determined as 4.

Table 3.2. Number of measurement points required to determine illuminances (Source: Türkoğlu and Çalkın 2006)

Room Index, k	Number of measurement points
$k < 1$	4
$1 \leq k < 2$	9
$2 \leq k < 3$	16
$3 < k$	25

A portable PeakTech® digital lightmeter with a silicon photo diode detector attached to the amplifier by a flexible cable was used for the field measurements, as shown in Figure 3.3. A portable stand made of metal was used to locate the measuring cell at a constant height for each reading. The height was 0.7m from the floor level. Measurements were taken 0.5m away from walls/columns/partitions and grid points were positioned with equal spacing (Figure 3.5).

Figure 3.3. The portable luxmeter used in this study

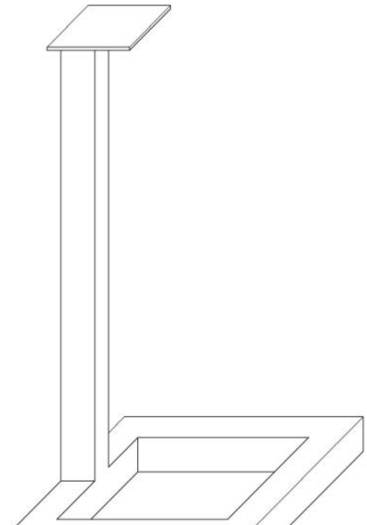


Figure 3.4. The portable stand to house the silicon detector of the lightmeter
(Source: CIBSE factfile 1996)

Measurement points were identified as A1 and A2 which are located near the window line; and B1 and B2 which are located near the interior wall. Drawings displaying the spacing of grid points for illuminance measurements (A1, A2, B1, B2) for two sample rooms and their heights from the floor level are shown in Figure 3.5 and Figure 3.6. The specific measurement points in the rooms at the ground floor plan are shown in Figure 3.7.

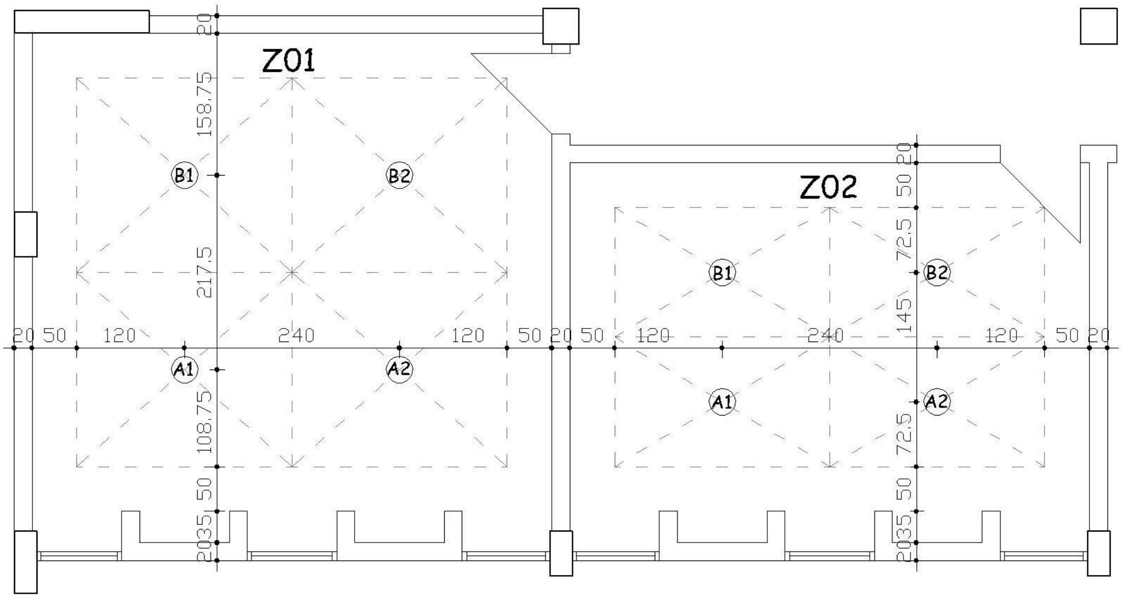


Figure 3.5. A representative drawing displaying the spacing of measurement grid points for sample rooms

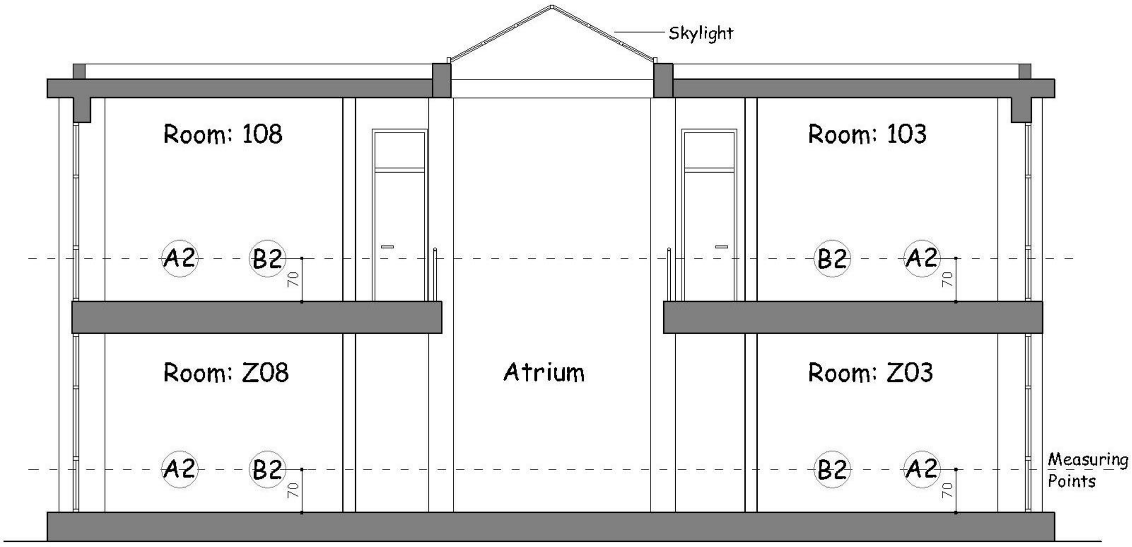


Figure 3.6. A-A section; displaying the location of measurement points

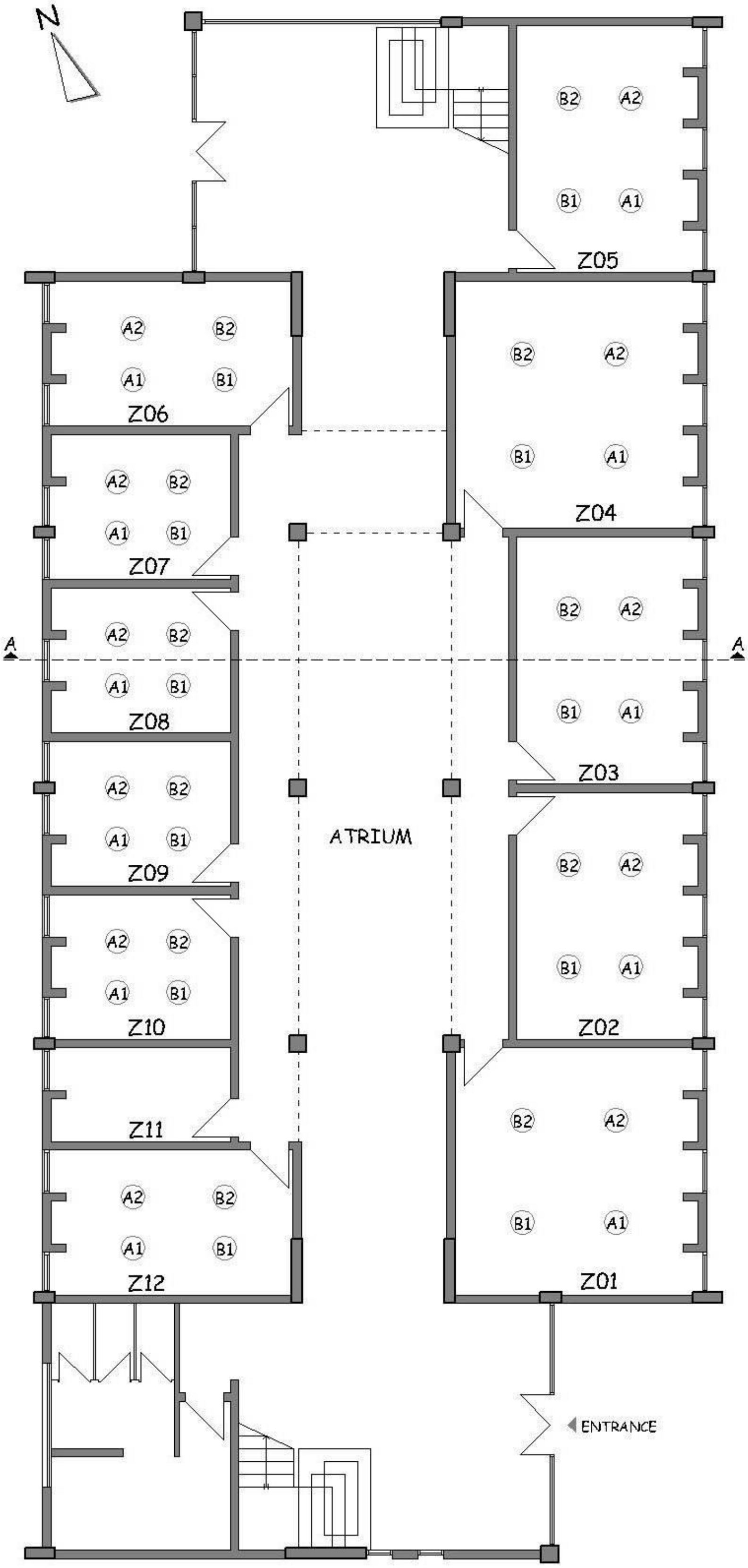


Figure 3.7. A schematic drawing of ground floor plan displaying illuminance measurement points

3.2.3. ANNs as a Prediction Tool

Daylighting predictions effect mostly in designing stage. Predicting the illumination level has been done in different ways. The most specific ones can be classified in three groups; model studies, analytical formulas and computer simulations (Egan 1983, Moore 1993, Lechner 2001, Park and Athienitis 2003). Scale models still represent a standard method for the assessment of the daylighting performance of buildings in spite of the capability of computer modeling for daylighting design (Thanachareonkit, et. al. 2005). In building design lighting computer programs are becoming more important. Designers can match right systems of lighting and also heating-cooling to their buildings. But the users still have difficulties to guess the range of errors to be expected when using these programs (Maamari, et al. 2006). There is a need for more holistic performance indicators and design selection procedures to judge the quality and quantity of daylight in a building (Reinhart and Fitz 2006). In this study, however, an artificial neural network model is offered as a new methodology to predict daylighting illuminance (Figure 3.8).

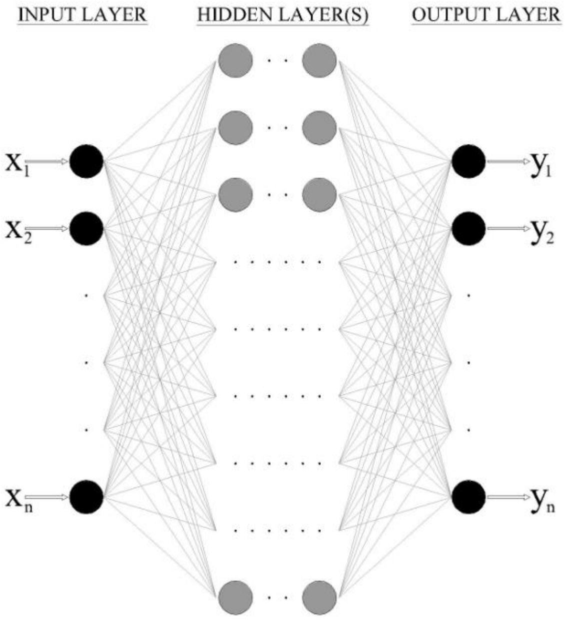


Figure 3.8. Schematic diagram of a typical neural network model

Artificial neural networks (ANN) are a type of artificial intelligence (computer system) which can create connections between mathematical processing elements (Taylor 2006). In other words, ANN is a massively parallel distributed processor made up of simple processing units. Information processing occurs at neurons. Signals are transmitted between neurons through connection weights. Each connection link is represented by its connection strength. As Lam et al. (2008) state, ANNs learn the relationship between the input and output variables. It has the ability to learn from experience and examples and then to adapt to changing situations. Therefore, it is clear that an ANN model works similar to the biological neural system (Taylor 2006, Lam, et al. 2008). It resembles the human brain in two aspects; knowledge is obtained by the learning process and neuron connection strengths are used to store the knowledge. Ayed (1997) mentions that ANNs are computer programs which simulate the biological structure of the human brain.

A typical neural network architecture including neurons, layers and their connection weights is presented in Figure 3.8. In the Figure; the first layer is called the input layer which may have n number of input neurons e.g. x_1, x_2, x_3,…., x_n. Each input neuron represents the input data. There may be single or more hidden layers including many neurons. The last layer is called the output layer. There may be one or more output neurons depending on the prediction problem. It consists of predicted values by the network. In addition, bias neurons are used to avoid bias in the model architecture. Bias node is considered in the input and inner hidden layers but not in the outer layer. There may be some unaccounted parameters that may affect the process. In order to account for the uncertainty effects bias is used. In general, -1 or +1 values are assigned to these bias nodes as input values. However, using a bias node is not compulsory.

A Neural Network is constructed by arranging several processing units in a number of layers (Ayed 1997). Knowledge is encoded into the network through the strength of the connections between different neurons which are called weights (Taylor 2006). Lam et al. (2008) define the process of ANN as follows; a neuron receives inputs over its incoming connections and then combines the inputs. It performs generally a non-linear operation. At the end of this process the network outputs the final results. At the training stage of the network both the inputs and outputs are presented to the network for thousands of cycles. Inputs represent the parameters of problem and outputs represent the solutions. The network evaluates the error between the actual and desired output at the end of each cycle. After this work it uses this error to modify the connection weights according to the training algorithms used (Ayed 1997).

Neural networks can learn to solve a problem. Learning is achieved through training the network. Lam et al (2008) define that training is the procedure by which the networks learn, and learning is, thus, the end result. In addition, Tasadduq et al. (2002) states that in the training process the weights of the network are determined. This would minimize an error function that is based on the actual and desired outputs. The prediction capability of the network is tested by the data that are selected from the whole data set (Hoo, et al. 2002). Training and testing of the network continued until no improvement in the output is achieved. This process is performed after a predetermined number of iterations (Lam, et al. 2008).

3.2.4. ANNs Model Construction

In this study a prediction model for daylighting illuminance for office buildings is presented. This model was prepared by the assistance of Artificial Neural Network, using the program; Microsoft Excel. The model was then subjected to sensitivity analysis to determine the relationship between input and output variables. NeuroSolutions Software by NeuroDimensions Inc was adopted for this application.

The neural network calculations in this study were performed applying Excel spreadsheet method. The spreadsheet represents a template for one hidden-layer NN (Neural Network) that is suitable for most applications (Hegazy and Ayed 1998). A spreadsheet simulation of a three-layer neural network of feed-forward type with one output node was employed to develop a prediction model for indoor illumination levels of office buildings. It is implemented on Microsoft Excel.

Six of the variables (distance from windows, number of windows, orientation of rooms, floor identification, dimensions of the room, point identification) that are concerning the case office building parameters, five variables (temperature, solar radiation, humidity, UV index and UV dose) about climatic conditions and two variables (day time, day hour) including date were considered as input variables.

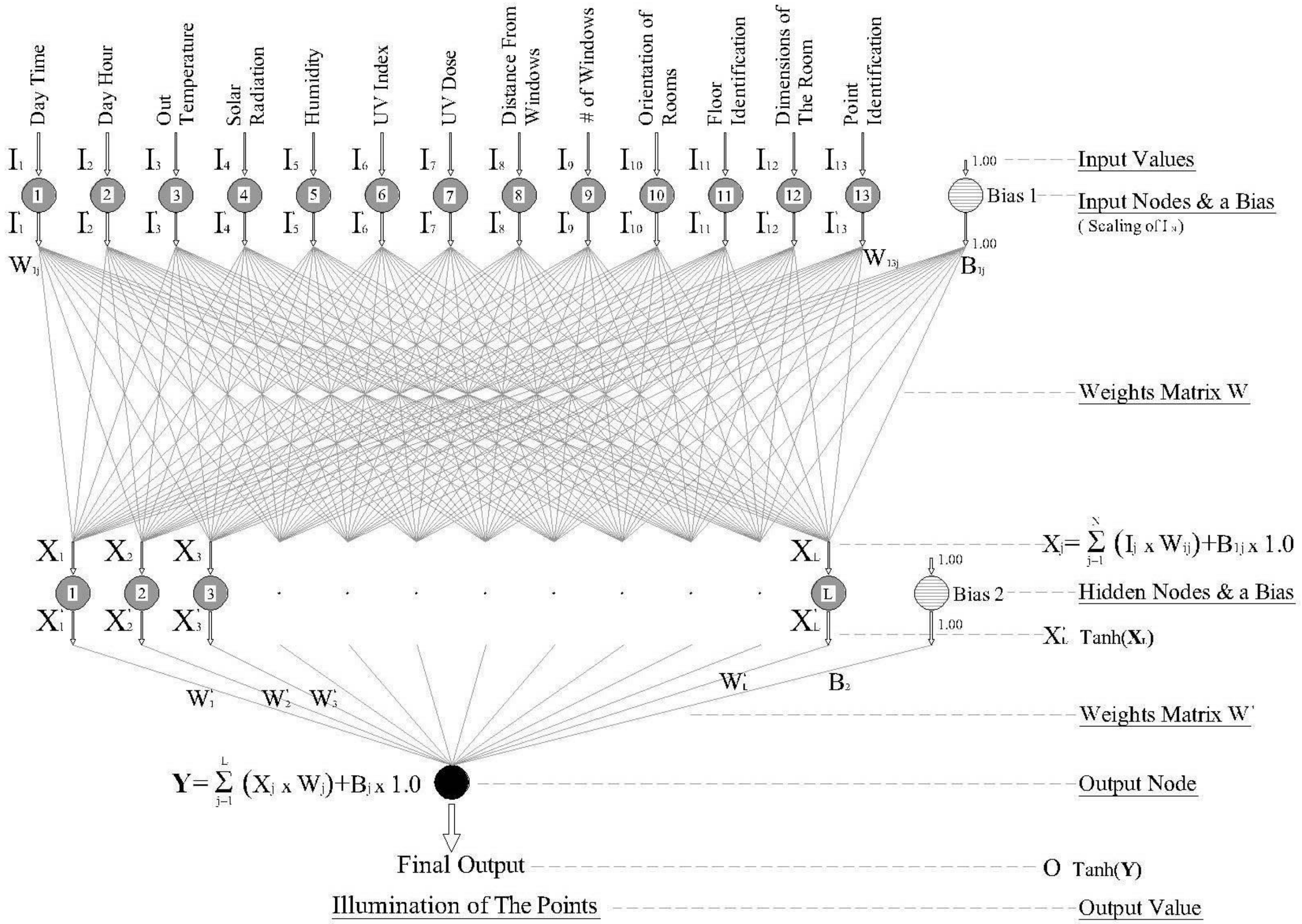


Figure 3.9. Structure of the best performing network

Illuminations of the measured points were used as the output variable. All the elements of the structure for the best performing network are shown in Figure 3.9.

The model in this study was constructed by following seven steps in the spreadsheet. These steps are mentioned as; data organization, data scaling, weight matrix (W), output of hidden nodes, weight matrix (W′), final NN output, scaling back NN output and calculating the error (Hegazy and Ayed 1998, Ayed 1997).

a) Data Organization:

This is the first step of the model where the case problem is completely analyzed. There are several variables called inputs which affect the problem. The other variable called output is the node that is a result of the input nodes. In this study the model was constructed with thirteen neurons in the input layer and one neuron was used for the output variable. Input variable includes day time, day hour, out temperature, solar radiation, humidity, UV index, UV dose, distance from windows, number of windows, orientation of rooms, floor identification, dimensions of the room (length/width), point identification. Output variable involves only illumination of the points.

In the Excel spreadsheet the data was transformed into numerical values and a table of these values was constituted. At the end of this table the minimum and the maximum values for each variable was calculated (Table 3.3). As a result of constructing this table, a spreadsheet matrix was formed. The database was divided into two groups. 80% of the data were for training the network and the remaining 20% of the data were for testing. The datas which were used in testing were totally different from the datas used in training. The model learning was performed with 80 data sets in the training step. In the testing step, the prediction capability of the model was tested with different 20 data sets.

Table 3.3. Data organization table

(Source: Hegazy and Ayed 1998)

	A	B	C	D	E	F
1	Project No	Inputs				Output
2		1	2	…….	N	O
3	1					
4	2					
5	3					
6	|					
7	|					
8	P					
9	Min:	=MIN(B3:B7)		…….		=MIN(F3:F7)
10	Max:	=MAX(B3:B7		…….		=MAX(F3:F7)

b) Data Scaling:

In the second step data scaling was performed. The variables in the table of the first step is scaled to a range from [-1 to 1] which is suitable for NN processing. This scaling process was performed by using the formula below:

$$Scaled\ Value = \frac{2\ x\ (Unscaled\ Value - Column\ Min)}{(Column\ Max - Column\ Min)} - 1 \qquad (3.2)$$

A second table was formed and the formula (3.2) was written in one cell and copied to all cells in the table of scaling matrix. A column was added at the right of this table called bias which had unit values related to the bias node (Table 3.4).

Table 3.4. Data scaling table

(Source: Hegazy and Ayed 1998)

	A	B	C	D	E	F
13	Project	Scaled Inputs				
14		1	2	…….	N	Bias 1
15	1					1
16	2					1
17	3					1
18	|					1
19	|					1
20	P					1

=2*(B3-B$8)/(B$9-B$8)-1

Made once and copied to all cells

c) Weight Matrix (Input and Hidden Node):

The weight matrix (W) between the inputs and the hidden layer was performed and initialized in the third step of the model (Table 3.5). It is suggested by Hegazy and Ayed (1998) that ‘‘the number of the hidden nodes was set as one-half of the total input and output nodes.’’

Table 3.5. Weight matrix (W)

(Source: Hegazy and Ayed 1998)

	A	B	C	D	E	F
25	To Hidden	Weight From Inputs & Bias 1				
26		I'_1	I'_2	…….	I'_n	Bias 1
27	Node 1					
28	Node 2					
29	…….					
30	Node L					

Cells contain weight values put initially as 1.0s. The matrix elements are set as variables in the optimization

d) Output of Hidden Nodes:

The fourth step is named as output of hidden nodes. In this step the hidden nodes processed the input data. The values which were forwarded to the next layer were produced at the end of this step. One hidden node (j) received activation (X_j). The formula of the activation is as follows:

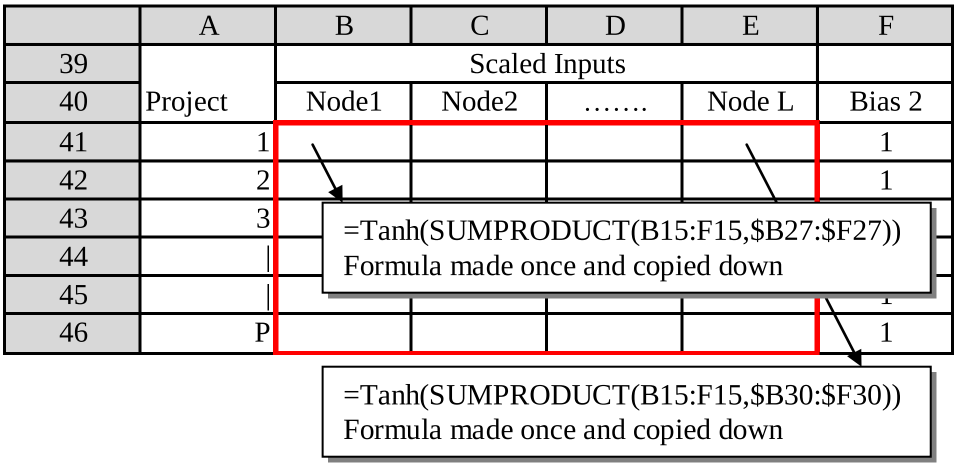
$$X_j = \sum_{i=1}^{N} (I_i x\ W_{ij}) + B_{ij} x\ 1.0 \tag{3.3}$$

This activation is defined as the sum of product of scaled inputs by the assistance of their connection weights (Table 3.6) (Hegazy and Ayed 1998). Each of the hidden nodes produced outputs (X_j') which were the functions of their activation. This function is shown in the formula 3.4.

$$X_j' = \tanh(X_j) \tag{3.4}$$

Table 3.6. Outputs of hidden nodes

(Source: Hegazy and Ayed 1998)



	A	B	C	D	E	F
39	Project	Scaled Inputs				
40		Node1	Node2	…….	Node L	Bias 2
41	1					1
42	2					1
43	3					
44	|					
45	|					1
46	P					1

=Tanh(SUMPRODUCT(B15:F15,$B27:$F27))
Formula made once and copied down

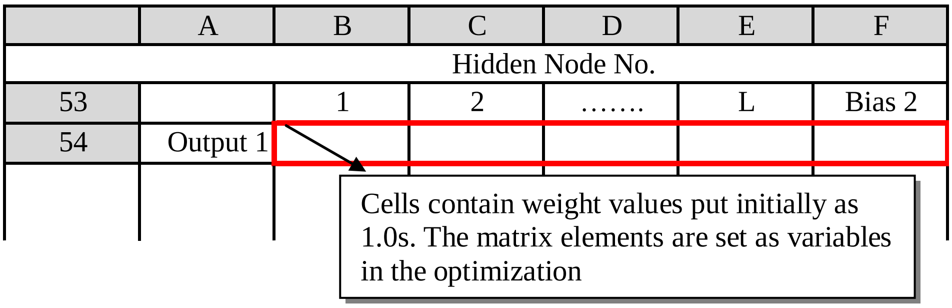
=Tanh(SUMPRODUCT(B15:F15,$B30:$F30))
Formula made once and copied down

e) Weight Matrix (Hidden and Bias Node):

The weight matrix (W′) which is similar to the one at the third step was constructed in the fifth step. This weight matrix connected the hidden (L) and bias node to the single output node (Table 3.7).

