A STUDYON INDOOR THERMAL COMFORT AND NEU ARCHITECTURE DEPARTMENT CLASSROOMS

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Aynur KARAOĞLU: A Study on İndoor Thermal Comfort and NEU Architecture Department Classrooms

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DECLARATION

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any reward. Where other sources of information have been used, they have been acknowledged.

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ABSTRACT

Among the most important requirements for user to provide a maximum level of physical and mental performance in any architectural space is the condition of thermal comfort. Variables of thermal comfort such as air temperature, mean radiant temperature, air velocity, humidity, metabolic activity and thermal properties of people's clothes are taken into consideration in this study.

Currently in our milieu, not enough attention is paid during design and construction processes on thermal performance of buildings. Buildings should be designed not only with min. and max. heating and cooling loads but also with thermal comfort satisfaction expectations for their occupants.

The aim of the study was to determine the existing conditions of thermal comfort of Architecture Department in Near East University.

Therefore, in the second chapter of the thesis report, definitions in relation to "thermal comfort" are dealt with.

Variables of thermal comfort are the subject of chapter three.

Effects of the climate and other factors of heat discomfort and thermal performance of buildings are handled in chapter four and five.

Chapter six is on a case study at Near East University classrooms of Architecture Department, where the heat measurements are given as output data. Inspection, findings and conclusion of the case study are presented in the same chapter.

Key words: thermal comfort, air temperature, mean radiant temperature, air velocity, humidity, metabolic activity, thermal comfort variables, heat measurements, thermal performance of buildings.

ÖZET

Herhangi bir mimari mekanda kullanıcıya ait fiziksel ve zihinsel performansı maksimum düzeyde sağlamak için en önemli koşul termal konfor durumudur. Termal konforun değişkenleri, hava sıcaklığı, ısıl konfor dercesi, radyant sıcaklık, hava hızı, nem, metabolik aktivite ve kişilerin giysi seçimi bu çalışmada incelenen konular arasındadır.

Günümüzde, tasarım ve inşaat sürecinde binaların termal performansına yeterinde özen gösterilmemektedir. Binalar sadece minimum ve maksimum ısıtma ve soğutma yükleriyle tasarlanmamalı, aynı zamanda içerisinde bulunan kullanıcıların termal konfor beklentilerini de karşılamalıdır.

Çalışmanın amacı, Yakın Doğu Üniversitesi Mimarlık Fakültesi'nde termal konfor durumunu incelemek ve ortaya koymak olarak belirlendi. Bu doğrultuda,

İkinci bölümde, "termal konfor" anlamı konu alınmakta,

Termal konforun değişkenleri üçüncü bölümün konusunu oluşturmaktadır,

Bölüm 4 ve bölüm 5 iklim ve diğer faktörlerin etkilerini ve binaların termal performansının açıklamasını içermektedir.

Bölüm 6 Yakın Doğu Üniversitesi Mimarlık Fakültesi dersliklerinde yapılan ısı ölçüm çalışmalarını içermektedir. Çalışmadan elde edilen bulgular, inceleme ve sonuçlar aynı bölümde sunulmuştur.

Anahtar sözcükler: termal konfor, hava sıcaklığı, radyant sıcaklık, hava hızı, nem, metabolik aktivite, termal konfor değişkenleri, ısı ölçümleri, binaların termal performansı.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATIONS

MET	Heat generated by metabolic activity (1MET=58.2 W/m^{2})
CLO	Insulation of clothing (1CLO=0.155 m^2K/W)
CIBSE	The Chartered Institution of Building Services Engineers
RH	Relative humidity
CET	Corrected effective temperature
PSI	Personal symptom index
PMV	Predicted mean vote
PPD	Percentage people dissatisfied
PSV	Passive stack ventilation
TRY	Test reference year