Table 3.7. Weights (W′) from hidden nodes to output node

(Source: Hegazy and Ayed 1998)



	A	B	C	D	E	F
	Hidden Node No.					
53		1	2	…….	L	Bias 2
54	Output 1					

Cells contain weight values put initially as 1.0s. The matrix elements are set as variables in the optimization

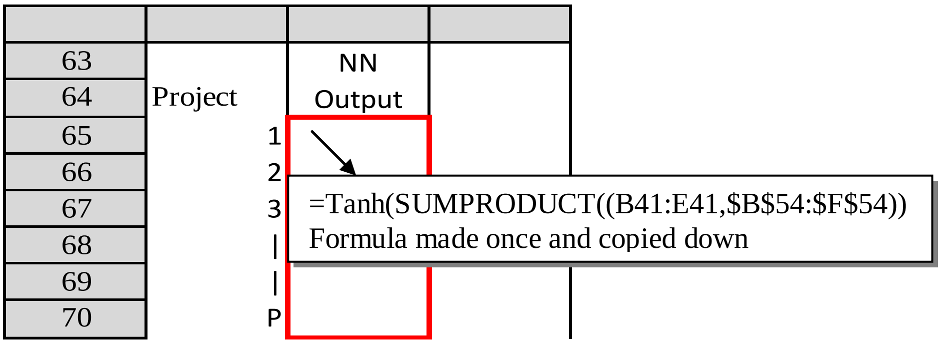
f) NN Output:

In the sixth step the final NN output (O) was calculated by the way similar to the step four (Table 3.8).

$$Y = \sum_{j=1}^{L} (X'_j \, x \, W'_{jl}) + B_2 \;\; x \; 1.0 \qquad (3.5)$$

Table 3.8. Final NN output

(Source: Hegazy and Ayed 1998)



63		NN Output	
64	Project		
65	1		
66	2		
67	3		
68	|		
69	|		
70	P		

=Tanh(SUMPRODUCT((B41:E41,$B$54:$F$54))
Formula made once and copied down

g) Scaling Back:

The last step of the model consisted of scaling back NN output and calculating the error (Table 3.9). The NN outputs (O) were scaled back to their normal values by the formula (3.6) which was the reverse version of the formula (3.2) used in the second step.

$$Output\ Scaled\ Back\ = \frac{(Output\ Value + 1)(Max\ Output - Min\ Output)}{2} + \ Min\ Output \qquad (3.6)$$

For the purpose of checking the measure of NN performance, the column is constructed under the process of finding out the error (3.7) between NN output and the actual output.

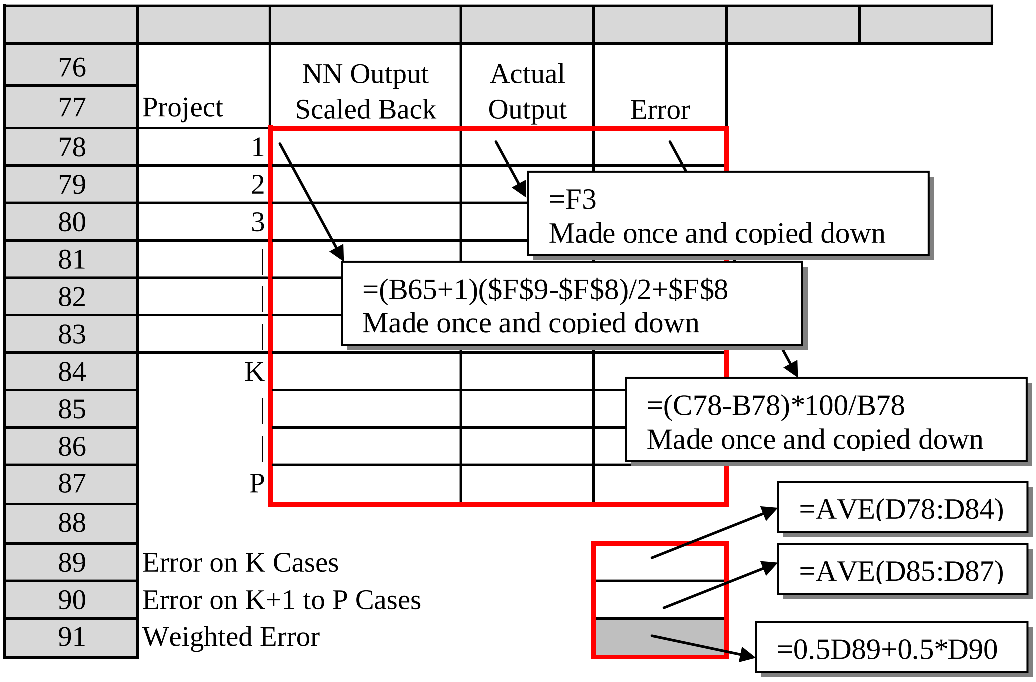
$$EstimatingError(\%)\ = \frac{(NeuralNetworkOutput - ActualOutput + 1)(Max\ Output - Min\ Output)}{ActualOutput}\ x\ 100 \qquad (3.7)$$

The outputs were divided into the groups namely, testing and training as it was arranged in the first step. After the testing the average mistake of each group, we can find a mutual solution to find performance of the NN by the assistance of the formula presented below:

$$WeightedError(\%) = 0.5(TestSetAverageError) + 0.5(TrainingSetAverageError) \qquad (3.8)$$

Table 3.9. Scaling back NN output and calculating the error

(Source: Hegazy and Ayed 1998)



76						
77	Project	NN Output Scaled Back	Actual Output	Error		
78	1					
79	2					
80	3					
81	|					
82	|					
83	|					
84	K					
85	|					
86	|					
87	P					
88						
89	Error on K Cases					
90	Error on K+1 to P Cases					
91	Weighted Error					

=F3
Made once and copied down

=(B65+1)($F$9-$F$8)/2+$F$8
Made once and copied down

=(C78-B78)*100/B78
Made once and copied down

=AVE(D78:D84)

=AVE(D85:D87)

=0.5D89+0.5*D90

In the last formula (3.8) although they are fewer from the training set, the test cases have an important role to ensure good generalization performance and avoid overtraining. By checking the outcomes of this calculation it can be seen that the model arrived at the optimum solution with an average percentage error. The prediction power of the model which can be defined as the predicted values in the model having close matches with the actual data is ensured. This testing can be more useful to get an idea about the general performance.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter involves three subsections, namely, results obtained from field measurements and the ANN model, sensitivity analysis which depicts the effects of each variable for the prediction and discussions of these according to literature and objectives.

4.1. Results

The ANN-Excel template was constructed to employ the development of daylight illuminance of offices in İYTE, by following the instructions mentioned in Literature (Hegazy and Ayed 1998). Utilizing the inputs and output defined (Figure 4.1), relevant data were entered for each measured variable. Data related to illuminance was gathered through field measurements. Building parameters were defined according to architectural drawings and weather data was obtained from a local weather station in the İYTE Campus. Finally, sensitivity analysis, is mentioned in the next section, was performed on the model to determine the effect of each input variable on the model output variable, by the use of Neuro Solutions.

The data was divided into two groups; the first one was used for training and the rest was for the testing of the model. As to have statistically balanced data, the training and testing data set had approximately the same minimum to maximum ranges and average illuminance values as in the main data set. There were a total of 100 data sets which were chosen randomly from 3960 data sets. Each data sets had 14 components (x_1, x_2, …, x_{13}; y) 13 of which are input variables whereas the 14th one is the output variable (Figure 4.1). The maximum and minimum numerical values of the input variables are shown in Table 4.1.

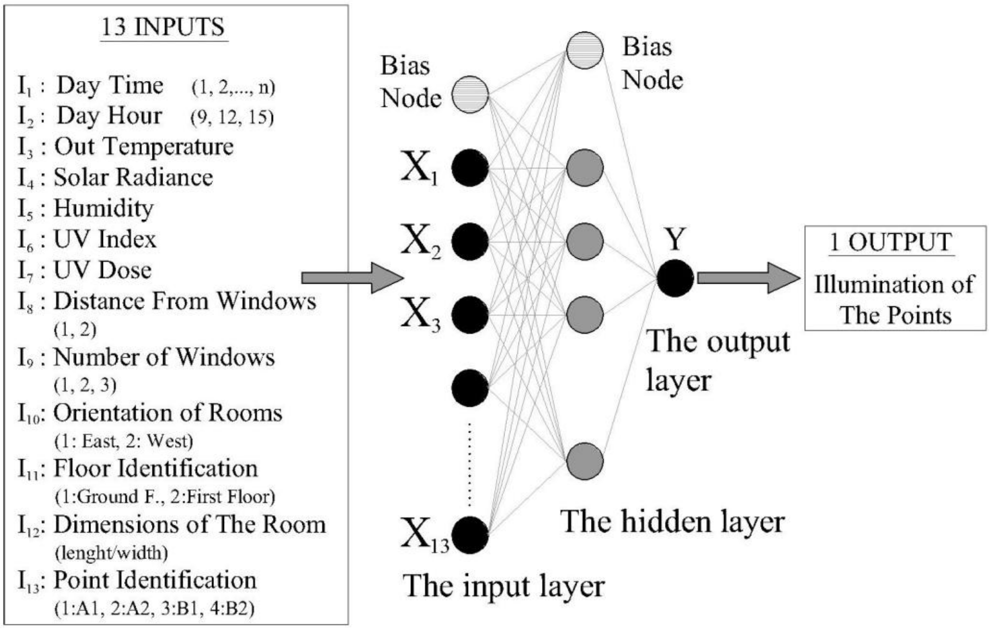


Figure 4.1. Description of ANN Inputs and Output

Table 4.1. The input variables used in the model construction

Code	Input variable	Data used in ANNs model	
		Minimum	Maximum
x_1	Date (1,2,….,100)	1	114
x_2	Hour (9.00, 12.00,15.00)	9.00	15.00
x_3	Outdoor temperature (^{0}C)	5.70	22.00
x_4	Solar Radiation	12.00	700.00
x_5	Humidity	29.00	89.00
x_6	UV Index	0.00	3.50
x_7	UV Dose	0.00	0.19
x_8	Distance to window (m)	1	2
x_9	# of Windows (1,2,3)	1	3
x_{10}	Orientation of rooms (1= East; 2= West)	1	2
x_{11}	Floor ID (1=ground floor; 2= first floor)	1	2
x_{12}	Room aspect ratio (length/width)	0.58	1.30
x_{13}	Point ID (1=A_1; 2=A_2; 3=B_1; 4=B_2)	1	4
y_1	Illuminance (lux)	9.40	1679.00

The first 80 of these data sets were used for training of the model and the remaining 20 for testing. In the model construction Microsoft Excel Solver was used for simplex optimization method to obtain the optimal weights. Hegazy and Ayed (1998) point out that ‘‘the number of hidden nodes is set as one-half of the total input and output nodes’’. In this study total number of hidden neurons was tested according to their results of final weighted error. It was obtained that seven is the appropriate number which is one-half of fourteen that was the total of thirteen inputs and one output (Table 4.2). As a result of this test; seven hidden nodes had the final weighted error of 2.20%. There were seventeen solver coded in Microsoft Excel using its macro programming features. Then it was linked to the ANN spreadsheet. The program then instructed to run for 100 iterations. The model’s performance is then measured by using the illuminance percentage error (IPE):

$$IPE = \frac{E(i) - T(i)}{T(i)} 100\% \tag{4.1}$$

where; E(i) is the estimated illuminance level, T(i) is the actual measured illuminance level and IPE is illuminance percentage error.

Table 4.2. Comparison of final weighted error percentages according to the number of hidden neurons

Number of Hidden Neurons	Percentage of Final Weighted Error
5	35.87%
6	20.62%
7	2.20%
8	2.20%
11	2.54%
13	2.20%

By following the outcomes of this calculation, the model arrived at the optimum solution with an average percentage training error of 1.08% for the output variable. Thus, the training of the model was successfully accomplished since the model was in accordance with the actual data (Figure 4.2). The trained model was tested with the group of 20 data sets after the application of optimization (Figure 4.3). The datas which were used in testing were totally different, independent from the datas used in training. The performance of the model was successful with an average error of 2.20%. Thus the prediction power of the model was 97.8% (Figure 4.4). The predicted values in the model had close matches with the actual data.

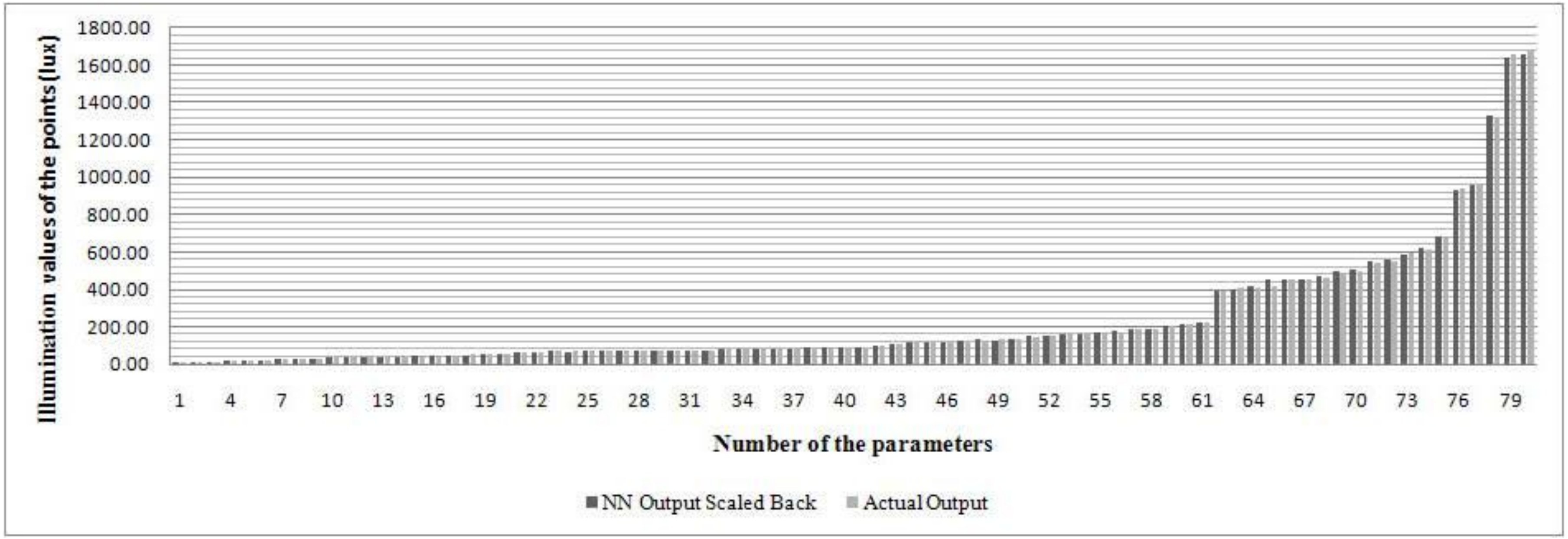


Figure 4.2. Observed vs. predicted illumination levels for training data sets

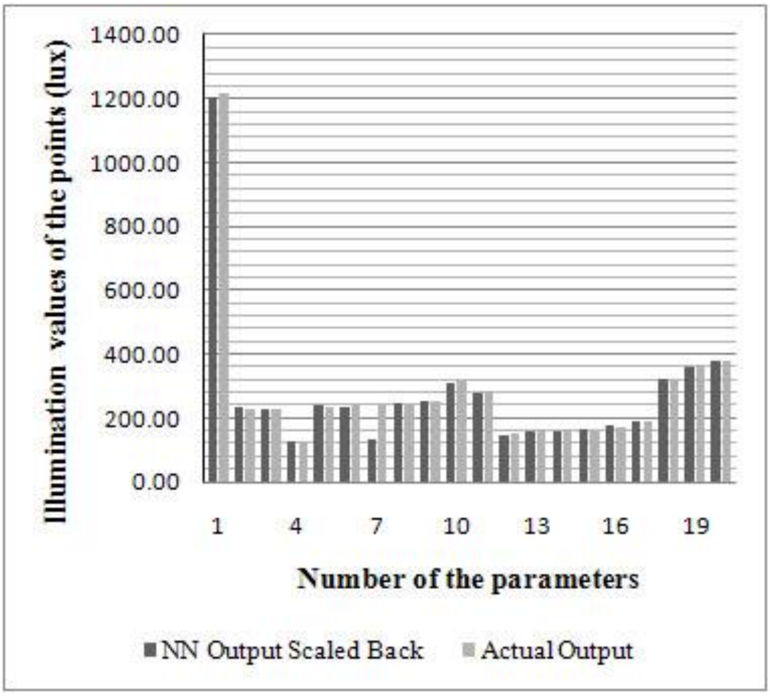


Figure 4.3. Observed vs. predicted illumination levels for testing data sets

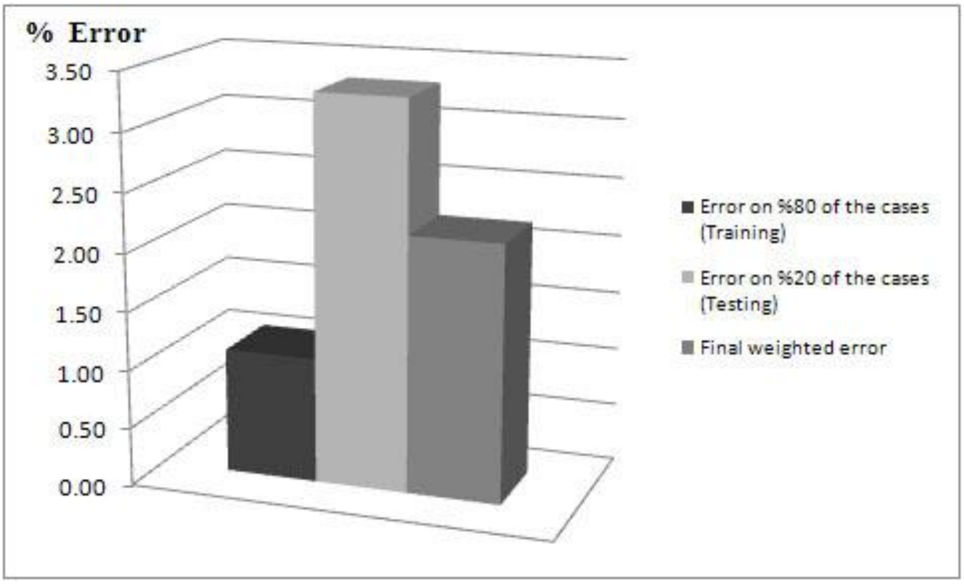


Figure 4.4. Comparison of the results

Table 4.3. Data organization table of the model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Step-1 : Original Unscaled Inputs**															
2	**INPUTS**															**OUTPUT**
3			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
4			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**			**Dist.from windows**	**# of windows**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	**Illumination of the points**
5	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	
6	1	Z1	1.00	15.00	12.80	40.00	69.00	0.00	0.00	1.00	3.00	1.00	1.00	0.98	1.00	9.40
7	2	Z1	7.00	15.00	18.40	109.00	60.00	0.40	0.02	1.00	3.00	1.00	1.00	0.98	1.00	11.80
8	3	101	3.00	15.00	10.90	53.00	82.00	0.00	0.00	2.00	3.00	1.00	2.00	0.98	3.00	12.60
9	4	103	29.00	15.00	14.80	39.00	83.00	0.00	0.00	1.00	3.00	1.00	2.00	1.30	2.00	19.00
10	5	107	28.00	15.00	14.80	82.00	63.00	0.00	0.00	1.00	2.00	2.00	2.00	0.77	1.00	21.10
11	6	Z12	28.00	15.00	14.80	82.00	63.00	0.00	0.00	2.00	2.00	2.00	1.00	0.58	3.00	21.60
12	7	107	22.00	15.00	14.10	78.00	78.00	0.00	0.00	2.00	2.00	2.00	2.00	0.77	3.00	24.40
13	8	101	7.00	15.00	18.40	109.00	60.00	0.40	0.02	2.00	3.00	1.00	2.00	0.98	4.00	25.50
14	9	104	37.00	9.00	8.80	23.00	84.00	0.00	0.00	2.00	3.00	1.00	2.00	1.30	3.00	30.00
15	10	Z12	107.00	15.00	14.20	115.00	64.00	0.60	0.03	2.00	2.00	2.00	1.00	0.58	4.00	36.80
16	11	Z1	7.00	12.00	19.10	608.00	47.00	2.40	0.13	2.00	3.00	1.00	1.00	0.98	3.00	37.00
17	12	Z3	28.00	15.00	14.80	82.00	63.00	0.00	0.00	1.00	3.00	1.00	1.00	1.30	2.00	37.60
18	13	104	62.00	9.00	5.70	98.00	88.00	0.00	0.00	2.00	3.00	1.00	2.00	1.30	3.00	37.80
19	14	106	31.00	9.00	8.00	12.00	75.00	0.00	0.00	1.00	2.00	2.00	2.00	0.58	2.00	39.30
20	15	112	31.00	9.00	8.00	12.00	75.00	0.00	0.00	1.00	1.00	2.00	2.00	1.13	1.00	42.30

(cont. on next page)

Table 4.3. (cont.) Data organization table of the model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Step-1 : Original Unscaled Inputs**															
2	**INPUTS**															**OUTPUT**
3			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
4			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**			**Dist.from windows**	**# of windows**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	**Illumination of the points**
5	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	
……	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..
86	81	Z9	1.00	9.00	12.10	43.00	84.00	0.00	0.00	2.00	2.00	2.00	1.00	0.77	3.00	218.00
87	82	103	114.00	12.00	20.10	683.00	31.00	3.50	0.19	1.00	3.00	1.00	2.00	1.30	2.00	228.00
88	83	Z4	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	3.00	1.00	1.00	0.98	3.00	229.00
89	84	111	1.00	9.00	12.10	43.00	84.00	0.00	0.00	2.00	2.00	2.00	2.00	0.77	3.00	125.00
90	85	Z1	106.00	9.00	6.20	398.00	77.00	1.10	0.06	2.00	3.00	1.00	1.00	0.98	4.00	235.00
91	86	104	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	3.00	1.00	2.00	1.30	3.00	238.00
……	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..
100	95	111	1.00	9.00	12.10	43.00	84.00	0.00	0.00	1.00	2.00	2.00	2.00	0.77	1.00	300.00
101	96	108	14.00	9.00	11.10	239.00	89.00	0.50	0.03	2.00	1.00	2.00	2.00	0.77	3.00	146.00
102	97	Z9	7.00	9.00	15.50	401.00	64.00	0.80	0.04	1.00	2.00	2.00	1.00	0.77	1.00	314.00
103	98	110	111.00	9.00	8.20	350.00	46.00	0.90	0.05	1.00	2.00	2.00	2.00	0.77	2.00	323.00
104	99	Z2	24.00	9.00	7.00	110.00	52.00	0.50	0.03	2.00	3.00	1.00	1.00	1.30	4.00	363.00
105	100	Z3	17.00	9.00	10.90	280.00	68.00	0.70	0.04	2.00	3.00	1.00	1.00	1.30	3.00	377.00
106	**Min. Value**		1.00	2.00	3.00	4.00	5.00	0.00	0.00	1.00	1.00	1.00	1.00	0.58	1.00	9.40
107	**Max. Value**		114.00	15.00	22.00	700.00	89.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	1679.00

Table 4.4. Data scaling table of the model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
111	**Step-2 : Scaled Inputs**															
112																
113	**INPUTS**															**OUTPUT**
114			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
115			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**			**Dist.from windows**	**# of windows**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	**Illumination of the points**
116	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	
117	1	Z1	-1.00	1.00	-0.13	-0.92	0.33	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	0.11	-1.00	1.00
118	2	Z1	-0.89	1.00	0.56	-0.72	0.03	-0.77	-0.79	-1.00	1.00	-1.00	-1.00	0.11	-1.00	1.00
119	3	101	-0.96	1.00	-0.36	-0.88	0.77	-1.00	-1.00	1.00	1.00	-1.00	1.00	0.11	0.33	1.00
120	4	103	-0.50	1.00	0.12	-0.92	0.80	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
121	5	107	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	-1.00	0.00	1.00	1.00	-0.47	-1.00	1.00
122	6	Z12	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	1.00	0.00	1.00	-1.00	-1.00	0.33	1.00
123	7	107	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
124	8	101	-0.89	1.00	0.56	-0.72	0.03	-0.77	-0.79	1.00	1.00	-1.00	1.00	0.11	1.00	1.00
125	9	104	-0.36	-1.00	-0.62	-0.97	0.83	-1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
126	10	Z12	0.88	1.00	0.04	-0.70	0.17	-0.66	-0.68	1.00	0.00	1.00	-1.00	-1.00	1.00	1.00
127	11	Z1	-0.89	0.00	0.64	0.73	-0.40	0.37	0.37	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
128	12	Z3	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	1.00	-0.33	1.00
129	13	104	0.08	-1.00	-1.00	-0.75	0.97	-1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
130	14	106	-0.47	-1.00	-0.72	-1.00	0.53	-1.00	-1.00	-1.00	0.00	1.00	1.00	-1.00	-0.33	1.00
131	15	112	-0.47	-1.00	-0.72	-1.00	0.53	-1.00	-1.00	-1.00	-1.00	1.00	1.00	0.53	-1.00	1.00

(cont. on next page)

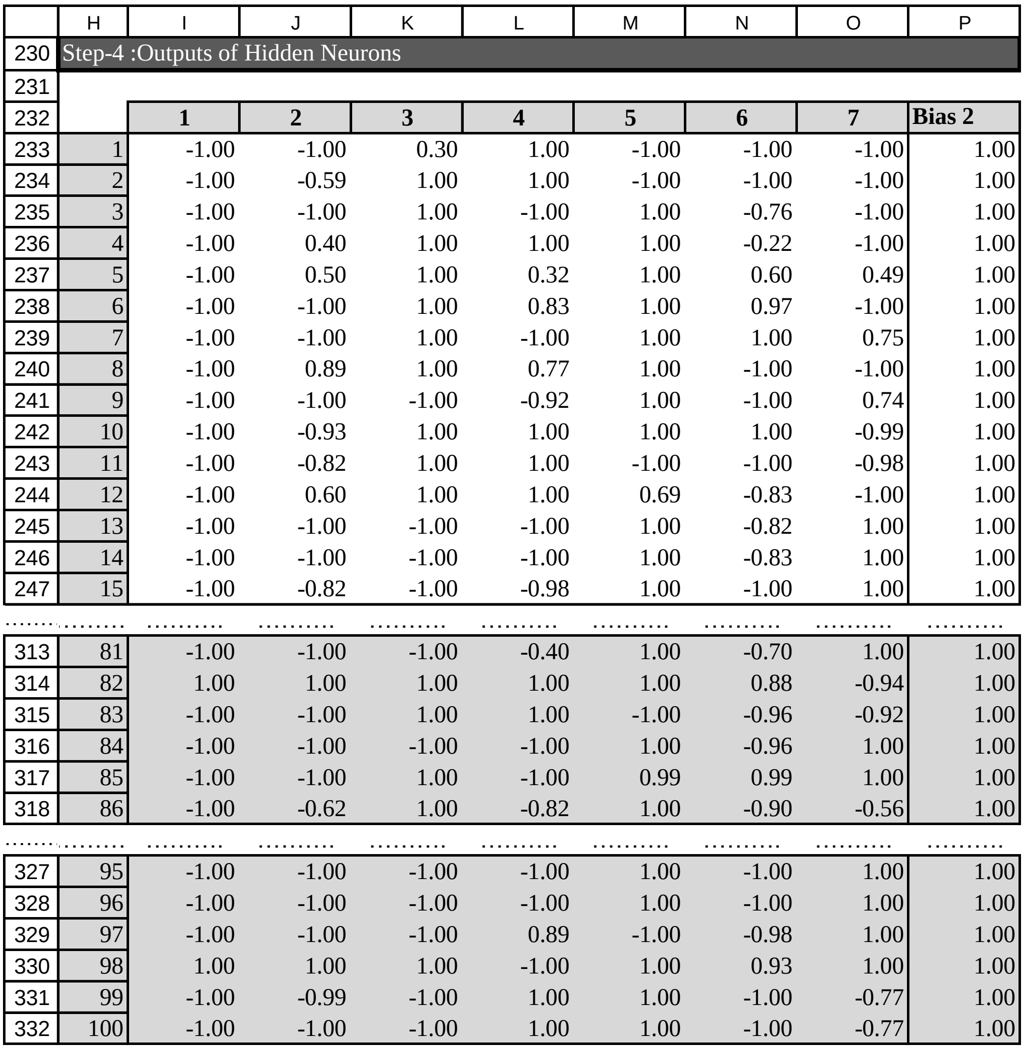
Table 4.4. (cont.) Data scaling table of the model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
111	**Step-2 : Scaled Inputs**															
112																
113	**INPUTS**															**OUTPUT**
114			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
115			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**			**Dist.from windows**	**# of windows**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	**Illumination of the points**
116	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	
……	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..
86	81	Z9	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	1.00	0.00	1.00	-1.00	-0.47	0.33	1.00
87	82	103	1.00	0.00	0.77	0.95	-0.93	1.00	1.00	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
88	83	Z4	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
89	84	111	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
90	85	Z1	0.86	-1.00	-0.94	0.12	0.60	-0.37	-0.37	1.00	1.00	-1.00	-1.00	0.11	1.00	1.00
91	86	104	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
……	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..	……..
100	95	111	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	-1.00	0.00	1.00	1.00	-0.47	-1.00	1.00
101	96	108	-0.77	-1.00	-0.34	-0.34	1.00	-0.71	-0.68	1.00	-1.00	1.00	1.00	-0.47	0.33	1.00
102	97	Z9	-0.89	-1.00	0.20	0.13	0.17	-0.54	-0.58	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
103	98	110	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	-1.00	0.00	1.00	1.00	-0.47	-0.33	1.00
104	99	Z2	-0.59	-1.00	-0.84	-0.72	-0.23	-0.71	-0.68	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
105	100	Z3	-0.72	-1.00	-0.36	-0.22	0.30	-0.60	-0.58	1.00	1.00	-1.00	-1.00	1.00	0.33	1.00

Table 4.5. Weight matrix (W) of the model

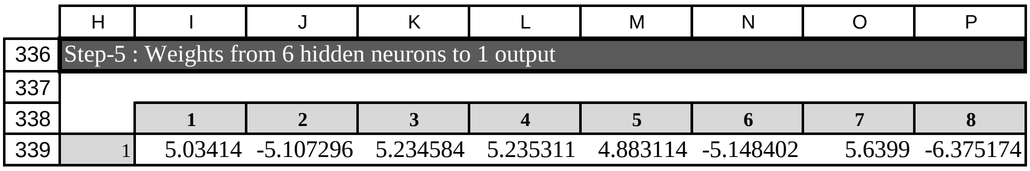
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
220	Step-3 : Weights														
221		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
222	1	29.104	-5.6517	41.875	-5.8039	-19.212	13.265	4.1737	-11.939	19.905	32.634	8.3608	41.115	1.9705	-14.764
223	2	2.5702	-1.5145	7.7615	-6.1532	-6.2146	-27.154	32.646	-3.8343	-0.123	1.4589	1.5273	2.7137	3.3605	1.7488
224	3	2.361	12.631	3.3083	10.353	-1.1152	-42.533	46.899	-6.0955	2.8353	-0.9775	1.1083	-10.037	17.369	14.395
225	4	5.0417	-0.1288	11.452	-12.009	-1.3013	-27.382	34.609	-2.6096	2.9864	1.6988	-5.4326	7.349	-0.6842	3.5049
226	5	4.7504	0.3648	-11.632	-18.191	-15.143	-32.483	36.703	10.255	3.7251	15.457	5.6989	19.037	0.9822	5.0388
227	6	1.6306	3.2973	-3.6928	0.621	3.1924	22.115	-17.498	-0.7186	4.4136	5.7525	-0.5588	1.8479	2.0691	0.3854
228	7	-2.3027	-2.9836	-7.7521	1.9415	2.6767	27.676	-20.938	-0.8265	-1.4516	2.8486	1.5314	-2.3763	-0.1089	4.7156

Table 4.6. Outputs of hidden nodes of the model



	H	I	J	K	L	M	N	O	P
230	Step-4 :Outputs of Hidden Neurons								
231									
232		1	2	3	4	5	6	7	Bias 2
233	1	-1.00	-1.00	0.30	1.00	-1.00	-1.00	-1.00	1.00
234	2	-1.00	-0.59	1.00	1.00	-1.00	-1.00	-1.00	1.00
235	3	-1.00	-1.00	1.00	-1.00	1.00	-0.76	-1.00	1.00
236	4	-1.00	0.40	1.00	1.00	1.00	-0.22	-1.00	1.00
237	5	-1.00	0.50	1.00	0.32	1.00	0.60	0.49	1.00
238	6	-1.00	-1.00	1.00	0.83	1.00	0.97	-1.00	1.00
239	7	-1.00	-1.00	1.00	-1.00	1.00	1.00	0.75	1.00
240	8	-1.00	0.89	1.00	0.77	1.00	-1.00	-1.00	1.00
241	9	-1.00	-1.00	-1.00	-0.92	1.00	-1.00	0.74	1.00
242	10	-1.00	-0.93	1.00	1.00	1.00	1.00	-0.99	1.00
243	11	-1.00	-0.82	1.00	1.00	-1.00	-1.00	-0.98	1.00
244	12	-1.00	0.60	1.00	1.00	0.69	-0.83	-1.00	1.00
245	13	-1.00	-1.00	-1.00	-1.00	1.00	-0.82	1.00	1.00
246	14	-1.00	-1.00	-1.00	-1.00	1.00	-0.83	1.00	1.00
247	15	-1.00	-0.82	-1.00	-0.98	1.00	-1.00	1.00	1.00
………	………	……….	……….	……….	……….	……….	……….	……….	……….
313	81	-1.00	-1.00	-1.00	-0.40	1.00	-0.70	1.00	1.00
314	82	1.00	1.00	1.00	1.00	1.00	0.88	-0.94	1.00
315	83	-1.00	-1.00	1.00	1.00	-1.00	-0.96	-0.92	1.00
316	84	-1.00	-1.00	-1.00	-1.00	1.00	-0.96	1.00	1.00
317	85	-1.00	-1.00	1.00	-1.00	0.99	0.99	1.00	1.00
318	86	-1.00	-0.62	1.00	-0.82	1.00	-0.90	-0.56	1.00
………	………	……….	……….	……….	……….	……….	……….	……….	……….
327	95	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00
328	96	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00
329	97	-1.00	-1.00	-1.00	0.89	-1.00	-0.98	1.00	1.00
330	98	1.00	1.00	1.00	-1.00	1.00	0.93	1.00	1.00
331	99	-1.00	-0.99	-1.00	1.00	1.00	-1.00	-0.77	1.00
332	100	-1.00	-1.00	-1.00	1.00	1.00	-1.00	-0.77	1.00

Table 4.7. Outputs of hidden nodes of the model



	H	I	J	K	L	M	N	O	P
336	Step-5 : Weights from 6 hidden neurons to 1 output								
337									
338		1	2	3	4	5	6	7	8
339	1	5.03414	-5.107296	5.234584	5.235311	4.883114	-5.148402	5.6399	-6.375174

Table 4.8. Final NNs output of the model

	J	K	L	M	N	O	P
342	Step-6 : NNs Output				Step-7 : Errors		
343							
344			**NN Output**		**NN Output Scaled Back**	**Actual Output**	**% Error**
345		1	-1.00		9.49	9.40	1.00
346		2	-1.00		11.68	11.80	1.00
347		3	-1.00		12.47	12.60	1.00
348		4	-0.99		18.81	19.00	1.00
349		5	-0.99		21.31	21.10	1.00
350		6	-0.99		21.38	21.60	1.00
351		7	-0.98		24.64	24.40	1.00
352		8	-0.98		25.75	25.50	1.00
353		9	-0.98		30.08	30.00	0.28
354		10	-0.97		37.17	36.80	1.00
355		11	-0.97		37.37	37.00	1.00
356		12	-0.97		37.98	37.60	1.00
357		13	-0.97		38.18	37.80	1.00
358		14	-0.96		39.69	39.30	1.00
359		15	-0.96		42.72	42.30	1.00
…..	…..	…..	…..	…..	…..	…..	…..
425		81	0.43		1203.84	1216.00	1.00
426		82	-0.74		230.28	228.00	1.00
427		83	-0.74		226.71	229.00	1.00
428		84	-0.86		126.25	125.00	1.00
429		85	-0.73		237.35	235.00	1.00
430		86	-0.73		235.62	238.00	1.00
…..	…..	…..	…..	…..	…..	…..	…..
439		95	-0.81		164.34	166.00	1.00
440		96	-0.80		174.53	172.80	1.00
441		97	-0.79		188.87	187.00	1.00
442		98	-0.63		319.77	323.00	1.00
443		99	-0.58		359.37	363.00	1.00
444		100	-0.56		380.77	377.00	1.00

Table 4.9. Percentages of the Errors of the model

Error on %80 of the cases (Training)	1.08
Error on %20 of the cases (Testing)	3.32

Final weighted error	2.20

4.2. Sensitivity Analysis

Sensitivity analysis explores the model response, evaluates the accuracy of model, tests the validity of the assumption made in engineering design (Song, et al. 2008). The mapping Y= f (X) between an output Y of a computational model and a set of uncertain input factors X= (X_1; . . . ; X_k) is analyzed in order to quantify the relative contribution of each input factor to the uncertainty of Y (Ratto, et al. 2008). Song et al. (2008) point out that ‘‘sensitivity is used to find the rate of change in a model output due to changes in the model inputs in deterministic design, which is usually performed by partial derivative analytically or numerically.’’

By employing sensitivity analysis on a trained network, some irrelevant inputs can be found and then eliminated. Such an elimination of irrelevant inputs can sometimes improve a network's performance. “This batch starts by varying the first input between its mean +/- a user defined number of standard deviations while all other inputs are fixed at their respective means. The network output is computed for a user defined number of steps above and below the mean. This process is then repeated for each input. Finally, a report is generated which summarizes the variation of each output with respect to the variation of each input. (NeuroSolutions 2002).

The model was subjected to sensitivity analysis to determine the effect of each input variable on the model output variable. The analysis was carried out by the assistance of the NeuroSolutions Software by NeuroDimensions Inc. The inputs and output was brought under the control of NeuroSolutions, but the network learning is disabled. As a result of this the model was avoided the effect of networks weights. The inputs to the network are changed every time. Then corresponding effect on the output is reported as a percentage in a figure.

In this model four parameters' sensitivity values are more than 40% which are found to be the most effective illuminance parameters. These parameters are; hour, number of windows, orientation and identification point. UV day as the parameter was found to be least effective for the model. A similar interaction was observed for the impact of dimensions of the room and outdoor temperature on lighting levels. The sensitivity percentages of the parameters are shown in the Figure 4.5.

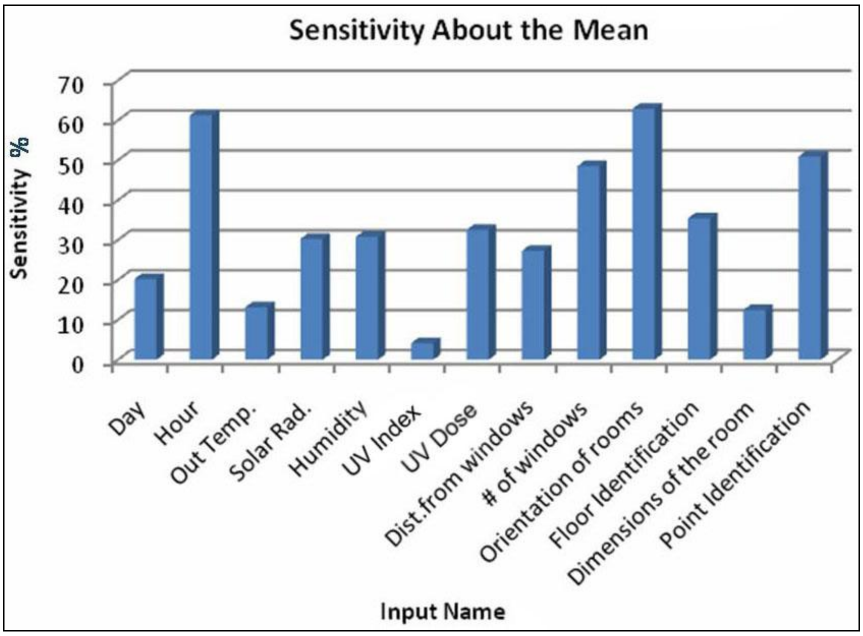


Figure 4.5. Effect percentages of the variables on the model

Orientation of rooms representing the 61% of sensitivity and hour representing the 60% of sensitivity were found to be the most effective variables in daylighting prediction. The following effective ones were point identification displaying almost 50% of sensitivity and number of windows displaying 48% of sensitivity On the other hand, UV, outdoor temperature and dimensions of the room were the least effective ones displaying 3%, 12% and 11% of sensitivity respectively.

All other parameters' sensitivity percentages ranged from 18 to 49, shown in Figure 4.5. All thirteen parameters that are used as inputs in the model have an effect which changes the average prediction accuracy of the model.

4.3. Discussions

Although artificial neural network (ANN) model, as an intelligence method, has been used in the modeling of several research processes for various fields, it is not very common in the field of architecture. For example, Akkurt et al. (2004) in the field of mechanical engineering applied ANNs to predict compressive strength of cement mortar. Sofuoğlu (2008) used ANN in the modeling of building-related symptoms in office buildings. Tayfur (2006), in the field of civil engineering, employed ANN to predict longitudinal dispersion coefficient in natural streams. Günaydin and Doğan (2004) estimated the cost of the structural systems of reinforced concrete structural skeleton buildings in the early architectural design phase by an ANN model in the field of construction management (Günaydın and Doğan 2004). Another study in the field of energy conservation, solar radiation modeling was constructed for different climates and the ANN model was satisfactorily applied to predict daily global radiation using sunshine duration (Lam, et al. 2008). Despite these studies in engineering fields, there was no real evidence in literature for ANN models' recent use in the field of architecture.

Results may guide further researchers and lighting designers in two ways, as iterated below.

a. If there will be a need to evaluate daylighting for existing office buildings, the method used in this study may be used for its simplicity and flexibility.

Although this study was conducted for only one office building, it was demonstrated that all building parameters and weather parameters displayed an important impact on daylighting illuminance.

b. Further investigations should be carried out in order to improve the model with the inclusion of more parameters and a larger set of data. This study also established the type of parameters that have more impact on illuminance and are explicitly to be considered in design stage.

a. Prediction methods:

Daylighting predictions effect mostly in designing stage. Predicting the illumination level has been done in different ways. The most specific ones can be classified in three groups; model studies, analytical formulas and computer simulations (Egan 1983, Moore 1993, Lechner 2001, Park and Athienitis 2003). In this study, however, an artificial neural network model is offered as a new methodology to predict daylighting illuminance. The method proposed in this study has several advantages. It is simple, less time consuming to conduct investigations and the model has a high capacity to learn and employ high amount of parameters.

In this study the data wasn’t predicted with other methods (analytical calculations, computer programs and scale models) and the model’s output wasn’t compared with these methods. In the future studies the data may be predicted with other methods and the ANN model’s output may be compared with these methods. Consequently, there can be a perceptible comparison of the daylighting prediction methods.

b. Illuminance measurement:

Illuminance values in different kind of days were measured. Because interior illuminance due to daylight changes as a function of sky conditions, absolute measurements of illuminance are not directly indicative of actual building performance.

The field study showed that the illuminance level at the office rooms which are placed at East of the building can be reached a maximum level of 1679 lux in the period between the months of November 2007 and February 2008. In addition the rooms which are placed at West of the building can be reached a minimum level 9.40 lux. These levels are not appropriate for office buildings according to the Turkish Standards where the illumination level in offices is suggested to be in a range from 300 to 750 lux.

Measurements in the field study provided detailed performance information under real sun and sky conditions. The illuminance from the sky is not constant, and the variations in daylight can be quite large depending on season, location or latitude, and weather condition (such as cloudiness). Simulating different seasonal conditions in this manner will superimpose several daylighting scenarios on the model. There can be more variables of different cases. The measurement of working plane illuminance may be used to assess whether installation performance meets specification.

c. The prediction power of the model:

The prediction power of the model which can be defined as the predicted values in the model having close matches with the actual data is ensured. This testing can be more useful to get an idea about the general performance. The prediction capability of the network was tested by the data that are selected from the whole data set. This model is an appropriate method for prediction because the datas which were used in testing were totally different, independent from the datas used in training. The model learning was performed with 80 data sets in the training step. In the testing step, the prediction capability of the model was tested with different 20 data sets. As to have statistically balanced data, the training and testing data set had approximately the same minimum to maximum ranges and average illuminance values as in the main data set. The test cases had an important role to ensure good generalization performance and avoid overtraining, in comparison they are fewer from the training set. It was considered that the model arrived at the optimum solution with an average percentage error by checking the outcomes of this process. Training and testing of the network continued until no improvement in the output is achieved. This process is performed after a predetermined 100 iterations. There were 1000 and 10000 iterations performed on the model. It was observed that when the number of iterations was increased there weren’t too many changes in the prediction power of the model. Whereas the number of the solver which was performed in the macro coded in the model was increased and it was seen that there wasn’t any change in the prediction power. The predetermined number of seventeen is found to be the most appropriate for this model. This model can be easily used in different cases.

d. The outcome of the sensitivity analysis:

The sensitivity analysis showed that the most effective illuminance parameters are hour, number of windows, orientation and identification point and the least effective parameters are dimensions of the room, outdoor temperature and UV. On the other hand all thirteen parameters that are used as inputs in the model have an effect which changes the average prediction accuracy of the model. This implies that for any daylighting design strategy, designers first should decide on the building orientation, window area and time concern, which have been very commonly known aspects in architecture. Thus this explains the models' satisfaction. Although least effective parameters have been mentioned in literature, the reason for their low impact may be the choice of a single sample building. Their impact may be proved by constructing another model with the inclusion of large number of data

This model may supply beneficial inputs in designing stage and in daylighting performance assessment of buildings by making predictions and comparisons. These researches can be able to become a base of a greater study about evaluating the comfort conditions of the office buildings.

CHAPTER 5

CONCLUSION

This study dealt with daylighting in office buildings. It concentrated on the prediction of daylighting illuminance in order to provide a design assist tool to determine illuminance and light distributions for architects and designers.

An intelligence model named Artificial Neural Networks was employed to predict daylighting illuminance. After a long procedure under working on parameters of the office building of the Faculty of Architecture in İYTE, it was possible to say that this model was agreeable to predict the daylight levels during the day. The input parameters of our model are as following; date, hour, outdoor temperature, solar radiation, humidity, UV Index and UV dose, distance to windows, number of windows, orientation of rooms, floor identification, room dimensions and point identification. These parameters were defined as relevant to guidelines and literature about daylighting design.

The model was tested by input parameters in order to see their effects on output parameter. It was clear that some input parameters such as hour, number of windows, orientation, and identification point had an important effect on illuminance. The least effect of UV was significant. However, it was noted that it still implied a slight impact on illuminance. According to the model, another noteworthy result was that all inputs had an effect. This seemed to be the primary factor for the models' success in predicting illuminance satisfactorily.

Because of having several methods such as guidelines, scale models, computer programs and analytical formula to determine daylight illuminance for a long time, all researchers have been familiar with those in many studies. They have realized their benefits and deficiencies as a result of experience. This new methodology can construct a new consciousness among researchers and architects who are interested in daylighting studies. It is an alternative way to test the illuminance and sure that researchers may prefer to follow this new method to see its results. Also they may enlarge the scope of this model by adding new formulas or by evaluating location parameters, climatic and geological aspects and environmental requirements.

The model has several advantages. It is simple, less time consuming to conduct investigations and the model has a high capacity to learn and employ high amount of parameters. The model can be used for different buildings by changing the type and number parameters according to new cases. As a result, this model can assist to have approximately exact predictions of daylight illuminances. Investigation about this subject may be able to support the office buildings' having intended daylight comfort conditions.

Consequently, researchers will then benefit from this model in daylighting performance assessment of buildings by making predictions and comparisons. Designers may use such a model as an assist tool in the daylighting design process by determining illuminance. Consequently, the utility of this model is the capability to depict satisfactory predictions of daylight illuminances and it is a less time consuming process in providing feedback information for existing buildings.

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APPENDIX A

DESCRIPTION OF THE CASE BUILDING

The subject building is associated with the Faculty of Architecture of İzmir Institute of Technology (İYTE) in İzmir, Turkey. This office building is situated in the northern part of the campus on a hilly site (latitude 38° 19'; longitude 26° 37'). Offices are located in a 2-story building (Block C) which is approximately 1072m^2. The story height for all rooms is 3.50m. There are a total of 24 rooms occupied by instructors and professors. Each floor contains 12 rooms of which 7 are facing west, 5 are facing east and an atrium located in the centre of the building with a large skylight (17.00 x 3.50m). A circulation corridor connects all rooms to the atrium. The rooms have windows which are placed from the ceiling to the floor of the rooms. All the windows have the width of 1.00m and 3.50m height.

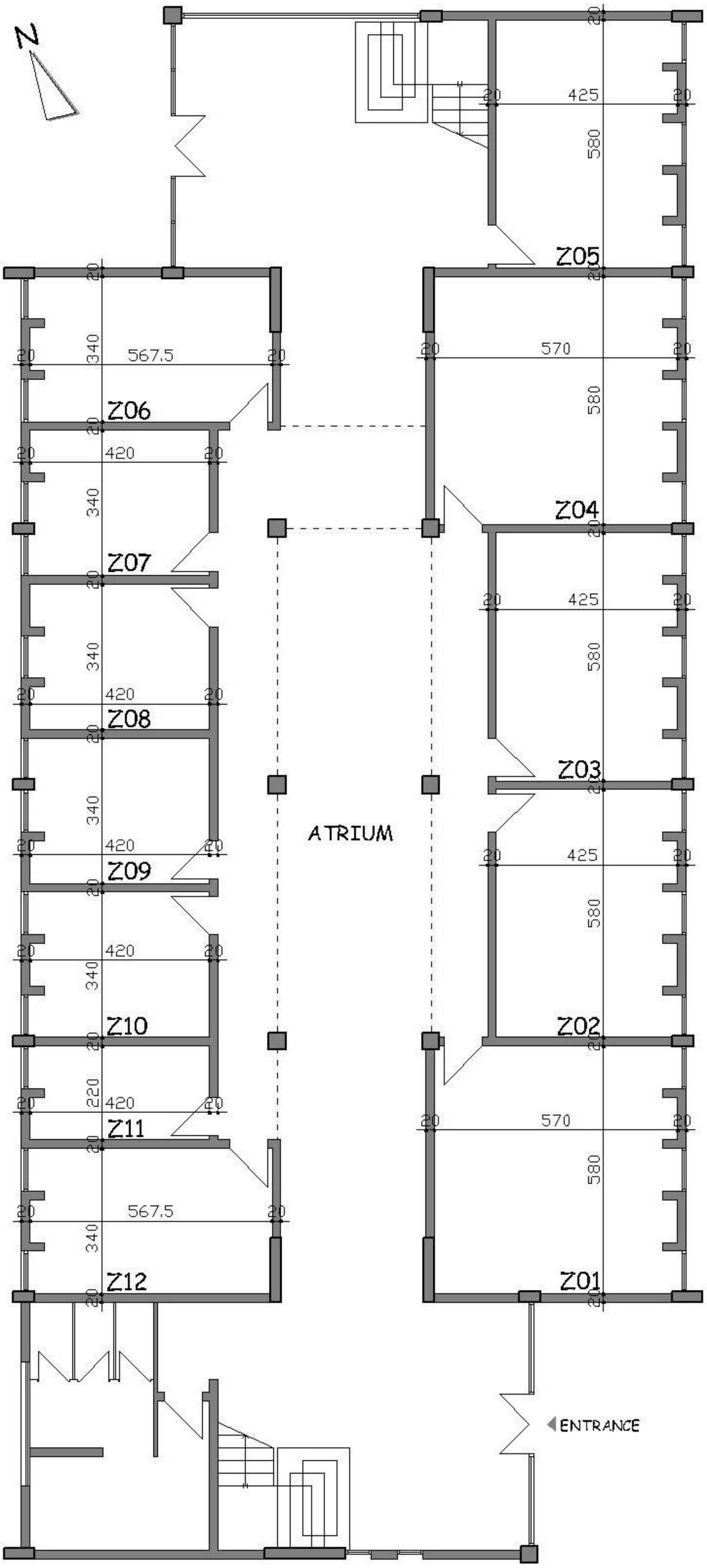


Figure A.1. Ground Floor Plan

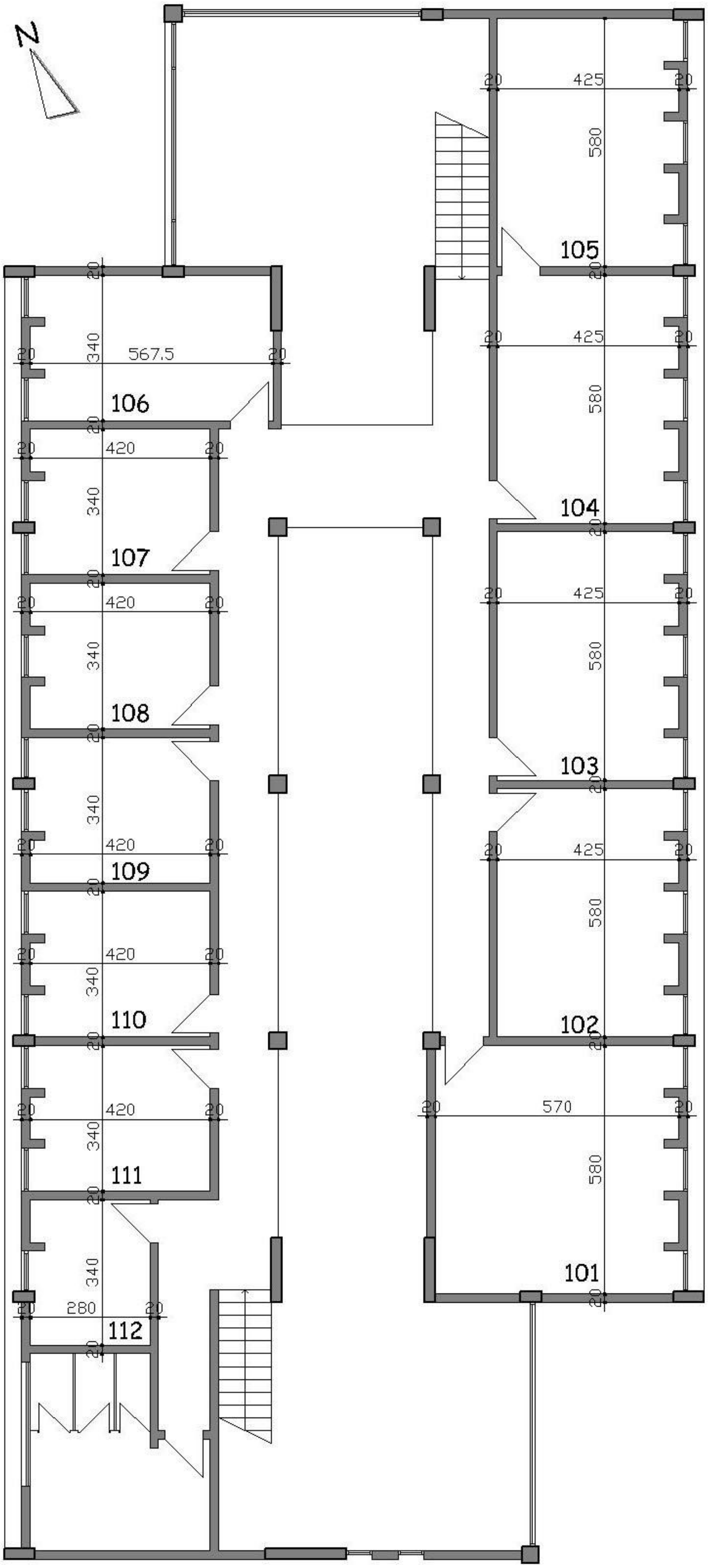


Figure A.2. First Floor Plan

APPENDIX B

EXAMPLES OF DATA SHEETS

In this section examples of the data sheets which were prepared for the illuminance measurements of the field study for one are presented. The measured illuminance level of each point that was arranged in the case office building's rooms was coded in the table of the data sheet. The measurements were performed three times in each survey day.

Table B.1. An example of a record sheet for illuminance measurements (Data table for 28th of February measured between the hours 09:00 am and 10:00 am)

Date			**Time**						
February.28.2008			09:00-10:00						
Ground Floor Rooms					**First Floor Rooms**				
Z1	A1	A2	B1	B2	**101**	A1	A2	B1	B2
	222	603	207	193		308	379	120	205
Z2	A1	A2	B1	B2	**102**	A1	A2	B1	B2
	555	669	385	369		235	683	463	405
Z3	A1	A2	B1	B2	**103**	A1	A2	B1	B2
	472	718	610	900		423	726	576	399
Z4	A1	A2	B1	B2	**104**	A1	A2	B1	B2
	236	518	297	266		277	428	221	223
Z5	A1	A2	B1	B2	**105**	A1	A2	B1	B2
	594	878	403	573		416	78	557	478
Z6	A1	A2	B1	B2	**106**	A1	A2	B1	B2
	268	371	53.5	60.8		950	480	111	83.6
Z7	A1	A2	B1	B2	**107**	A1	A2	B1	B2
	1146	617	102	87.5		224	253	42.6	46
Z8	A1	A2	B1	B2	**108**	A1	A2	B1	B2
	476	860	42.4	58.1		258	314	80.2	71.5
Z9	A1	A2	B1	B2	**109**	A1	A2	B1	B2
	432	743	206	288		569	1032	162	228
Z10	A1	A2	B1	B2	**110**	A1	A2	B1	B2
	312	320	112	115		484	478	229	218
Z11	A1	A2	B1	B2	**111**	A1	A2	B1	B2
X						497	489	166	185
Z12	A1	A2	B1	B2	**112**	A1	A2	B1	B2
	408	488	64.1	65.2		743	456	175	246

Table B.2. An example of a record sheet for illuminance measurements (Data table for 28th of February measured between the hours 12:00 am and 01:00 pm)

Date			**Time**						
February.28.2008			12:00-13:00						
Ground Floor Rooms					**First Floor Rooms**				
Z1	A1	A2	B1	B2	**101**	A1	A2	B1	B2
	191	128	27.2	30		208	136	50.1	54.8
Z2	A1	A2	B1	B2	**102**	A1	A2	B1	B2
	231	158	65.8	53.9		102	218	160	176
Z3	A1	A2	B1	B2	**103**	A1	A2	B1	B2
	145	130	137	80.8		297	228	284	218
Z4	A1	A2	B1	B2	**104**	A1	A2	B1	B2
	143	185	82.1	59.2		141	188	96.6	175
Z5	A1	A2	B1	B2	**105**	A1	A2	B1	B2
	233	182	137	183		306	315	282	181
Z6	A1	A2	B1	B2	**106**	A1	A2	B1	B2
	427	849	105	112		882	393	63.3	72.6
Z7	A1	A2	B1	B2	**107**	A1	A2	B1	B2
	2250	1237	200	175		1237	797	178	79.9
Z8	A1	A2	B1	B2	**108**	A1	A2	B1	B2
	927	1080	113	112		637	453	105	111
Z9	A1	A2	B1	B2	**109**	A1	A2	B1	B2
	753	899	333	488		760	1471	197	215
Z10	A1	A2	B1	B2	**110**	A1	A2	B1	B2
	872	637	195	132		447	657	232	206
Z11	A1	A2	B1	B2	**111**	A1	A2	B1	B2
X						493	632	198	243
Z12	A1	A2	B1	B2	**112**	A1	A2	B1	B2
	695	722	54.8	67.2		808	459	342	314

Table B.3. An example of a record sheet for illuminance measurements (Data table for 28th of February measured between the hours 03:00 pm and 04:00 pm)

Date			**Time**						
February.28.2008			15:00-16:00						
Ground Floor Rooms					**First Floor Rooms**				
Z1	A1	A2	B1	B2	**101**	A1	A2	B1	B2
	59.5	59.2	32.3	17.5		57.3	28.3	26.8	27
Z2	A1	A2	B1	B2	**102**	A1	A2	B1	B2
	95.1	99.8	52.4	46.6		58	66.9	58.9	62
Z3	A1	A2	B1	B2	**103**	A1	A2	B1	B2
	85.2	98.2	80.5	90.1		78.4	68.2	61.4	48.7
Z4	A1	A2	B1	B2	**104**	A1	A2	B1	B2
	37.2	84.8	33.3	28		69.5	47	62.3	56.9
Z5	A1	A2	B1	B2	**105**	A1	A2	B1	B2
	61.6	64.4	58	60.1		89	78.3	90.7	69.3
Z6	A1	A2	B1	B2	**106**	A1	A2	B1	B2
	62.3	150	14.1	14.5		64.8	63.8	11.3	12.5
Z7	A1	A2	B1	B2	**107**	A1	A2	B1	B2
	455	180	24.7	26.3		154	151	75	68.1
Z8	A1	A2	B1	B2	**108**	A1	A2	B1	B2
	194	223	11.9	11.6		74.6	73	16.5	18.6
Z9	A1	A2	B1	B2	**109**	A1	A2	B1	B2
	263	281	73.5	86.9		181	252	32.7	39
Z10	A1	A2	B1	B2	**110**	A1	A2	B1	B2
	207	210	29.3	32.9		126	183	45.4	46
Z11	A1	A2	B1	B2	**111**	A1	A2	B1	B2
X						114	149	39.6	50.2
Z12	A1	A2	B1	B2	**112**	A1	A2	B1	B2
	149	191	17.5	18.9		260	166	84.8	71.8

APPENDIX C

THE METEOROLOGICAL DATA

The meteorological data was obtained from the Weather Station in the Department of Mechanical Engineering in İYTE (Tosun 2008) in order to use for the application of the model. The meteorological data contained the period between the months November 2007 and February 2008. There is a descriptive example of the meteorological data sheet presented below (Table C.1). The graphs of the whole data are shown in the Figures C.1-5.

Table C.1. Meteorological data of February (Date: 21-27.02.2008)

Date	**Time**	**Temp. Out**	**Out Hum.**	**Solar Rad.**	**UV Index**	**UV Dose**
21.02.2008	09:00	11.2	64	184	0.8	0.04
21.02.2008	12:00	14.2	58	339	2.1	0.11
21.02.2008	15:00	14.2	64	115	0.6	0.03
22.02.2008	09:00	12.8	80	306	0.8	0.04
22.02.2008	12:00	16.2	53	587	2	0.11
22.02.2008	15:00	16.7	48	223	1	0.05
23.02.2008	09:00	9.2	90	294	0.8	0.04
23.02.2008	12:00	14.8	64	656	2.7	0.14
23.02.2008	15:00	15.2	51	486	1.3	0.07
24.02.2008	09:00	12.8	63	303	0.8	0.04
24.02.2008	12:00	14.5	55	654	2.7	0.14
24.02.2008	15:00	15.8	42	496	1.6	0.09
25.02.2008	09:00	8.2	46	350	0.9	0.05
25.02.2008	12:00	11.9	35	700	3.2	0.17
25.02.2008	15:00	14	25	525	1.9	0.1
26.02.2008	09:00	11.8	33	347	1	0.05
26.02.2008	12:00	14.8	28	697	3.5	0.19
26.02.2008	15:00	17.4	21	509	2	0.11
27.02.2008	09:00	10.8	74	321	1	0.05
27.02.2008	12:00	20.2	29	611	3.2	0.17
27.02.2008	14:30	20.5	38	578	2.5	0.13

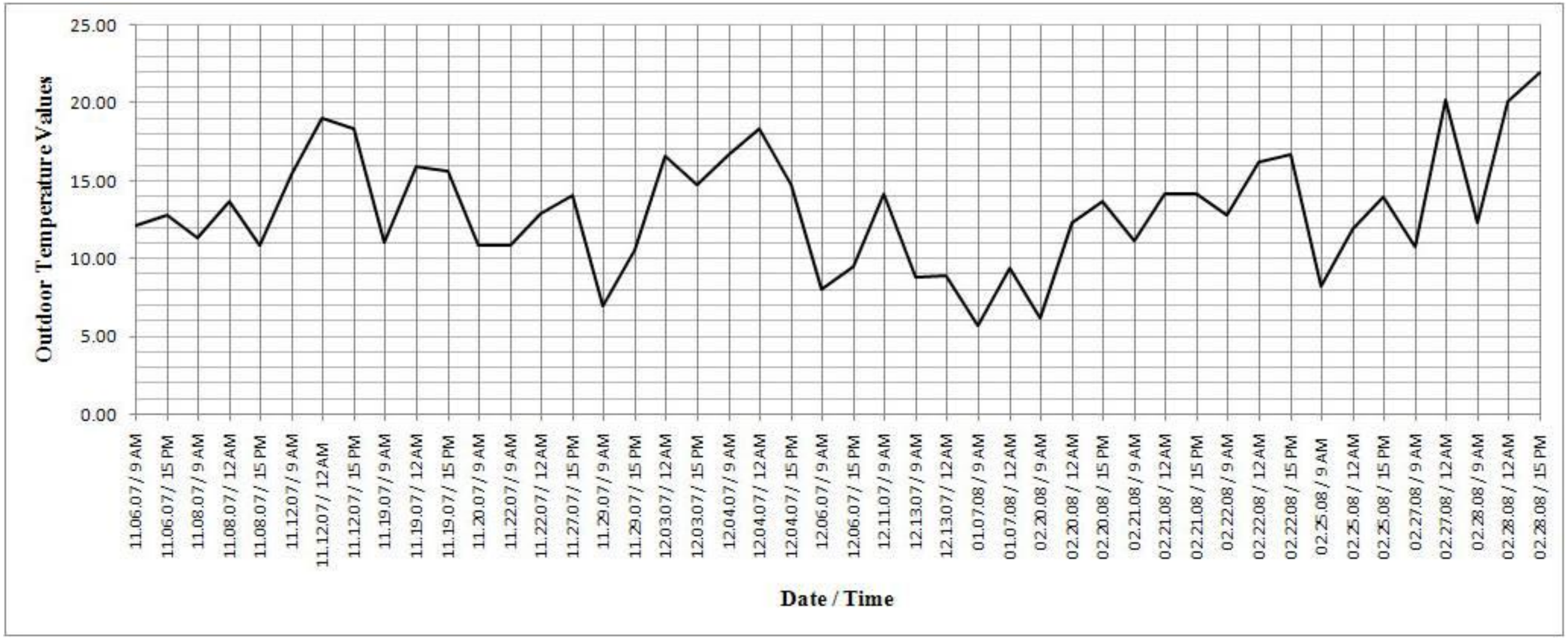


Figure C.1. The Graph of Outdoor Temperature

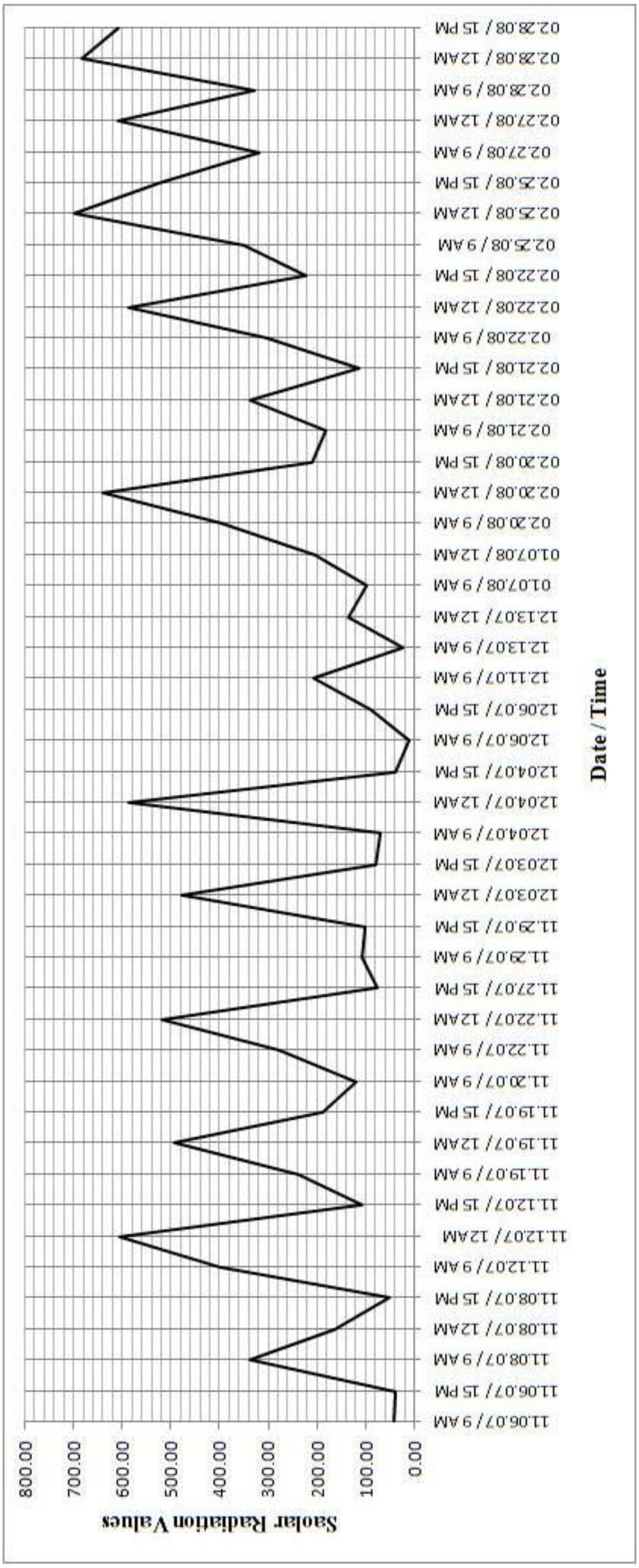


Figure C.2. The Graph of Solar Radiation

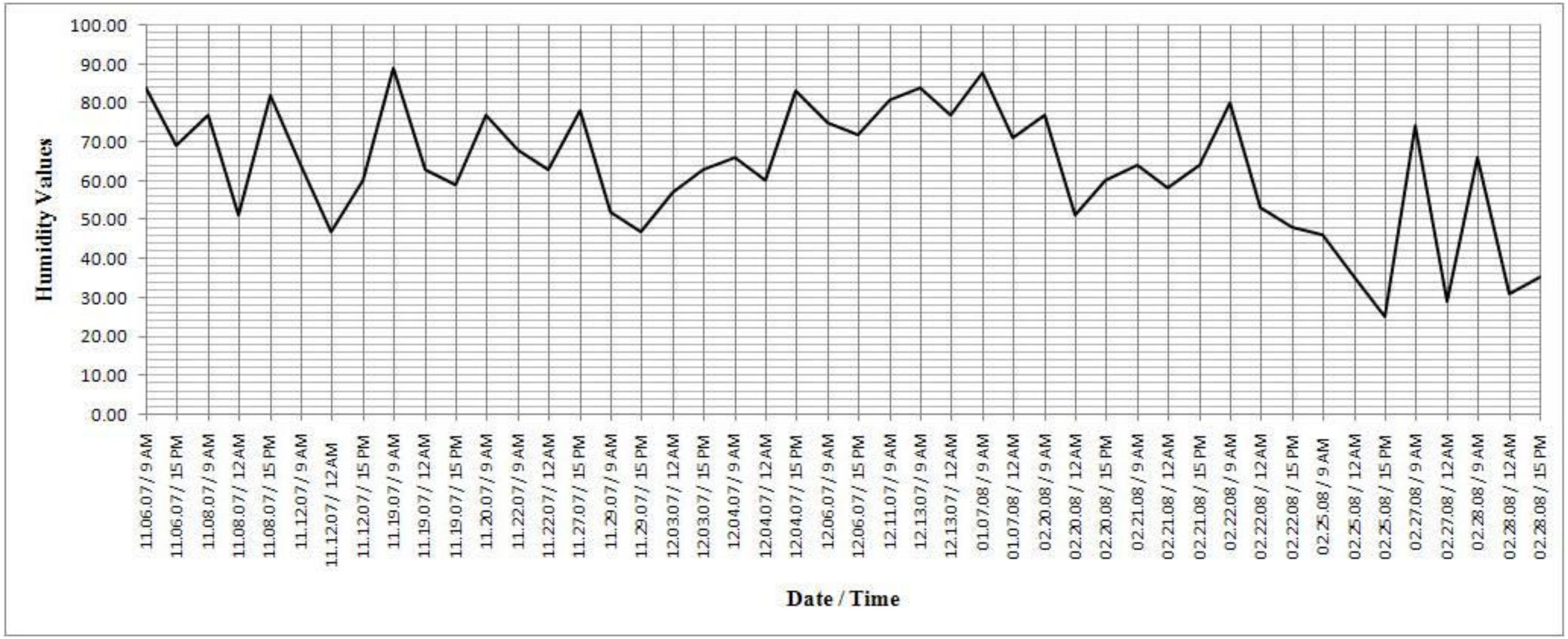


Figure C.3. The Graph of Humidity

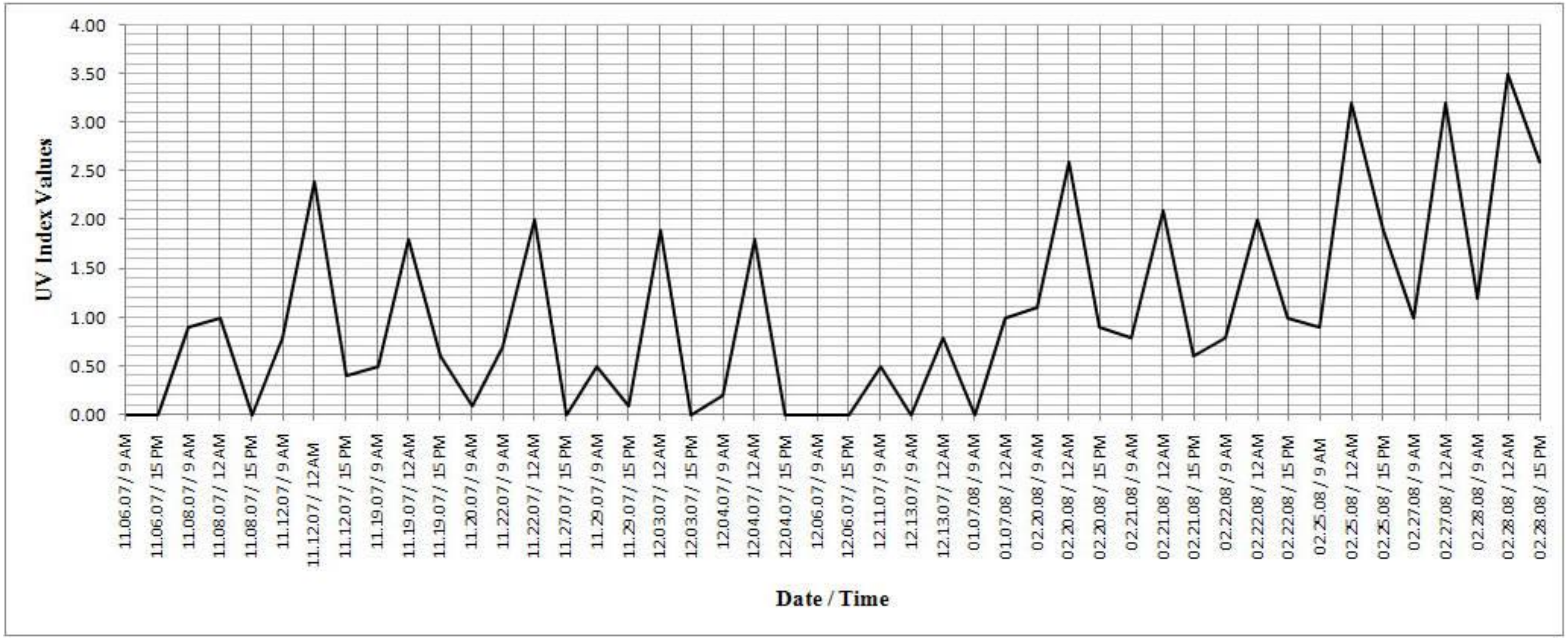


Figure C.4. The Graph of UV Index

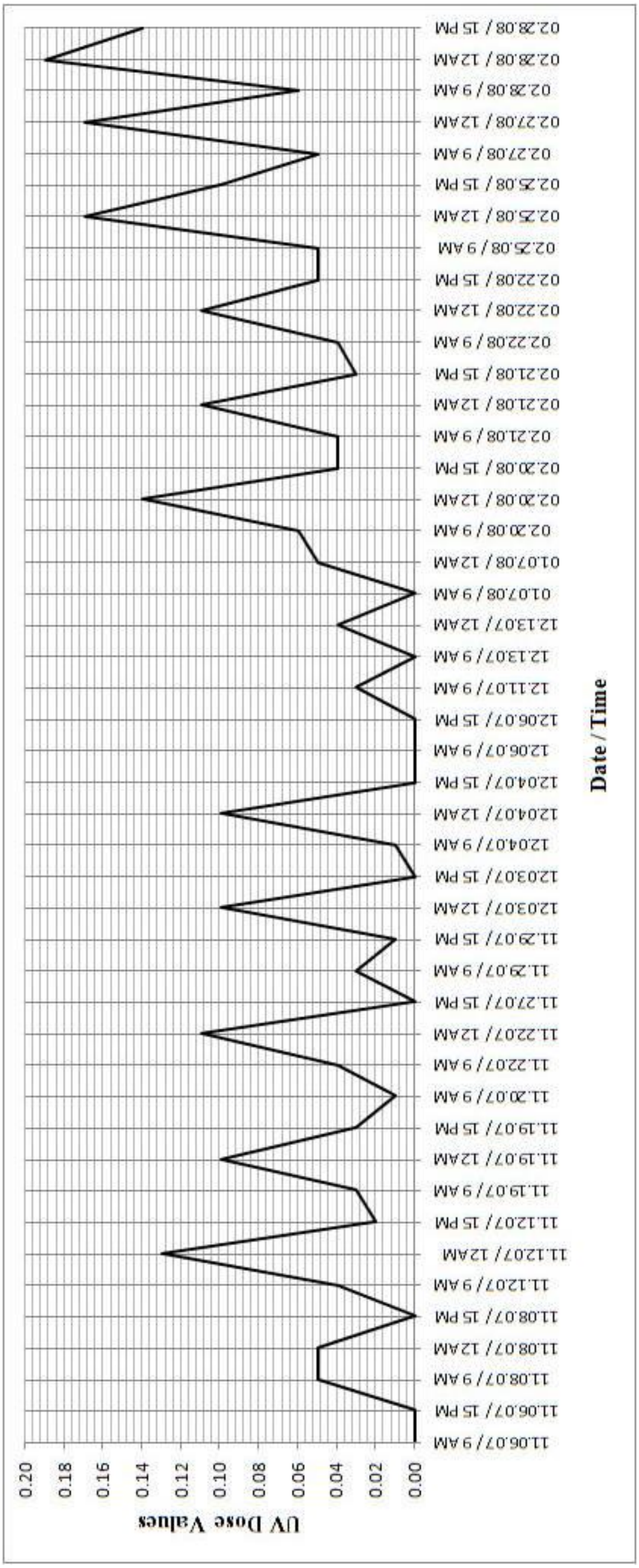


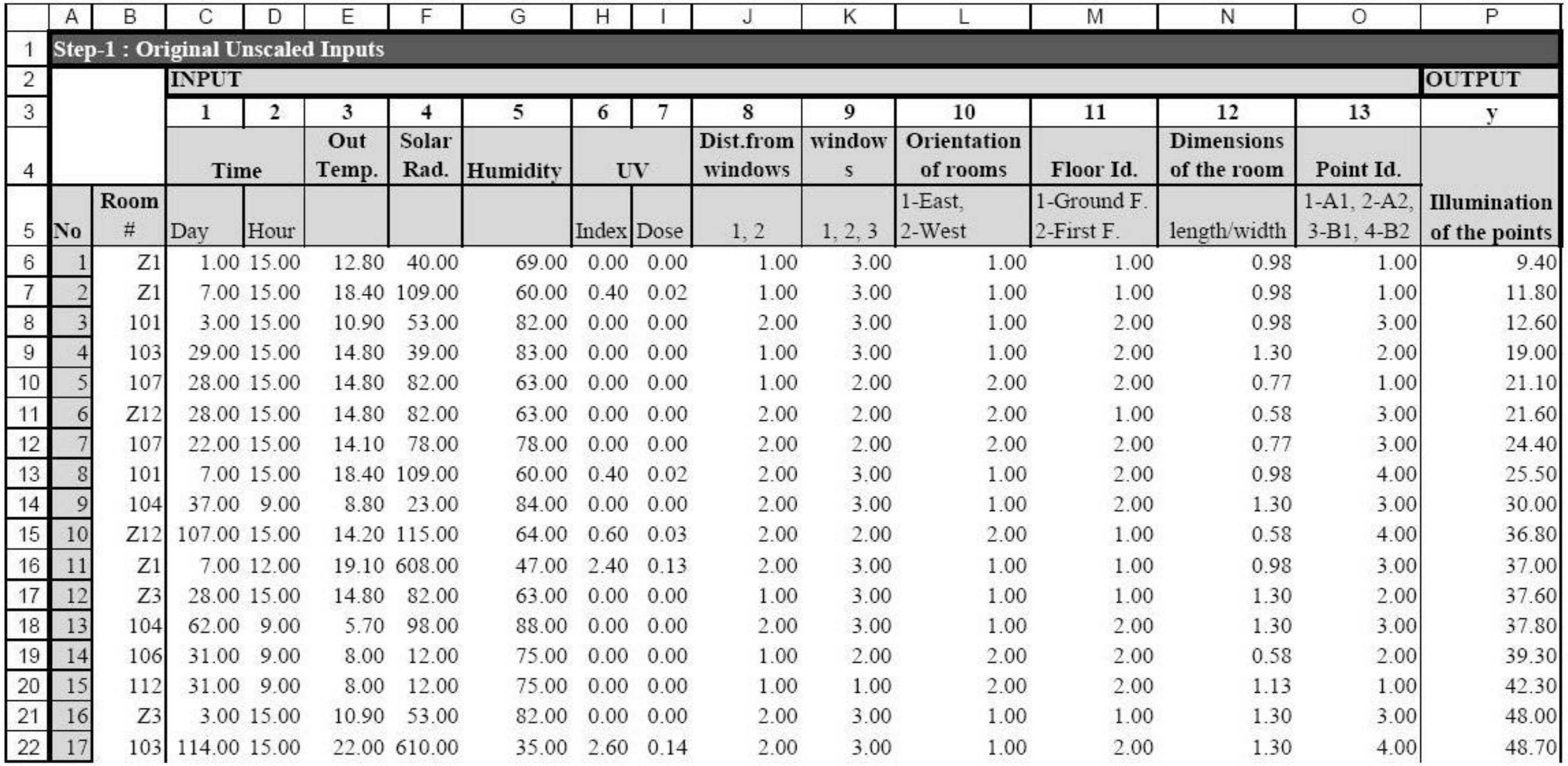
Figure C.5. The Graph of UV Dose

APPENDIX D

DATA IN THE ANN MODEL

In this section the real parameters which were used in the ANNs model construction are presented. Two variables for time (date, hour), five weather determinants (outdoor temperature, solar radiation, humidity, UV Index and UV dose) and six building parameters (distance to windows, number of windows, orientation of rooms, floor identification, room dimensions and point identification) were considered as input variables. Illuminance was used as the output variable. The data was divided into two groups; the first 80 of these data sets were used for training and the remaining 20 for testing. The spread sheet that was performed by the assistance of the Excel program had seven steps. These steps are shown in the following tables below.

Table D.1. The parameters of the first step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Step-1 : Original Unscaled Inputs**															
2			**INPUT**													**OUTPUT**
3			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
4			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**	**UV**		**Dist.from windows**	**windows**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	
5	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	**Illumination of the points**
6	1	Z1	1.00	15.00	12.80	40.00	69.00	0.00	0.00	1.00	3.00	1.00	1.00	0.98	1.00	9.40
7	2	Z1	7.00	15.00	18.40	109.00	60.00	0.40	0.02	1.00	3.00	1.00	1.00	0.98	1.00	11.80
8	3	101	3.00	15.00	10.90	53.00	82.00	0.00	0.00	2.00	3.00	1.00	2.00	0.98	3.00	12.60
9	4	103	29.00	15.00	14.80	39.00	83.00	0.00	0.00	1.00	3.00	1.00	2.00	1.30	2.00	19.00
10	5	107	28.00	15.00	14.80	82.00	63.00	0.00	0.00	1.00	2.00	2.00	2.00	0.77	1.00	21.10
11	6	Z12	28.00	15.00	14.80	82.00	63.00	0.00	0.00	2.00	2.00	2.00	1.00	0.58	3.00	21.60
12	7	107	22.00	15.00	14.10	78.00	78.00	0.00	0.00	2.00	2.00	2.00	2.00	0.77	3.00	24.40
13	8	101	7.00	15.00	18.40	109.00	60.00	0.40	0.02	2.00	3.00	1.00	2.00	0.98	4.00	25.50
14	9	104	37.00	9.00	8.80	23.00	84.00	0.00	0.00	2.00	3.00	1.00	2.00	1.30	3.00	30.00
15	10	Z12	107.00	15.00	14.20	115.00	64.00	0.60	0.03	2.00	2.00	2.00	1.00	0.58	4.00	36.80
16	11	Z1	7.00	12.00	19.10	608.00	47.00	2.40	0.13	2.00	3.00	1.00	1.00	0.98	3.00	37.00
17	12	Z3	28.00	15.00	14.80	82.00	63.00	0.00	0.00	1.00	3.00	1.00	1.00	1.30	2.00	37.60
18	13	104	62.00	9.00	5.70	98.00	88.00	0.00	0.00	2.00	3.00	1.00	2.00	1.30	3.00	37.80
19	14	106	31.00	9.00	8.00	12.00	75.00	0.00	0.00	1.00	2.00	2.00	2.00	0.58	2.00	39.30
20	15	112	31.00	9.00	8.00	12.00	75.00	0.00	0.00	1.00	1.00	2.00	2.00	1.13	1.00	42.30
21	16	Z3	3.00	15.00	10.90	53.00	82.00	0.00	0.00	2.00	3.00	1.00	1.00	1.30	3.00	48.00
22	17	103	114.00	15.00	22.00	610.00	35.00	2.60	0.14	2.00	3.00	1.00	2.00	1.30	4.00	48.70

(cont. on next page)

Table D.1 (cont.) The parameters of the first step

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
23	18	Z4	22.00	15.00	14.10	78.00	78.00	0.00	0.00	2.00	3.00	1.00	1.00	0.98	3.00	49.00
24	19	Z8	111.00	12.00	11.90	700.00	35.00	3.20	0.17	2.00	1.00	2.00	1.00	0.77	3.00	54.20
25	20	Z3	37.00	9.00	8.80	23.00	84.00	0.00	0.00	2.00	3.00	1.00	1.00	1.30	3.00	55.00
26	21	102	114.00	15.00	22.00	610.00	35.00	2.60	0.14	1.00	3.00	1.00	2.00	1.30	1.00	58.00
27	22	Z12	24.00	9.00	7.00	110.00	52.00	0.50	0.03	2.00	2.00	2.00	1.00	0.58	3.00	59.00
28	23	Z12	108.00	9.00	12.80	306.00	80.00	0.80	0.04	2.00	2.00	2.00	1.00	0.58	4.00	67.00
29	24	Z7	111.00	9.00	8.20	350.00	46.00	0.90	0.05	2.00	2.00	2.00	1.00	0.77	4.00	67.10
30	25	Z7	22.00	15.00	14.10	78.00	78.00	0.00	0.00	2.00	2.00	2.00	1.00	0.77	4.00	68.00
31	26	Z8	17.00	12.00	12.90	520.00	63.00	2.00	0.11	2.00	1.00	2.00	1.00	0.77	3.00	70.00
32	27	106	37.00	9.00	8.80	23.00	84.00	0.00	0.00	1.00	2.00	2.00	2.00	0.58	1.00	70.40
33	28	Z3	31.00	15.00	9.50	89.00	72.00	0.00	0.00	1.00	3.00	1.00	1.00	1.30	2.00	71.10
34	29	112	114.00	15.00	22.00	610.00	35.00	2.60	0.14	2.00	1.00	2.00	2.00	1.13	4.00	71.80
35	30	Z1	28.00	12.00	16.60	480.00	57.00	1.90	0.10	2.00	3.00	1.00	1.00	0.98	3.00	72.00
36	31	Z6	22.00	15.00	14.10	78.00	78.00	0.00	0.00	1.00	2.00	2.00	1.00	0.58	1.00	72.80
37	32	Z7	31.00	15.00	9.50	89.00	72.00	0.00	0.00	2.00	2.00	2.00	1.00	0.77	4.00	74.40
38	33	Z8	108.00	9.00	12.80	306.00	80.00	0.80	0.04	2.00	1.00	2.00	1.00	0.77	3.00	76.80
39	34	Z9	1.00	15.00	12.80	40.00	69.00	0.00	0.00	2.00	2.00	2.00	1.00	0.77	3.00	78.00
40	35	Z3	62.00	12.00	9.40	206.00	71.00	1.00	0.05	2.00	3.00	1.00	1.00	1.30	4.00	78.00
41	36	Z12	15.00	9.00	10.90	121.00	77.00	0.10	0.01	1.00	2.00	2.00	1.00	0.58	1.00	81.20
42	37	Z7	37.00	9.00	8.80	23.00	84.00	0.00	0.00	1.00	2.00	2.00	1.00	0.77	2.00	83.00
43	38	106	106.00	12.00	12.30	642.00	51.00	2.60	0.14	2.00	2.00	2.00	2.00	0.58	4.00	87.30
44	39	Z12	111.00	12.00	11.90	700.00	35.00	3.20	0.17	2.00	2.00	2.00	1.00	0.58	3.00	88.80
45	40	Z5	22.00	15.00	14.10	78.00	78.00	0.00	0.00	2.00	3.00	1.00	1.00	1.30	4.00	90.00
46	41	111	35.00	9.00	14.20	207.00	81.00	0.50	0.03	2.00	2.00	2.00	2.00	0.77	3.00	91.40

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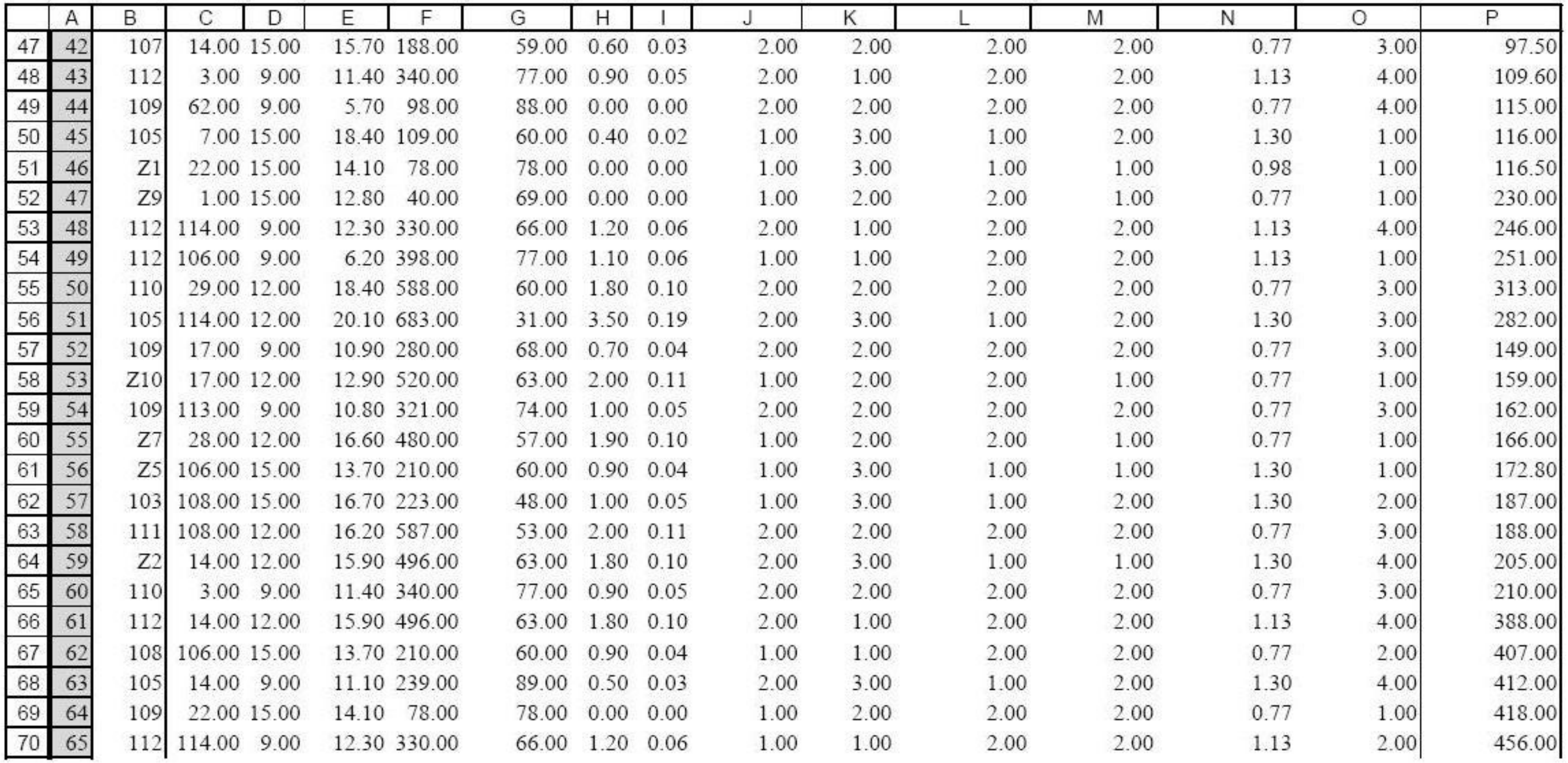
Table D.1 (cont.) The parameters of the first step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
47	42	107	14.00	15.00	15.70	188.00	59.00	0.60	0.03	2.00	2.00	2.00	2.00	0.77	3.00	97.50
48	43	112	3.00	9.00	11.40	340.00	77.00	0.90	0.05	2.00	1.00	2.00	2.00	1.13	4.00	109.60
49	44	109	62.00	9.00	5.70	98.00	88.00	0.00	0.00	2.00	2.00	2.00	2.00	0.77	4.00	115.00
50	45	105	7.00	15.00	18.40	109.00	60.00	0.40	0.02	1.00	3.00	1.00	2.00	1.30	1.00	116.00
51	46	Z1	22.00	15.00	14.10	78.00	78.00	0.00	0.00	1.00	3.00	1.00	1.00	0.98	1.00	116.50
52	47	Z9	1.00	15.00	12.80	40.00	69.00	0.00	0.00	1.00	2.00	2.00	1.00	0.77	1.00	230.00
53	48	112	114.00	9.00	12.30	330.00	66.00	1.20	0.06	2.00	1.00	2.00	2.00	1.13	4.00	246.00
54	49	112	106.00	9.00	6.20	398.00	77.00	1.10	0.06	1.00	1.00	2.00	2.00	1.13	1.00	251.00
55	50	110	29.00	12.00	18.40	588.00	60.00	1.80	0.10	2.00	2.00	2.00	2.00	0.77	3.00	313.00
56	51	105	114.00	12.00	20.10	683.00	31.00	3.50	0.19	2.00	3.00	1.00	2.00	1.30	3.00	282.00
57	52	109	17.00	9.00	10.90	280.00	68.00	0.70	0.04	2.00	2.00	2.00	2.00	0.77	3.00	149.00
58	53	Z10	17.00	12.00	12.90	520.00	63.00	2.00	0.11	1.00	2.00	2.00	1.00	0.77	1.00	159.00
59	54	109	113.00	9.00	10.80	321.00	74.00	1.00	0.05	2.00	2.00	2.00	2.00	0.77	3.00	162.00
60	55	Z7	28.00	12.00	16.60	480.00	57.00	1.90	0.10	1.00	2.00	2.00	1.00	0.77	1.00	166.00
61	56	Z5	106.00	15.00	13.70	210.00	60.00	0.90	0.04	1.00	3.00	1.00	1.00	1.30	1.00	172.80
62	57	103	108.00	15.00	16.70	223.00	48.00	1.00	0.05	1.00	3.00	1.00	2.00	1.30	2.00	187.00
63	58	111	108.00	12.00	16.20	587.00	53.00	2.00	0.11	2.00	2.00	2.00	2.00	0.77	3.00	188.00
64	59	Z2	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	3.00	1.00	1.00	1.30	4.00	205.00
65	60	110	3.00	9.00	11.40	340.00	77.00	0.90	0.05	2.00	2.00	2.00	2.00	0.77	3.00	210.00
66	61	112	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	1.00	2.00	2.00	1.13	4.00	388.00
67	62	108	106.00	15.00	13.70	210.00	60.00	0.90	0.04	1.00	1.00	2.00	2.00	0.77	2.00	407.00
68	63	105	14.00	9.00	11.10	239.00	89.00	0.50	0.03	2.00	3.00	1.00	2.00	1.30	4.00	412.00
69	64	109	22.00	15.00	14.10	78.00	78.00	0.00	0.00	1.00	2.00	2.00	2.00	0.77	1.00	418.00
70	65	112	114.00	9.00	12.30	330.00	66.00	1.20	0.06	1.00	1.00	2.00	2.00	1.13	2.00	456.00

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Table D.1 (cont.) The parameters of the first step

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
71	66	112	114.00	9.00	12.30	330.00	66.00	1.20	0.06	1.00	1.00	2.00	2.00	1.13	2.00	456.00
72	67	101	113.00	12.00	20.20	611.00	29.00	3.20	0.17	1.00	3.00	1.00	2.00	0.98	2.00	463.00
73	68	111	114.00	9.00	12.30	330.00	66.00	1.20	0.06	1.00	2.00	2.00	2.00	0.77	2.00	489.00
74	69	Z3	108.00	9.00	12.80	306.00	80.00	0.80	0.04	2.00	3.00	1.00	1.00	1.30	4.00	498.00
75	70	Z5	24.00	9.00	7.00	110.00	52.00	0.50	0.03	2.00	3.00	1.00	1.00	1.30	3.00	543.00
76	71	Z10	108.00	12.00	16.20	587.00	53.00	2.00	0.11	1.00	2.00	2.00	1.00	0.77	2.00	553.00
77	72	Z2	113.00	9.00	10.80	321.00	74.00	1.00	0.05	1.00	3.00	1.00	1.00	1.30	1.00	594.00
78	73	Z6	106.00	15.00	13.70	210.00	60.00	0.90	0.04	1.00	2.00	2.00	1.00	0.58	1.00	615.00
79	74	Z5	17.00	9.00	10.90	280.00	68.00	0.70	0.04	2.00	3.00	1.00	1.00	1.30	4.00	679.00
80	75	103	24.00	9.00	7.00	110.00	52.00	0.50	0.03	1.00	3.00	1.00	2.00	1.30	1.00	938.00
81	76	109	108.00	12.00	16.20	587.00	53.00	2.00	0.11	1.00	2.00	2.00	2.00	0.77	2.00	968.00
82	77	Z4	111.00	9.00	8.20	350.00	46.00	0.90	0.05	1.00	3.00	1.00	1.00	0.98	2.00	1320.00
83	78	Z7	107.00	12.00	14.20	339.00	58.00	2.10	0.11	1.00	2.00	2.00	1.00	0.77	1.00	1657.00
84	79	107	108.00	15.00	16.70	223.00	48.00	1.00	0.05	1.00	2.00	2.00	2.00	0.77	2.00	1679.00
85	80	Z3	111.00	9.00	8.20	350.00	46.00	0.90	0.05	2.00	3.00	1.00	1.00	1.30	4.00	1216.00

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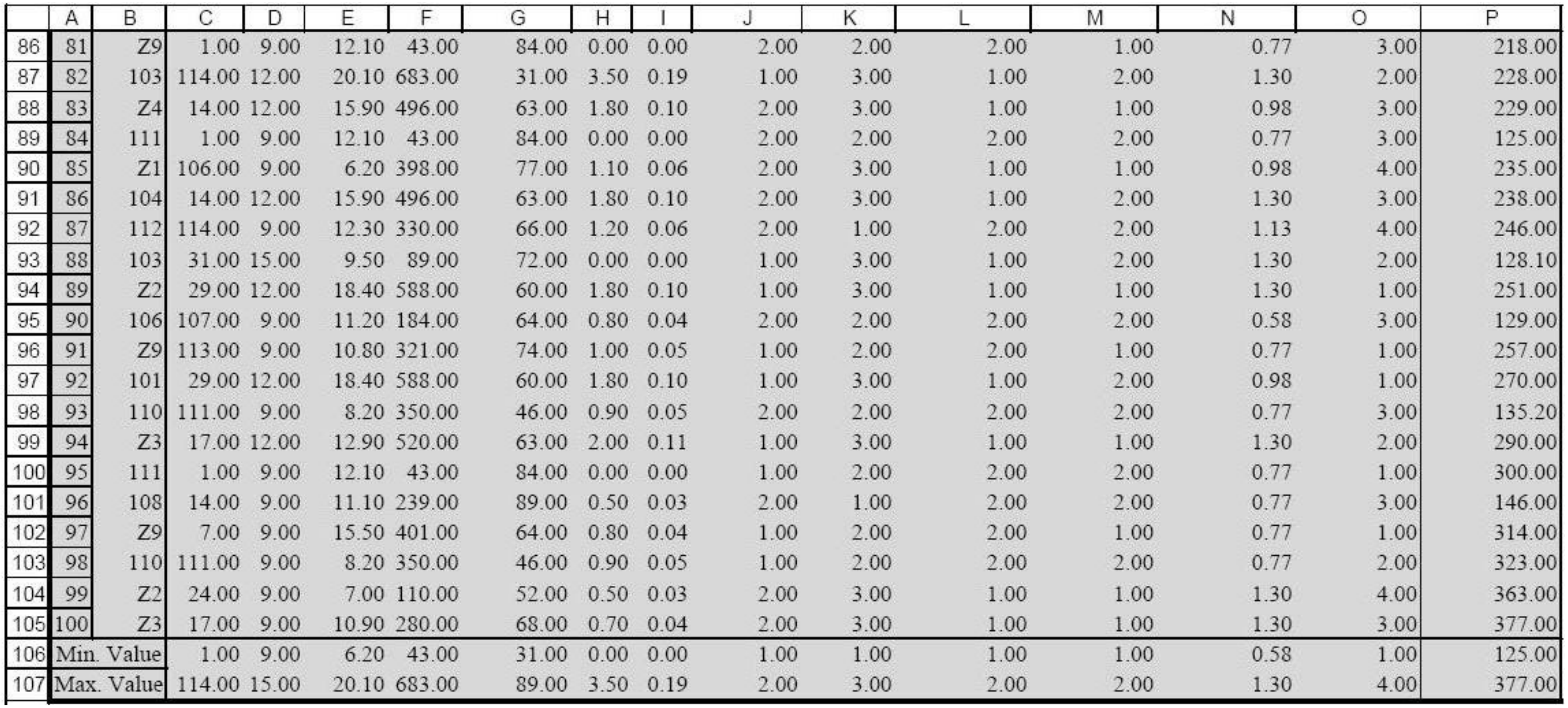
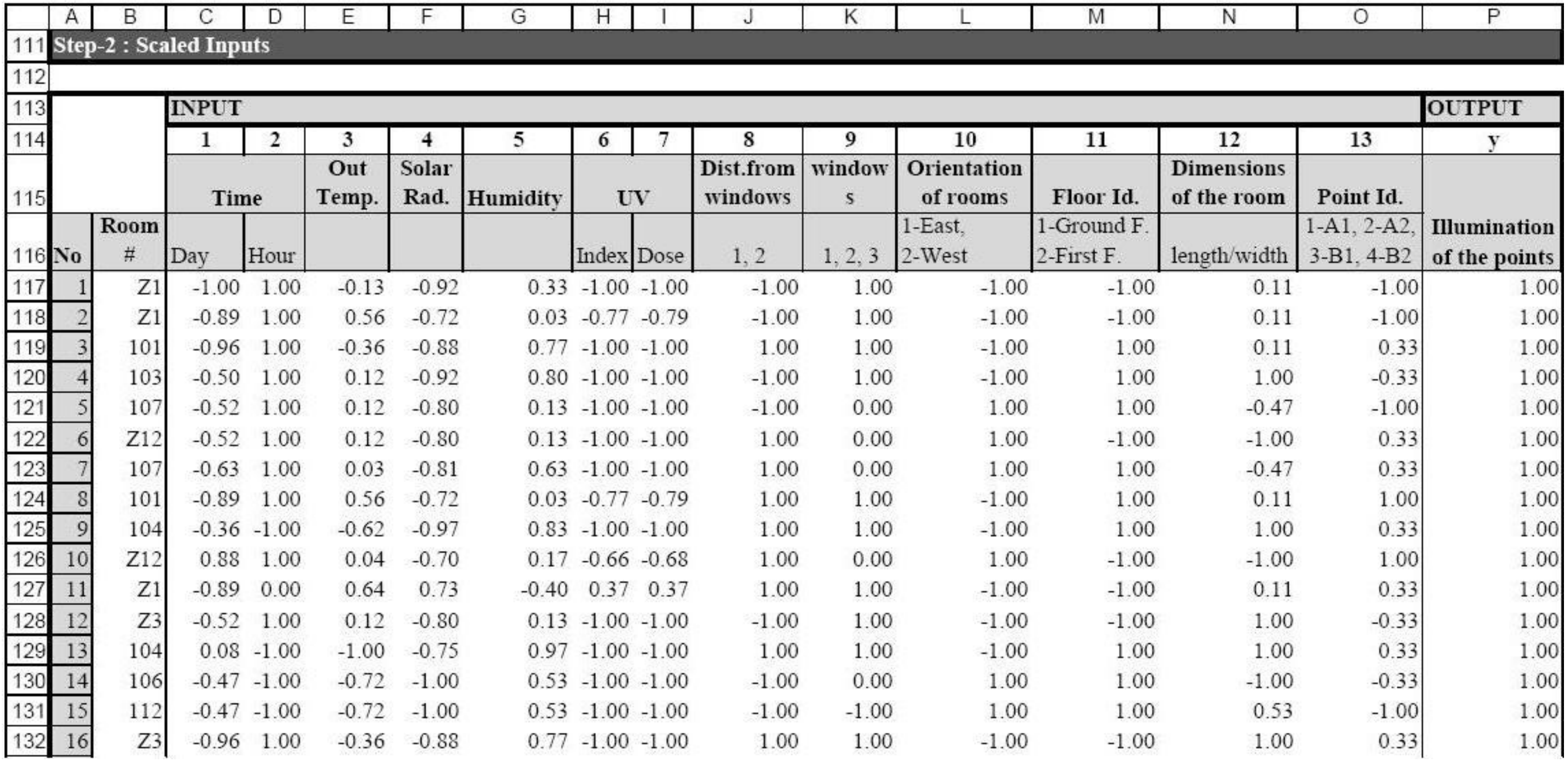
Table D.1 (cont.) The parameters of the first step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
86	81	Z9	1.00	9.00	12.10	43.00	84.00	0.00	0.00	2.00	2.00	2.00	1.00	0.77	3.00	218.00
87	82	103	114.00	12.00	20.10	683.00	31.00	3.50	0.19	1.00	3.00	1.00	2.00	1.30	2.00	228.00
88	83	Z4	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	3.00	1.00	1.00	0.98	3.00	229.00
89	84	111	1.00	9.00	12.10	43.00	84.00	0.00	0.00	2.00	2.00	2.00	2.00	0.77	3.00	125.00
90	85	Z1	106.00	9.00	6.20	398.00	77.00	1.10	0.06	2.00	3.00	1.00	1.00	0.98	4.00	235.00
91	86	104	14.00	12.00	15.90	496.00	63.00	1.80	0.10	2.00	3.00	1.00	2.00	1.30	3.00	238.00
92	87	112	114.00	9.00	12.30	330.00	66.00	1.20	0.06	2.00	1.00	2.00	2.00	1.13	4.00	246.00
93	88	103	31.00	15.00	9.50	89.00	72.00	0.00	0.00	1.00	3.00	1.00	2.00	1.30	2.00	128.10
94	89	Z2	29.00	12.00	18.40	588.00	60.00	1.80	0.10	1.00	3.00	1.00	1.00	1.30	1.00	251.00
95	90	106	107.00	9.00	11.20	184.00	64.00	0.80	0.04	2.00	2.00	2.00	2.00	0.58	3.00	129.00
96	91	Z9	113.00	9.00	10.80	321.00	74.00	1.00	0.05	1.00	2.00	2.00	1.00	0.77	1.00	257.00
97	92	101	29.00	12.00	18.40	588.00	60.00	1.80	0.10	1.00	3.00	1.00	2.00	0.98	1.00	270.00
98	93	110	111.00	9.00	8.20	350.00	46.00	0.90	0.05	2.00	2.00	2.00	2.00	0.77	3.00	135.20
99	94	Z3	17.00	12.00	12.90	520.00	63.00	2.00	0.11	1.00	3.00	1.00	1.00	1.30	2.00	290.00
100	95	111	1.00	9.00	12.10	43.00	84.00	0.00	0.00	1.00	2.00	2.00	2.00	0.77	1.00	300.00
101	96	108	14.00	9.00	11.10	239.00	89.00	0.50	0.03	2.00	1.00	2.00	2.00	0.77	3.00	146.00
102	97	Z9	7.00	9.00	15.50	401.00	64.00	0.80	0.04	1.00	2.00	2.00	1.00	0.77	1.00	314.00
103	98	110	111.00	9.00	8.20	350.00	46.00	0.90	0.05	1.00	2.00	2.00	2.00	0.77	2.00	323.00
104	99	Z2	24.00	9.00	7.00	110.00	52.00	0.50	0.03	2.00	3.00	1.00	1.00	1.30	4.00	363.00
105	100	Z3	17.00	9.00	10.90	280.00	68.00	0.70	0.04	2.00	3.00	1.00	1.00	1.30	3.00	377.00
106	Min. Value		1.00	9.00	6.20	43.00	31.00	0.00	0.00	1.00	1.00	1.00	1.00	0.58	1.00	125.00
107	Max. Value		114.00	15.00	20.10	683.00	89.00	3.50	0.19	2.00	3.00	2.00	2.00	1.30	4.00	377.00

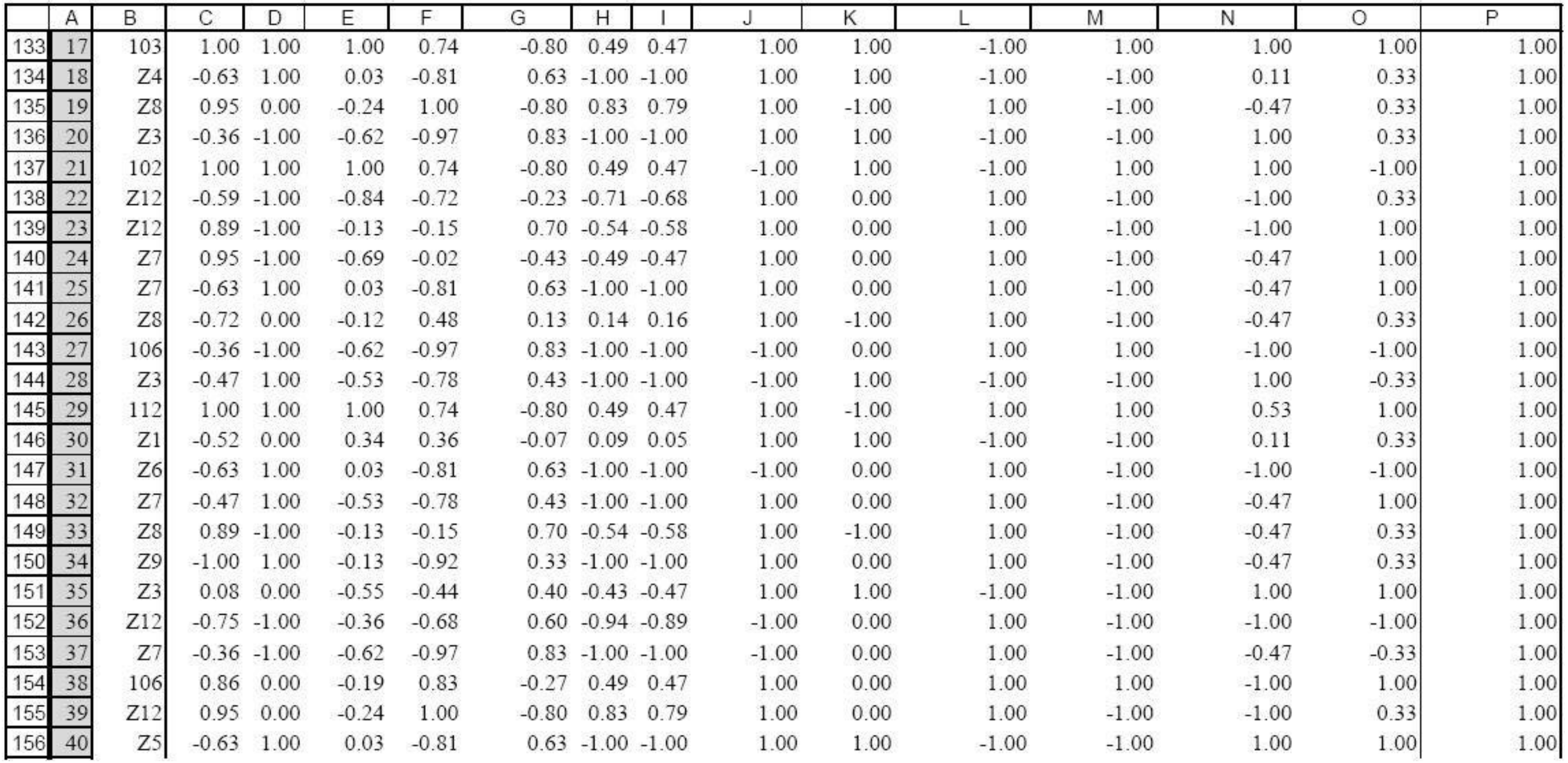
Table D.2. The parameters of the second step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
111	**Step-2 : Scaled Inputs**															
112																
113			**INPUT**													**OUTPUT**
114			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**y**
115			**Time**		**Out Temp.**	**Solar Rad.**	**Humidity**	**UV**		**Dist.from windows**	**window s**	**Orientation of rooms**	**Floor Id.**	**Dimensions of the room**	**Point Id.**	
116	**No**	**Room #**	Day	Hour				Index	Dose	1, 2	1, 2, 3	1-East, 2-West	1-Ground F. 2-First F.	length/width	1-A1, 2-A2, 3-B1, 4-B2	**Illumination of the points**
117	1	Z1	-1.00	1.00	-0.13	-0.92	0.33	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	0.11	-1.00	1.00
118	2	Z1	-0.89	1.00	0.56	-0.72	0.03	-0.77	-0.79	-1.00	1.00	-1.00	-1.00	0.11	-1.00	1.00
119	3	101	-0.96	1.00	-0.36	-0.88	0.77	-1.00	-1.00	1.00	1.00	-1.00	1.00	0.11	0.33	1.00
120	4	103	-0.50	1.00	0.12	-0.92	0.80	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
121	5	107	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	-1.00	0.00	1.00	1.00	-0.47	-1.00	1.00
122	6	Z12	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	1.00	0.00	1.00	-1.00	-1.00	0.33	1.00
123	7	107	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
124	8	101	-0.89	1.00	0.56	-0.72	0.03	-0.77	-0.79	1.00	1.00	-1.00	1.00	0.11	1.00	1.00
125	9	104	-0.36	-1.00	-0.62	-0.97	0.83	-1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
126	10	Z12	0.88	1.00	0.04	-0.70	0.17	-0.66	-0.68	1.00	0.00	1.00	-1.00	-1.00	1.00	1.00
127	11	Z1	-0.89	0.00	0.64	0.73	-0.40	0.37	0.37	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
128	12	Z3	-0.52	1.00	0.12	-0.80	0.13	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	1.00	-0.33	1.00
129	13	104	0.08	-1.00	-1.00	-0.75	0.97	-1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
130	14	106	-0.47	-1.00	-0.72	-1.00	0.53	-1.00	-1.00	-1.00	0.00	1.00	1.00	-1.00	-0.33	1.00
131	15	112	-0.47	-1.00	-0.72	-1.00	0.53	-1.00	-1.00	-1.00	-1.00	1.00	1.00	0.53	-1.00	1.00
132	16	Z3	-0.96	1.00	-0.36	-0.88	0.77	-1.00	-1.00	1.00	1.00	-1.00	-1.00	1.00	0.33	1.00

(cont. on next page)

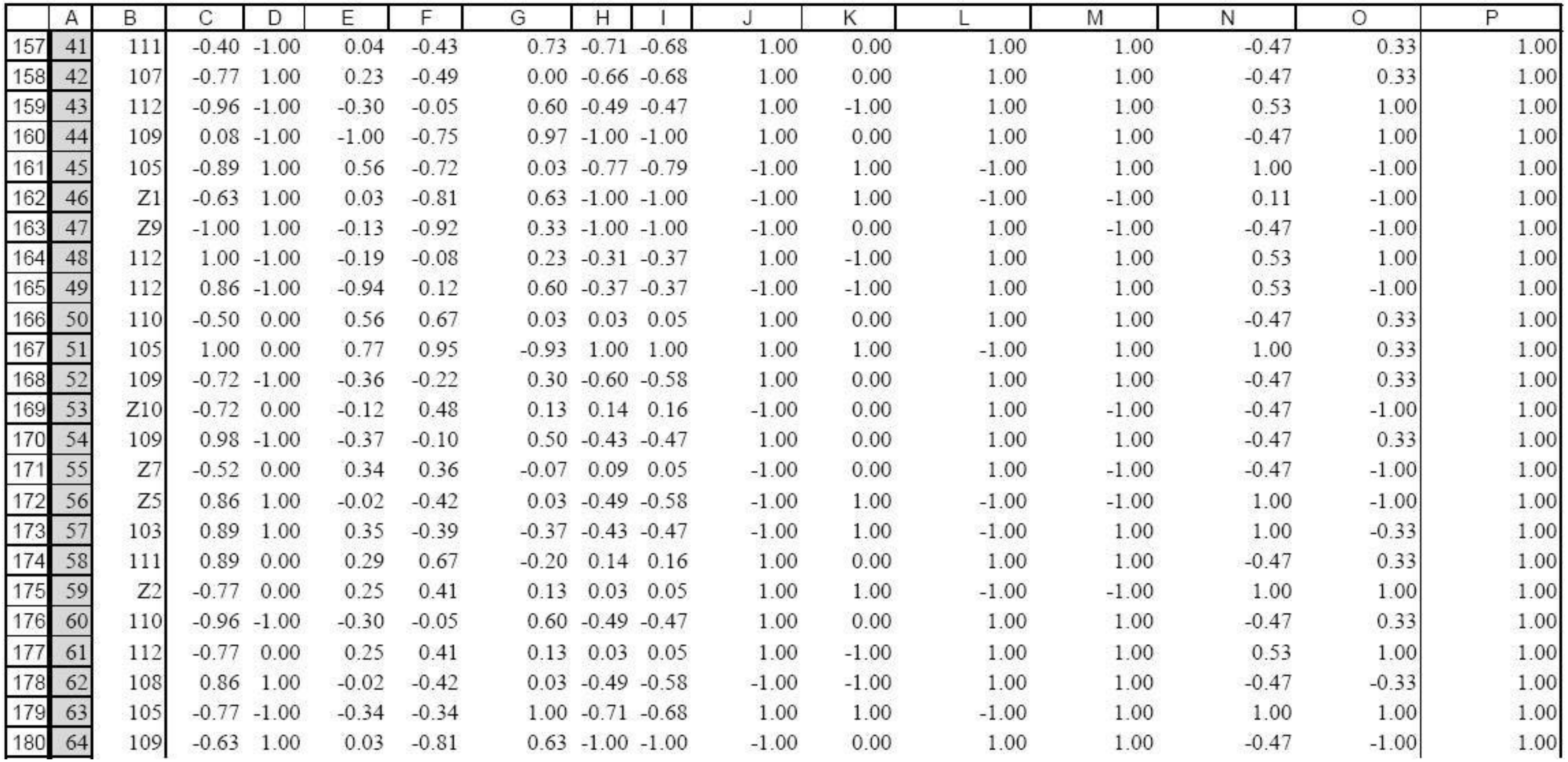
Table D.2 (cont.) The parameters of the second step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
133	17	103	1.00	1.00	1.00	0.74	-0.80	0.49	0.47	1.00	1.00	-1.00	1.00	1.00	1.00	1.00
134	18	Z4	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
135	19	Z8	0.95	0.00	-0.24	1.00	-0.80	0.83	0.79	1.00	-1.00	1.00	-1.00	-0.47	0.33	1.00
136	20	Z3	-0.36	-1.00	-0.62	-0.97	0.83	-1.00	-1.00	1.00	1.00	-1.00	-1.00	1.00	0.33	1.00
137	21	102	1.00	1.00	1.00	0.74	-0.80	0.49	0.47	-1.00	1.00	-1.00	1.00	1.00	-1.00	1.00
138	22	Z12	-0.59	-1.00	-0.84	-0.72	-0.23	-0.71	-0.68	1.00	0.00	1.00	-1.00	-1.00	0.33	1.00
139	23	Z12	0.89	-1.00	-0.13	-0.15	0.70	-0.54	-0.58	1.00	0.00	1.00	-1.00	-1.00	1.00	1.00
140	24	Z7	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	1.00	0.00	1.00	-1.00	-0.47	1.00	1.00
141	25	Z7	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	1.00	0.00	1.00	-1.00	-0.47	1.00	1.00
142	26	Z8	-0.72	0.00	-0.12	0.48	0.13	0.14	0.16	1.00	-1.00	1.00	-1.00	-0.47	0.33	1.00
143	27	106	-0.36	-1.00	-0.62	-0.97	0.83	-1.00	-1.00	-1.00	0.00	1.00	1.00	-1.00	-1.00	1.00
144	28	Z3	-0.47	1.00	-0.53	-0.78	0.43	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	1.00	-0.33	1.00
145	29	112	1.00	1.00	1.00	0.74	-0.80	0.49	0.47	1.00	-1.00	1.00	1.00	0.53	1.00	1.00
146	30	Z1	-0.52	0.00	0.34	0.36	-0.07	0.09	0.05	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
147	31	Z6	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	-1.00	0.00	1.00	-1.00	-1.00	-1.00	1.00
148	32	Z7	-0.47	1.00	-0.53	-0.78	0.43	-1.00	-1.00	1.00	0.00	1.00	-1.00	-0.47	1.00	1.00
149	33	Z8	0.89	-1.00	-0.13	-0.15	0.70	-0.54	-0.58	1.00	-1.00	1.00	-1.00	-0.47	0.33	1.00
150	34	Z9	-1.00	1.00	-0.13	-0.92	0.33	-1.00	-1.00	1.00	0.00	1.00	-1.00	-0.47	0.33	1.00
151	35	Z3	0.08	0.00	-0.55	-0.44	0.40	-0.43	-0.47	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
152	36	Z12	-0.75	-1.00	-0.36	-0.68	0.60	-0.94	-0.89	-1.00	0.00	1.00	-1.00	-1.00	-1.00	1.00
153	37	Z7	-0.36	-1.00	-0.62	-0.97	0.83	-1.00	-1.00	-1.00	0.00	1.00	-1.00	-0.47	-0.33	1.00
154	38	106	0.86	0.00	-0.19	0.83	-0.27	0.49	0.47	1.00	0.00	1.00	1.00	-1.00	1.00	1.00
155	39	Z12	0.95	0.00	-0.24	1.00	-0.80	0.83	0.79	1.00	0.00	1.00	-1.00	-1.00	0.33	1.00
156	40	Z5	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00

(cont. on next page)

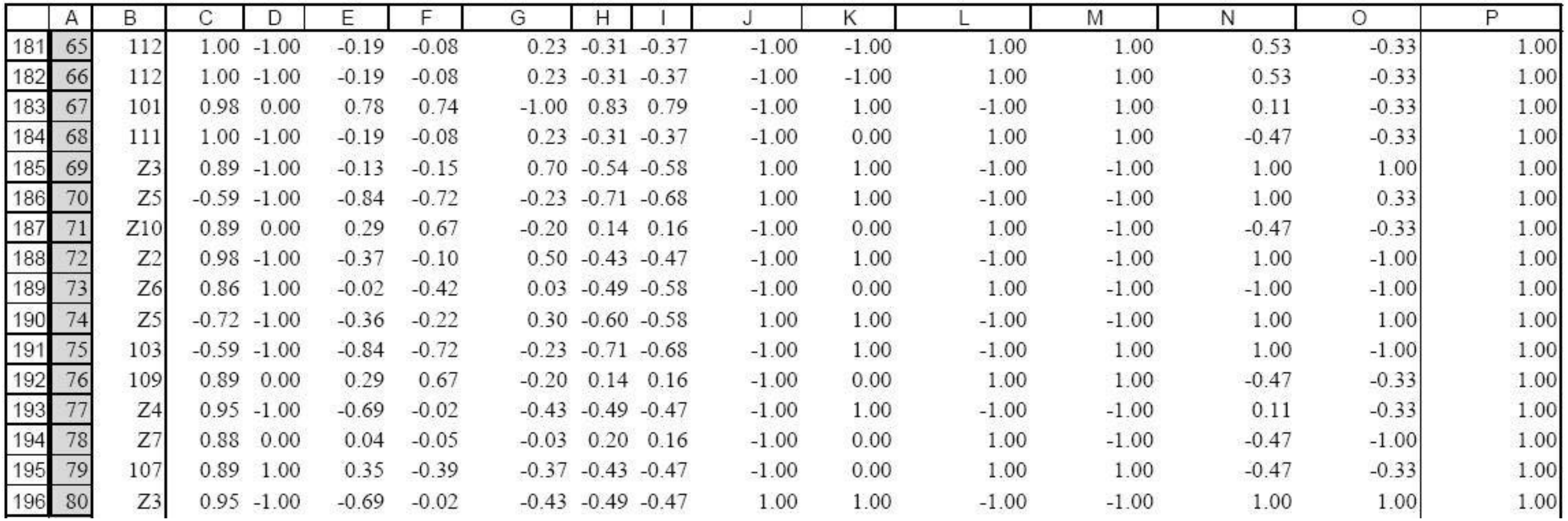
Table D.2 (cont.) The parameters of the second step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
157	41	111	-0.40	-1.00	0.04	-0.43	0.73	-0.71	-0.68	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
158	42	107	-0.77	1.00	0.23	-0.49	0.00	-0.66	-0.68	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
159	43	112	-0.96	-1.00	-0.30	-0.05	0.60	-0.49	-0.47	1.00	-1.00	1.00	1.00	0.53	1.00	1.00
160	44	109	0.08	-1.00	-1.00	-0.75	0.97	-1.00	-1.00	1.00	0.00	1.00	1.00	-0.47	1.00	1.00
161	45	105	-0.89	1.00	0.56	-0.72	0.03	-0.77	-0.79	-1.00	1.00	-1.00	1.00	1.00	-1.00	1.00
162	46	Z1	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	0.11	-1.00	1.00
163	47	Z9	-1.00	1.00	-0.13	-0.92	0.33	-1.00	-1.00	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
164	48	112	1.00	-1.00	-0.19	-0.08	0.23	-0.31	-0.37	1.00	-1.00	1.00	1.00	0.53	1.00	1.00
165	49	112	0.86	-1.00	-0.94	0.12	0.60	-0.37	-0.37	-1.00	-1.00	1.00	1.00	0.53	-1.00	1.00
166	50	110	-0.50	0.00	0.56	0.67	0.03	0.03	0.05	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
167	51	105	1.00	0.00	0.77	0.95	-0.93	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
168	52	109	-0.72	-1.00	-0.36	-0.22	0.30	-0.60	-0.58	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
169	53	Z10	-0.72	0.00	-0.12	0.48	0.13	0.14	0.16	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
170	54	109	0.98	-1.00	-0.37	-0.10	0.50	-0.43	-0.47	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
171	55	Z7	-0.52	0.00	0.34	0.36	-0.07	0.09	0.05	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
172	56	Z5	0.86	1.00	-0.02	-0.42	0.03	-0.49	-0.58	-1.00	1.00	-1.00	-1.00	1.00	-1.00	1.00
173	57	103	0.89	1.00	0.35	-0.39	-0.37	-0.43	-0.47	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
174	58	111	0.89	0.00	0.29	0.67	-0.20	0.14	0.16	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
175	59	Z2	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
176	60	110	-0.96	-1.00	-0.30	-0.05	0.60	-0.49	-0.47	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
177	61	112	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	-1.00	1.00	1.00	0.53	1.00	1.00
178	62	108	0.86	1.00	-0.02	-0.42	0.03	-0.49	-0.58	-1.00	-1.00	1.00	1.00	-0.47	-0.33	1.00
179	63	105	-0.77	-1.00	-0.34	-0.34	1.00	-0.71	-0.68	1.00	1.00	-1.00	1.00	1.00	1.00	1.00
180	64	109	-0.63	1.00	0.03	-0.81	0.63	-1.00	-1.00	-1.00	0.00	1.00	1.00	-0.47	-1.00	1.00

(cont. on next page)

Table D.2 (cont.) The parameters of the second step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
181	65	112	1.00	-1.00	-0.19	-0.08	0.23	-0.31	-0.37	-1.00	-1.00	1.00	1.00	0.53	-0.33	1.00
182	66	112	1.00	-1.00	-0.19	-0.08	0.23	-0.31	-0.37	-1.00	-1.00	1.00	1.00	0.53	-0.33	1.00
183	67	101	0.98	0.00	0.78	0.74	-1.00	0.83	0.79	-1.00	1.00	-1.00	1.00	0.11	-0.33	1.00
184	68	111	1.00	-1.00	-0.19	-0.08	0.23	-0.31	-0.37	-1.00	0.00	1.00	1.00	-0.47	-0.33	1.00
185	69	Z3	0.89	-1.00	-0.13	-0.15	0.70	-0.54	-0.58	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
186	70	Z5	-0.59	-1.00	-0.84	-0.72	-0.23	-0.71	-0.68	1.00	1.00	-1.00	-1.00	1.00	0.33	1.00
187	71	Z10	0.89	0.00	0.29	0.67	-0.20	0.14	0.16	-1.00	0.00	1.00	-1.00	-0.47	-0.33	1.00
188	72	Z2	0.98	-1.00	-0.37	-0.10	0.50	-0.43	-0.47	-1.00	1.00	-1.00	-1.00	1.00	-1.00	1.00
189	73	Z6	0.86	1.00	-0.02	-0.42	0.03	-0.49	-0.58	-1.00	0.00	1.00	-1.00	-1.00	-1.00	1.00
190	74	Z5	-0.72	-1.00	-0.36	-0.22	0.30	-0.60	-0.58	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
191	75	103	-0.59	-1.00	-0.84	-0.72	-0.23	-0.71	-0.68	-1.00	1.00	-1.00	1.00	1.00	-1.00	1.00
192	76	109	0.89	0.00	0.29	0.67	-0.20	0.14	0.16	-1.00	0.00	1.00	1.00	-0.47	-0.33	1.00
193	77	Z4	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	-1.00	1.00	-1.00	-1.00	0.11	-0.33	1.00
194	78	Z7	0.88	0.00	0.04	-0.05	-0.03	0.20	0.16	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
195	79	107	0.89	1.00	0.35	-0.39	-0.37	-0.43	-0.47	-1.00	0.00	1.00	1.00	-0.47	-0.33	1.00
196	80	Z3	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00

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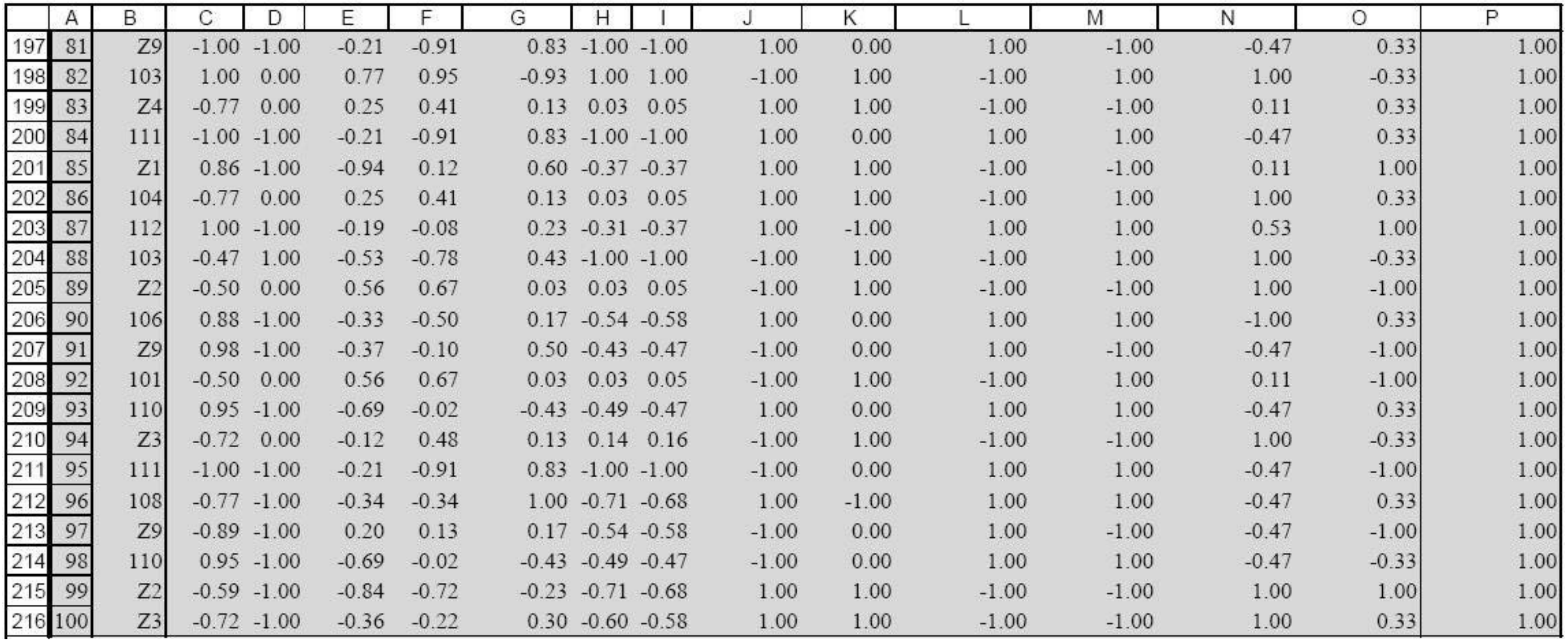
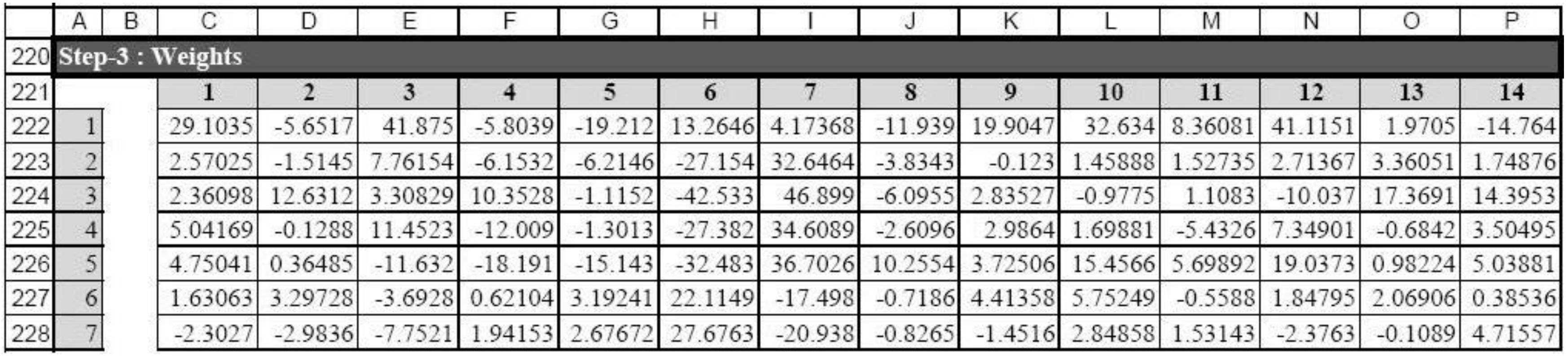
Table D.2 (cont.) The parameters of the second step



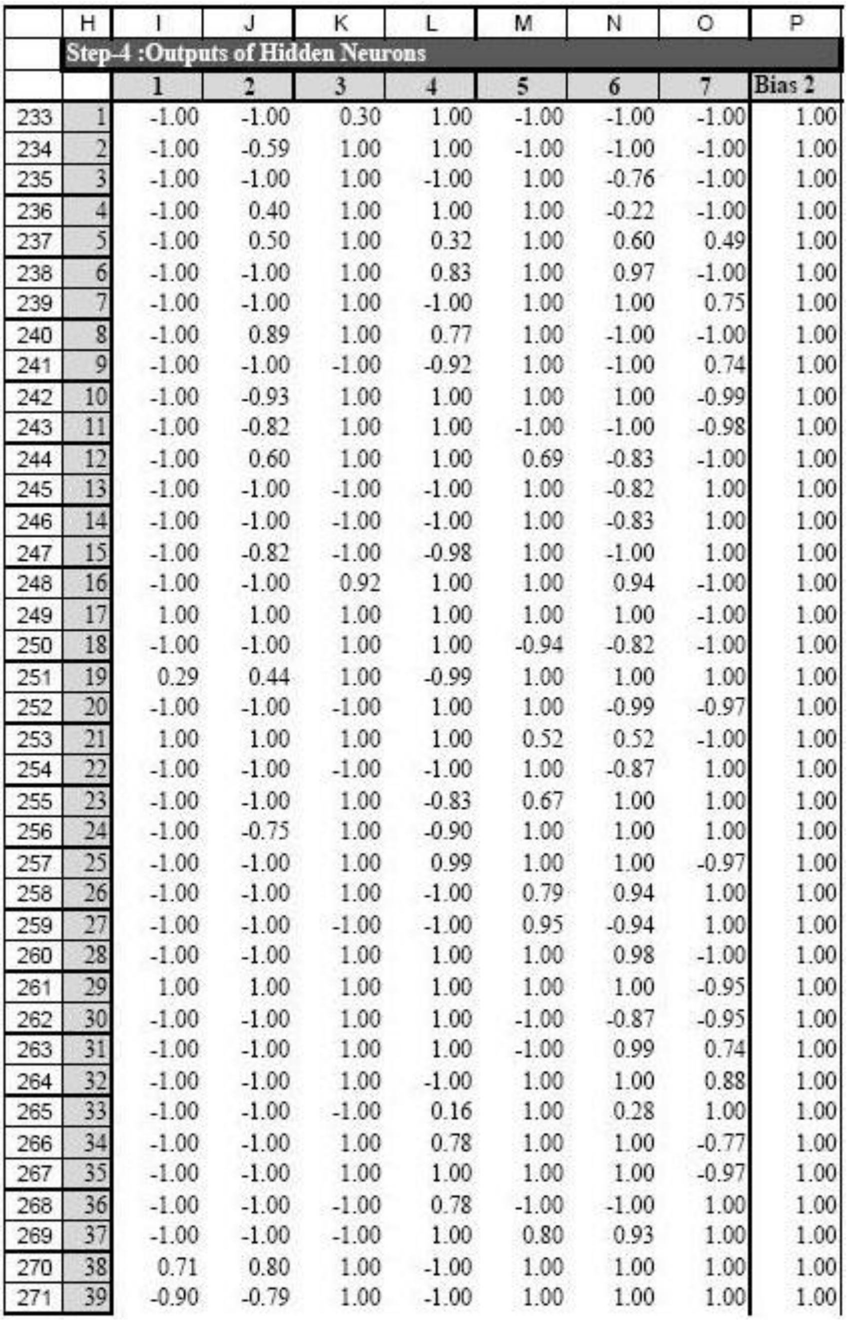
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
197	81	Z9	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	1.00	0.00	1.00	-1.00	-0.47	0.33	1.00
198	82	103	1.00	0.00	0.77	0.95	-0.93	1.00	1.00	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
199	83	Z4	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	1.00	-1.00	-1.00	0.11	0.33	1.00
200	84	111	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
201	85	Z1	0.86	-1.00	-0.94	0.12	0.60	-0.37	-0.37	1.00	1.00	-1.00	-1.00	0.11	1.00	1.00
202	86	104	-0.77	0.00	0.25	0.41	0.13	0.03	0.05	1.00	1.00	-1.00	1.00	1.00	0.33	1.00
203	87	112	1.00	-1.00	-0.19	-0.08	0.23	-0.31	-0.37	1.00	-1.00	1.00	1.00	0.53	1.00	1.00
204	88	103	-0.47	1.00	-0.53	-0.78	0.43	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00	-0.33	1.00
205	89	Z2	-0.50	0.00	0.56	0.67	0.03	0.03	0.05	-1.00	1.00	-1.00	-1.00	1.00	-1.00	1.00
206	90	106	0.88	-1.00	-0.33	-0.50	0.17	-0.54	-0.58	1.00	0.00	1.00	1.00	-1.00	0.33	1.00
207	91	Z9	0.98	-1.00	-0.37	-0.10	0.50	-0.43	-0.47	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
208	92	101	-0.50	0.00	0.56	0.67	0.03	0.03	0.05	-1.00	1.00	-1.00	1.00	0.11	-1.00	1.00
209	93	110	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	1.00	0.00	1.00	1.00	-0.47	0.33	1.00
210	94	Z3	-0.72	0.00	-0.12	0.48	0.13	0.14	0.16	-1.00	1.00	-1.00	-1.00	1.00	-0.33	1.00
211	95	111	-1.00	-1.00	-0.21	-0.91	0.83	-1.00	-1.00	-1.00	0.00	1.00	1.00	-0.47	-1.00	1.00
212	96	108	-0.77	-1.00	-0.34	-0.34	1.00	-0.71	-0.68	1.00	-1.00	1.00	1.00	-0.47	0.33	1.00
213	97	Z9	-0.89	-1.00	0.20	0.13	0.17	-0.54	-0.58	-1.00	0.00	1.00	-1.00	-0.47	-1.00	1.00
214	98	110	0.95	-1.00	-0.69	-0.02	-0.43	-0.49	-0.47	-1.00	0.00	1.00	1.00	-0.47	-0.33	1.00
215	99	Z2	-0.59	-1.00	-0.84	-0.72	-0.23	-0.71	-0.68	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00
216	100	Z3	-0.72	-1.00	-0.36	-0.22	0.30	-0.60	-0.58	1.00	1.00	-1.00	-1.00	1.00	0.33	1.00

Table D.3. The parameters of the third step



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
220	Step-3 : Weights															
221			1	2	3	4	5	6	7	8	9	10	11	12	13	14
222	1		29.1035	-5.6517	41.875	-5.8039	-19.212	13.2646	4.17368	-11.939	19.9047	32.634	8.36081	41.1151	1.9705	-14.764
223	2		2.57025	-1.5145	7.76154	-6.1532	-6.2146	-27.154	32.6464	-3.8343	-0.123	1.45888	1.52735	2.71367	3.36051	1.74876
224	3		2.36098	12.6312	3.30829	10.3528	-1.1152	-42.533	46.899	-6.0955	2.83527	-0.9775	1.1083	-10.037	17.3691	14.3953
225	4		5.04169	-0.1288	11.4523	-12.009	-1.3013	-27.382	34.6089	-2.6096	2.9864	1.69881	-5.4326	7.34901	-0.6842	3.50495
226	5		4.75041	0.36485	-11.632	-18.191	-15.143	-32.483	36.7026	10.2554	3.72506	15.4566	5.69892	19.0373	0.98224	5.03881
227	6		1.63063	3.29728	-3.6928	0.62104	3.19241	22.1149	-17.498	-0.7186	4.41358	5.75249	-0.5588	1.84795	2.06906	0.38536
228	7		-2.3027	-2.9836	-7.7521	1.94153	2.67672	27.6763	-20.938	-0.8265	-1.4516	2.84858	1.53143	-2.3763	-0.1089	4.71557

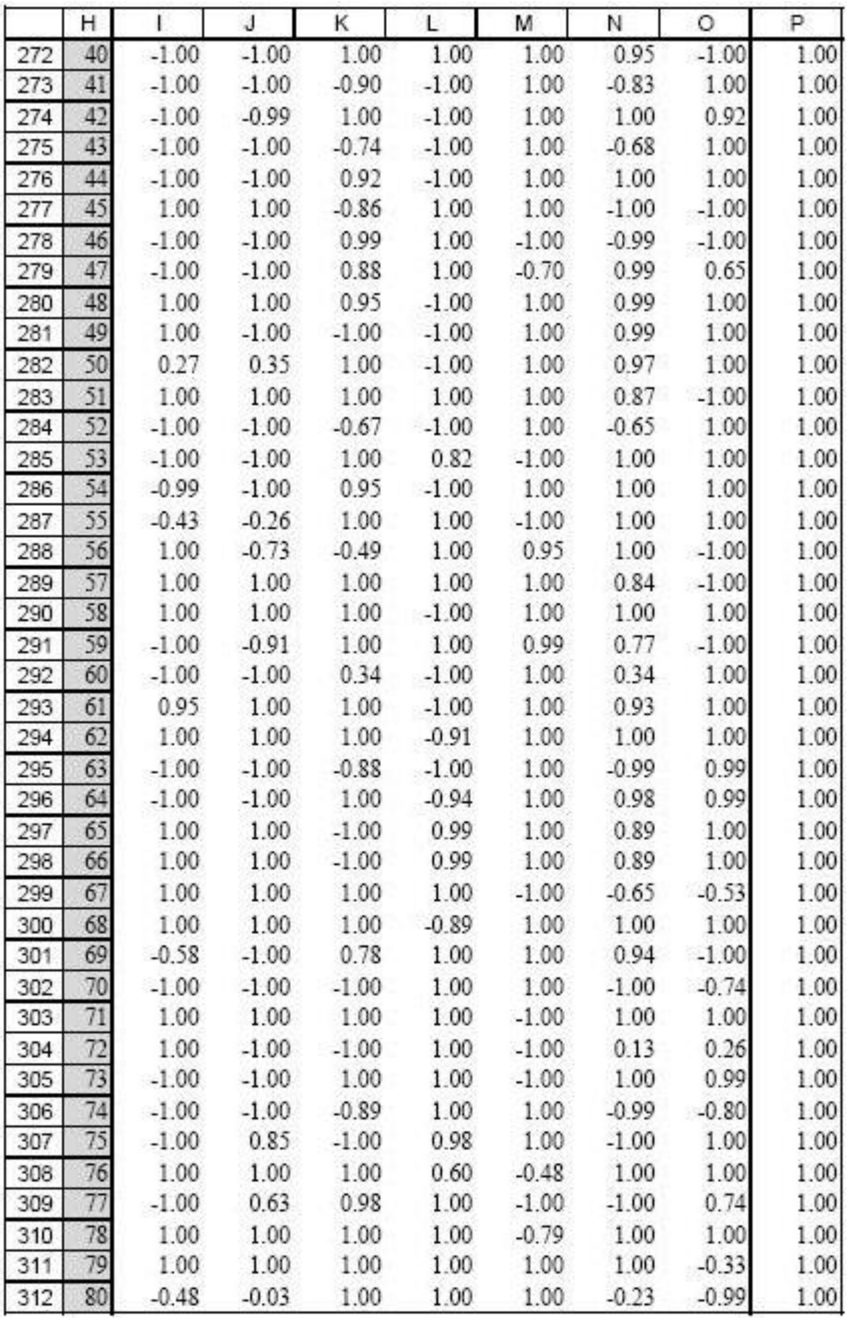
Table D.4. The parameters of the fourth step



	H	I	J	K	L	M	N	O	P
	Step-4 :Outputs of Hidden Neurons								
		1	2	3	4	5	6	7	Bias 2
233	1	-1.00	-1.00	0.30	1.00	-1.00	-1.00	-1.00	1.00
234	2	-1.00	-0.59	1.00	1.00	-1.00	-1.00	-1.00	1.00
235	3	-1.00	-1.00	1.00	-1.00	1.00	-0.76	-1.00	1.00
236	4	-1.00	0.40	1.00	1.00	1.00	-0.22	-1.00	1.00
237	5	-1.00	0.50	1.00	0.32	1.00	0.60	0.49	1.00
238	6	-1.00	-1.00	1.00	0.83	1.00	0.97	-1.00	1.00
239	7	-1.00	-1.00	1.00	-1.00	1.00	1.00	0.75	1.00
240	8	-1.00	0.89	1.00	0.77	1.00	-1.00	-1.00	1.00
241	9	-1.00	-1.00	-1.00	-0.92	1.00	-1.00	0.74	1.00
242	10	-1.00	-0.93	1.00	1.00	1.00	1.00	-0.99	1.00
243	11	-1.00	-0.82	1.00	1.00	-1.00	-1.00	-0.98	1.00
244	12	-1.00	0.60	1.00	1.00	0.69	-0.83	-1.00	1.00
245	13	-1.00	-1.00	-1.00	-1.00	1.00	-0.82	1.00	1.00
246	14	-1.00	-1.00	-1.00	-1.00	1.00	-0.83	1.00	1.00
247	15	-1.00	-0.82	-1.00	-0.98	1.00	-1.00	1.00	1.00
248	16	-1.00	-1.00	0.92	1.00	1.00	0.94	-1.00	1.00
249	17	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	1.00
250	18	-1.00	-1.00	1.00	1.00	-0.94	-0.82	-1.00	1.00
251	19	0.29	0.44	1.00	-0.99	1.00	1.00	1.00	1.00
252	20	-1.00	-1.00	-1.00	1.00	1.00	-0.99	-0.97	1.00
253	21	1.00	1.00	1.00	1.00	0.52	0.52	-1.00	1.00
254	22	-1.00	-1.00	-1.00	-1.00	1.00	-0.87	1.00	1.00
255	23	-1.00	-1.00	1.00	-0.83	0.67	1.00	1.00	1.00
256	24	-1.00	-0.75	1.00	-0.90	1.00	1.00	1.00	1.00
257	25	-1.00	-1.00	1.00	0.99	1.00	1.00	-0.97	1.00
258	26	-1.00	-1.00	1.00	-1.00	0.79	0.94	1.00	1.00
259	27	-1.00	-1.00	-1.00	-1.00	0.95	-0.94	1.00	1.00
260	28	-1.00	-1.00	1.00	1.00	1.00	0.98	-1.00	1.00
261	29	1.00	1.00	1.00	1.00	1.00	1.00	-0.95	1.00
262	30	-1.00	-1.00	1.00	1.00	-1.00	-0.87	-0.95	1.00
263	31	-1.00	-1.00	1.00	1.00	-1.00	0.99	0.74	1.00
264	32	-1.00	-1.00	1.00	-1.00	1.00	1.00	0.88	1.00
265	33	-1.00	-1.00	-1.00	0.16	1.00	0.28	1.00	1.00
266	34	-1.00	-1.00	1.00	0.78	1.00	1.00	-0.77	1.00
267	35	-1.00	-1.00	1.00	1.00	1.00	1.00	-0.97	1.00
268	36	-1.00	-1.00	-1.00	0.78	-1.00	-1.00	1.00	1.00
269	37	-1.00	-1.00	-1.00	1.00	0.80	0.93	1.00	1.00
270	38	0.71	0.80	1.00	-1.00	1.00	1.00	1.00	1.00
271	39	-0.90	-0.79	1.00	-1.00	1.00	1.00	1.00	1.00

(cont. on next page)

Table D.4. (cont.) The parameters of the fourth step



	H	I	J	K	L	M	N	O	P
272	40	-1.00	-1.00	1.00	1.00	1.00	0.95	-1.00	1.00
273	41	-1.00	-1.00	-0.90	-1.00	1.00	-0.83	1.00	1.00
274	42	-1.00	-0.99	1.00	-1.00	1.00	1.00	0.92	1.00
275	43	-1.00	-1.00	-0.74	-1.00	1.00	-0.68	1.00	1.00
276	44	-1.00	-1.00	0.92	-1.00	1.00	1.00	1.00	1.00
277	45	1.00	1.00	-0.86	1.00	1.00	-1.00	-1.00	1.00
278	46	-1.00	-1.00	0.99	1.00	-1.00	-0.99	-1.00	1.00
279	47	-1.00	-1.00	0.88	1.00	-0.70	0.99	0.65	1.00
280	48	1.00	1.00	0.95	-1.00	1.00	0.99	1.00	1.00
281	49	1.00	-1.00	-1.00	-1.00	1.00	0.99	1.00	1.00
282	50	0.27	0.35	1.00	-1.00	1.00	0.97	1.00	1.00
283	51	1.00	1.00	1.00	1.00	1.00	0.87	-1.00	1.00
284	52	-1.00	-1.00	-0.67	-1.00	1.00	-0.65	1.00	1.00
285	53	-1.00	-1.00	1.00	0.82	-1.00	1.00	1.00	1.00
286	54	-0.99	-1.00	0.95	-1.00	1.00	1.00	1.00	1.00
287	55	-0.43	-0.26	1.00	1.00	-1.00	1.00	1.00	1.00
288	56	1.00	-0.73	-0.49	1.00	0.95	1.00	-1.00	1.00
289	57	1.00	1.00	1.00	1.00	1.00	0.84	-1.00	1.00
290	58	1.00	1.00	1.00	-1.00	1.00	1.00	1.00	1.00
291	59	-1.00	-0.91	1.00	1.00	0.99	0.77	-1.00	1.00
292	60	-1.00	-1.00	0.34	-1.00	1.00	0.34	1.00	1.00
293	61	0.95	1.00	1.00	-1.00	1.00	0.93	1.00	1.00
294	62	1.00	1.00	1.00	-0.91	1.00	1.00	1.00	1.00
295	63	-1.00	-1.00	-0.88	-1.00	1.00	-0.99	0.99	1.00
296	64	-1.00	-1.00	1.00	-0.94	1.00	0.98	0.99	1.00
297	65	1.00	1.00	-1.00	0.99	1.00	0.89	1.00	1.00
298	66	1.00	1.00	-1.00	0.99	1.00	0.89	1.00	1.00
299	67	1.00	1.00	1.00	1.00	-1.00	-0.65	-0.53	1.00
300	68	1.00	1.00	1.00	-0.89	1.00	1.00	1.00	1.00
301	69	-0.58	-1.00	0.78	1.00	1.00	0.94	-1.00	1.00
302	70	-1.00	-1.00	-1.00	1.00	1.00	-1.00	-0.74	1.00
303	71	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	1.00
304	72	1.00	-1.00	-1.00	1.00	-1.00	0.13	0.26	1.00
305	73	-1.00	-1.00	1.00	1.00	-1.00	1.00	0.99	1.00
306	74	-1.00	-1.00	-0.89	1.00	1.00	-0.99	-0.80	1.00
307	75	-1.00	0.85	-1.00	0.98	1.00	-1.00	1.00	1.00
308	76	1.00	1.00	1.00	0.60	-0.48	1.00	1.00	1.00
309	77	-1.00	0.63	0.98	1.00	-1.00	-1.00	0.74	1.00
310	78	1.00	1.00	1.00	1.00	-0.79	1.00	1.00	1.00
311	79	1.00	1.00	1.00	1.00	1.00	1.00	-0.33	1.00
312	80	-0.48	-0.03	1.00	1.00	1.00	-0.23	-0.99	1.00

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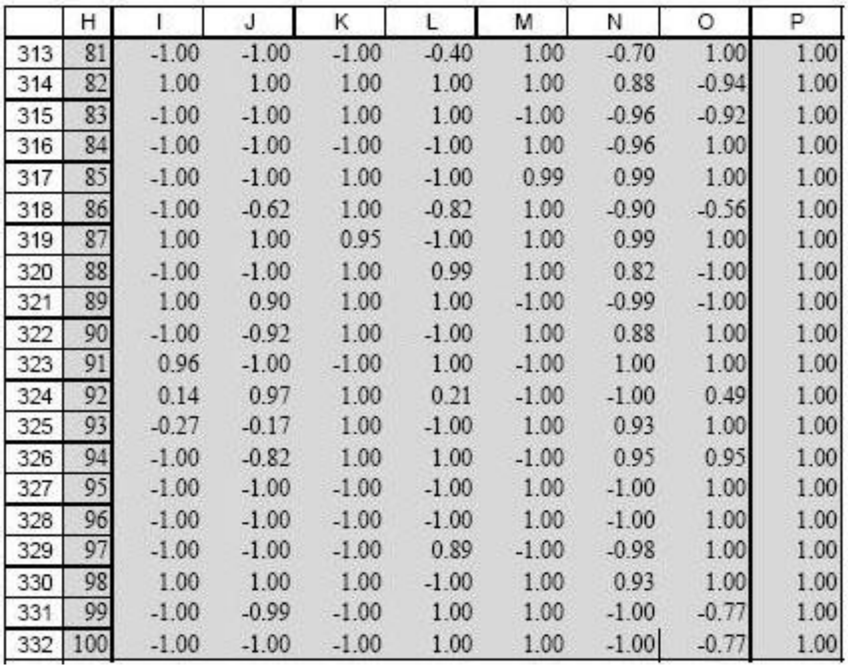
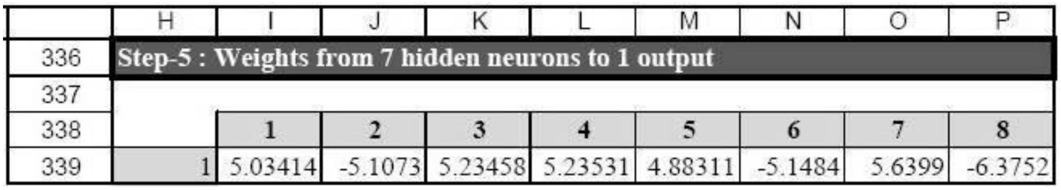
Table D.4. (cont.) The parameters of the fourth step



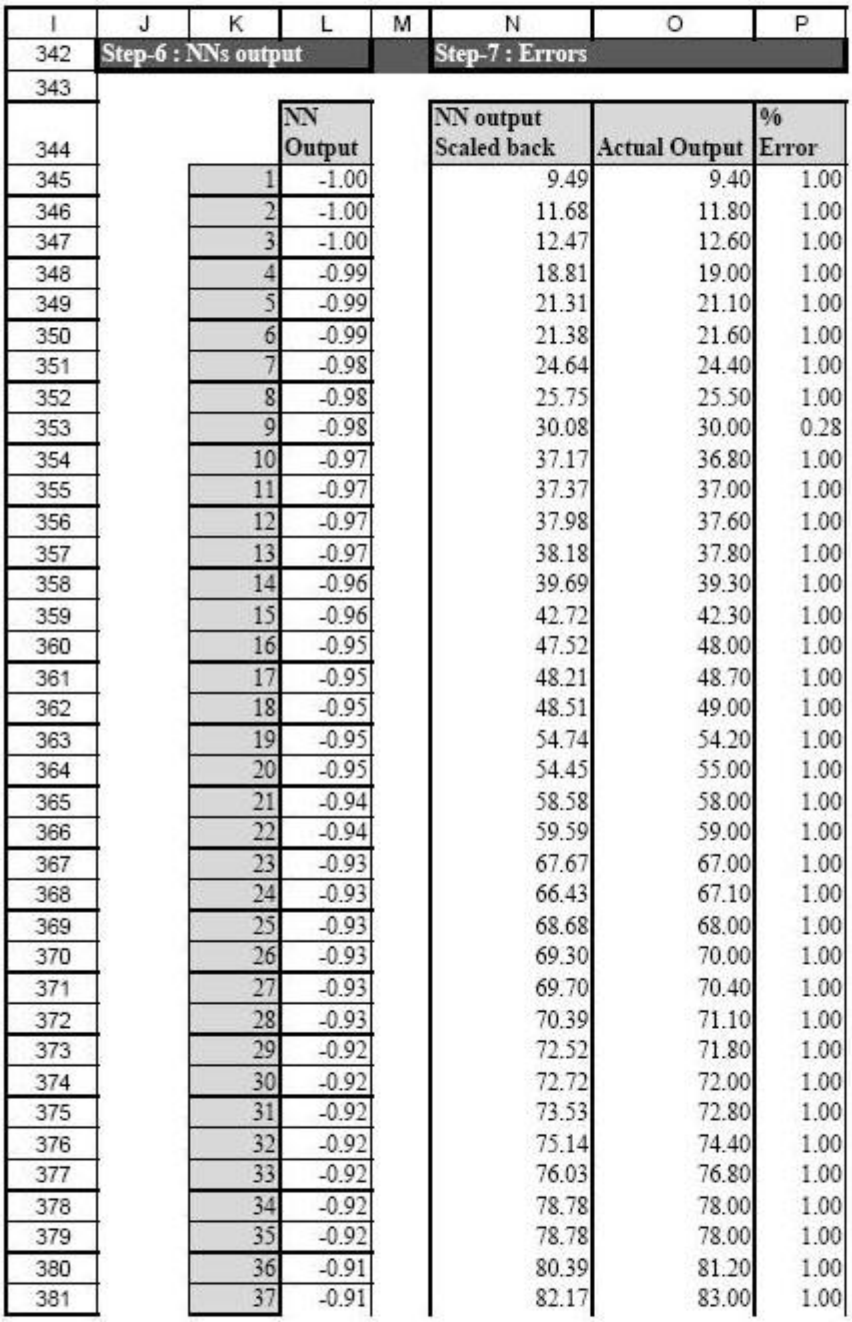
	H	I	J	K	L	M	N	O	P
313	81	-1.00	-1.00	-1.00	-0.40	1.00	-0.70	1.00	1.00
314	82	1.00	1.00	1.00	1.00	1.00	0.88	-0.94	1.00
315	83	-1.00	-1.00	1.00	1.00	-1.00	-0.96	-0.92	1.00
316	84	-1.00	-1.00	-1.00	-1.00	1.00	-0.96	1.00	1.00
317	85	-1.00	-1.00	1.00	-1.00	0.99	0.99	1.00	1.00
318	86	-1.00	-0.62	1.00	-0.82	1.00	-0.90	-0.56	1.00
319	87	1.00	1.00	0.95	-1.00	1.00	0.99	1.00	1.00
320	88	-1.00	-1.00	1.00	0.99	1.00	0.82	-1.00	1.00
321	89	1.00	0.90	1.00	1.00	-1.00	-0.99	-1.00	1.00
322	90	-1.00	-0.92	1.00	-1.00	1.00	0.88	1.00	1.00
323	91	0.96	-1.00	-1.00	1.00	-1.00	1.00	1.00	1.00
324	92	0.14	0.97	1.00	0.21	-1.00	-1.00	0.49	1.00
325	93	-0.27	-0.17	1.00	-1.00	1.00	0.93	1.00	1.00
326	94	-1.00	-0.82	1.00	1.00	-1.00	0.95	0.95	1.00
327	95	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00
328	96	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00
329	97	-1.00	-1.00	-1.00	0.89	-1.00	-0.98	1.00	1.00
330	98	1.00	1.00	1.00	-1.00	1.00	0.93	1.00	1.00
331	99	-1.00	-0.99	-1.00	1.00	1.00	-1.00	-0.77	1.00
332	100	-1.00	-1.00	-1.00	1.00	1.00	-1.00	-0.77	1.00

Table D.5. The parameters of the fifth step



	H	I	J	K	L	M	N	O	P
336	**Step-5 : Weights from 7 hidden neurons to 1 output**								
337									
338		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
339	1	5.03414	-5.1073	5.23458	5.23531	4.88311	-5.1484	5.6399	-6.3752

Table D.6. The parameters of the sixth step and the seventh step



I	J	K	L	M	N	O	P
342	**Step-6 : NNs output**				**Step-7 : Errors**		
343							
344			**NN Output**		**NN output Scaled back**	**Actual Output**	**% Error**
345		1	-1.00		9.49	9.40	1.00
346		2	-1.00		11.68	11.80	1.00
347		3	-1.00		12.47	12.60	1.00
348		4	-0.99		18.81	19.00	1.00
349		5	-0.99		21.31	21.10	1.00
350		6	-0.99		21.38	21.60	1.00
351		7	-0.98		24.64	24.40	1.00
352		8	-0.98		25.75	25.50	1.00
353		9	-0.98		30.08	30.00	0.28
354		10	-0.97		37.17	36.80	1.00
355		11	-0.97		37.37	37.00	1.00
356		12	-0.97		37.98	37.60	1.00
357		13	-0.97		38.18	37.80	1.00
358		14	-0.96		39.69	39.30	1.00
359		15	-0.96		42.72	42.30	1.00
360		16	-0.95		47.52	48.00	1.00
361		17	-0.95		48.21	48.70	1.00
362		18	-0.95		48.51	49.00	1.00
363		19	-0.95		54.74	54.20	1.00
364		20	-0.95		54.45	55.00	1.00
365		21	-0.94		58.58	58.00	1.00
366		22	-0.94		59.59	59.00	1.00
367		23	-0.93		67.67	67.00	1.00
368		24	-0.93		66.43	67.10	1.00
369		25	-0.93		68.68	68.00	1.00
370		26	-0.93		69.30	70.00	1.00
371		27	-0.93		69.70	70.40	1.00
372		28	-0.93		70.39	71.10	1.00
373		29	-0.92		72.52	71.80	1.00
374		30	-0.92		72.72	72.00	1.00
375		31	-0.92		73.53	72.80	1.00
376		32	-0.92		75.14	74.40	1.00
377		33	-0.92		76.03	76.80	1.00
378		34	-0.92		78.78	78.00	1.00
379		35	-0.92		78.78	78.00	1.00
380		36	-0.91		80.39	81.20	1.00
381		37	-0.91		82.17	83.00	1.00

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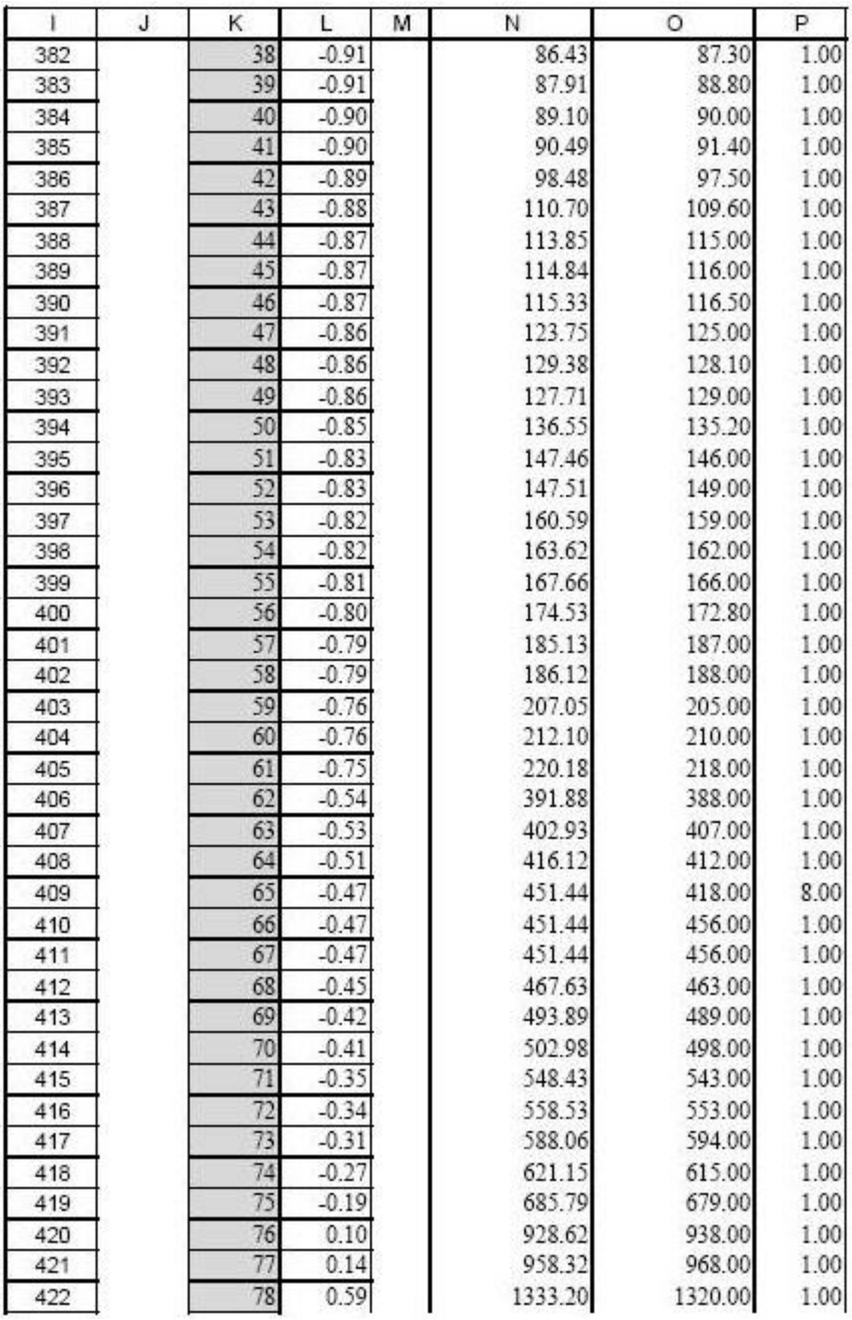
Table D.6. (cont.) The parameters of the sixth step and the seventh step



I	J	K	L	M	N	O	P
382		38	-0.91		86.43	87.30	1.00
383		39	-0.91		87.91	88.80	1.00
384		40	-0.90		89.10	90.00	1.00
385		41	-0.90		90.49	91.40	1.00
386		42	-0.89		98.48	97.50	1.00
387		43	-0.88		110.70	109.60	1.00
388		44	-0.87		113.85	115.00	1.00
389		45	-0.87		114.84	116.00	1.00
390		46	-0.87		115.33	116.50	1.00
391		47	-0.86		123.75	125.00	1.00
392		48	-0.86		129.38	128.10	1.00
393		49	-0.86		127.71	129.00	1.00
394		50	-0.85		136.55	135.20	1.00
395		51	-0.83		147.46	146.00	1.00
396		52	-0.83		147.51	149.00	1.00
397		53	-0.82		160.59	159.00	1.00
398		54	-0.82		163.62	162.00	1.00
399		55	-0.81		167.66	166.00	1.00
400		56	-0.80		174.53	172.80	1.00
401		57	-0.79		185.13	187.00	1.00
402		58	-0.79		186.12	188.00	1.00
403		59	-0.76		207.05	205.00	1.00
404		60	-0.76		212.10	210.00	1.00
405		61	-0.75		220.18	218.00	1.00
406		62	-0.54		391.88	388.00	1.00
407		63	-0.53		402.93	407.00	1.00
408		64	-0.51		416.12	412.00	1.00
409		65	-0.47		451.44	418.00	8.00
410		66	-0.47		451.44	456.00	1.00
411		67	-0.47		451.44	456.00	1.00
412		68	-0.45		467.63	463.00	1.00
413		69	-0.42		493.89	489.00	1.00
414		70	-0.41		502.98	498.00	1.00
415		71	-0.35		548.43	543.00	1.00
416		72	-0.34		558.53	553.00	1.00
417		73	-0.31		588.06	594.00	1.00
418		74	-0.27		621.15	615.00	1.00
419		75	-0.19		685.79	679.00	1.00
420		76	0.10		928.62	938.00	1.00
421		77	0.14		958.32	968.00	1.00
422		78	0.59		1333.20	1320.00	1.00

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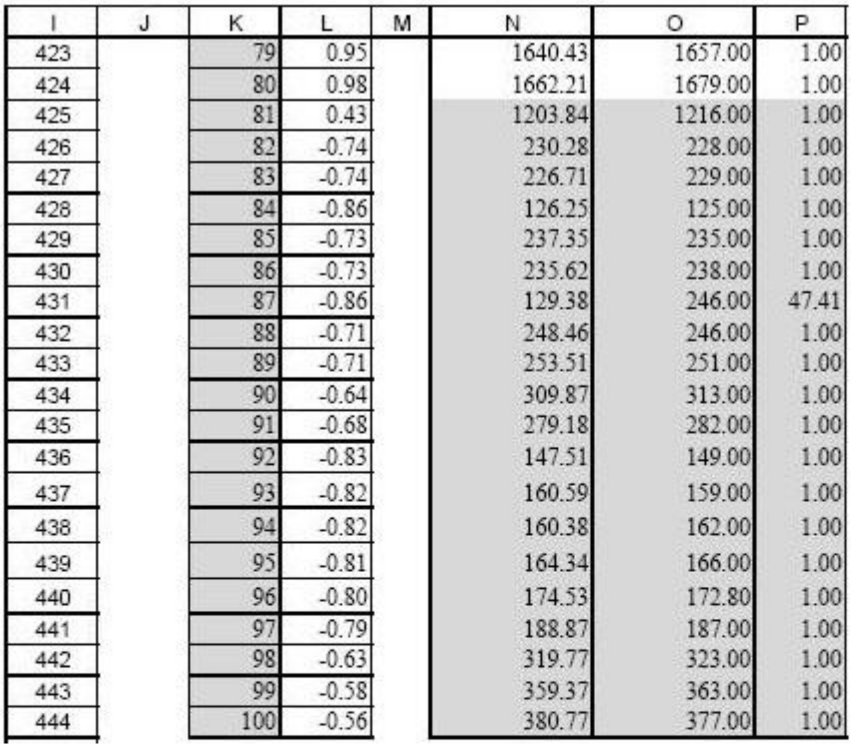
Table D.6. (cont.) The parameters of the sixth step and the seventh step



I	J	K	L	M	N	O	P
423		79	0.95		1640.43	1657.00	1.00
424		80	0.98		1662.21	1679.00	1.00
425		81	0.43		1203.84	1216.00	1.00
426		82	-0.74		230.28	228.00	1.00
427		83	-0.74		226.71	229.00	1.00
428		84	-0.86		126.25	125.00	1.00
429		85	-0.73		237.35	235.00	1.00
430		86	-0.73		235.62	238.00	1.00
431		87	-0.86		129.38	246.00	47.41
432		88	-0.71		248.46	246.00	1.00
433		89	-0.71		253.51	251.00	1.00
434		90	-0.64		309.87	313.00	1.00
435		91	-0.68		279.18	282.00	1.00
436		92	-0.83		147.51	149.00	1.00
437		93	-0.82		160.59	159.00	1.00
438		94	-0.82		160.38	162.00	1.00
439		95	-0.81		164.34	166.00	1.00
440		96	-0.80		174.53	172.80	1.00
441		97	-0.79		188.87	187.00	1.00
442		98	-0.63		319.77	323.00	1.00
443		99	-0.58		359.37	363.00	1.00
444		100	-0.56		380.77	377.00	1.00

Table D.7. The Error percentages of the training and testing cases and final weighted error

K	L	M	N	O	P
448		Error on %80 of the cases (Training)			1.08
449		Error on %20 of the cases (Testing)			3.32
450					
451		**Final weighted error**			**2.20**