LIST OF SYMBOLS

°C	Degree Celsius, scale and unit of measurement for temperature
°F	Fahrenheit - temperature scale
M	Metabolic rate, W/m^2
E / Emax	Required evaporative cooling
S.P.	Subjective response of sensible perspiration to the climatic conditions
W	Mechanical work performed by the body
C	Convective heat exchange
R	Radiant heat exchange
V	Airspeed over the body (m/s)
HRa	Humidity ratio of air (gr/kg)
p	Coefficient depending on clothing type
dbt	Dry bulb temperature
wbt	Wet bulb temperature
t_{res}	Resultant temperature (°C)
t_{mrt}	Mean radiant temperature (°C)
t_a	Air temperature (°C)
t_{cl}	Clothing surface temperature
h-1	Ventilation infiltration rate
E	Ventilation efficiency
Ce	Concentration of pollutant at exhaust
Cs	Concentration of pollutant in supply
ppm	Number of molecules of CO2 in every one million molecules of dried air (water vapor removed)
Qv	Heat loss or gain in watts
Va	Ventilation rate in air changes per hour (ac/h)
V_l	Ventilation rate in litres per second per person (l/s/p)
pC	Volumetric heat capacity of air = 1200 Jm-3K-1

ΔT	Internal/external air temperature difference (OC)
Ps	Pressure difference in pascals (Pa)
ρ	Density of air at temperature T
g	Acceleration due to gravity = 9.8 m/S2
h	height between openings (m)
Ti	Inside temperature in kelvins
T*e*	External temperature in kelvins
Pw	Pressure difference across the building (Pa)
Cp_1 and Cp_2	Pressure coefficients across the building in relation to the wind speed (*v*) and air density (ρ)
C	Cloudiness
t_{sa}	Sol-air temperature
t_{ao}	Sol-air temperature
α	Solar absorbtance
ε	Long-wave emissivity
R_{so}	External surface resistance
I_s	Solar irradiance (W/m^2)
I_1	Long-wave radiation loss *(W/m^2)*
v	Mean wind speed (m/s) at height *H* (m)
v^r	Mean wind speed (m/s) at height 10m
Ps	Static pressure
*P*d	Dynamic pressure
Pt	Stagnation pressure
r	Air density
v	Wind speed (m/s) at a reference height, *h* (m)
ρ	Density of the air (kg/m^3)
C_p	Pressure coefficient measured with reference to the wind speed at the height
J	Joule; energy expended (or work done) in applying a force of one

	newton through a distance of one meter
W	Watts; the rate of energy use per second 1J/s (1 kW = 1000 J/s)
kWh	Kilowatt-hour; 1 kWh = 3600J
k	Thermal conductivity, the property of a material's ability to conduct heat
R	Thermal resistance (m2.K/W)
X	Thickness (m)
k	Thermal conductivity (W/m.K)
U	Overall heat transfer coefficient
Q_c	Convective heat transfer (W)
h_c	Convective heat transfer coefficient ($Wm^{-2}K^{-1}$)
t_a	Air temperature (°C)
t_s	Surface temperature (°C)
µm	Micrometer
Q_r	Radiation emitted by the surface
E	Surface emissivity
T	Surface temperature (°C)
W	Tale of evaporation from the surface
h_c	Convective heat transfer coefficient
P_{va}	Vapor pressure in air
P_s	Saturation vapor pressure at surface temperature
$R_{1,2,3....}$	Thermal resistance of element 1.2.3... ($m^2K.W^{-1}$)
x	Thickness (m)
k	Thermal conductivity ($W.m^{-1}.K^{-1}$)
Δ *T*	Inside/outside air temperature difference
R*si*	Internal surface resistance
v_r	Vapor resistivity (Ns/kg.m)
x	Thickness of material (m)
d*V*p	Drop in vapor pressure across a given thickness of material (kPa)

Vr	Vapor resistance of material (Ns/kg)
V_R	Vapor resistance of construction (Ns/kg)
dVp	Vapor drop across construction (kPa)
t_{ei}	Environment temperature
t_{mrt}	Mean radiant temperature
t_{ai}	Air temperature
E	The seasonal energy use (W)
Q_f	Fabric heat loss
Q_v	Ventilation heat loss
T_i	Average internal temperature
T_{sa}	Seasonal average temperature
Eff	Efficiency of heating system
T_{su}	Supply air temperature
T_{ex}	Extract air temperature
C_p	Volumetric specific heat of air
csa	Volume now rate/air speed

Chapter 1.

1. INTRODUCTION

A healthy and comfortable thermal environment of indoor workspace helps users to evolve their work efficiency by maintaining various comfort related parameters within the desired range. Thermal comfort is "the condition of mind which expresses satisfaction with the thermal environment". Thermal comfort is affected by heat. Human body have a certain thermal balance. In order to preserve this balance human body should be protected against effects of external conditions. Human maintains his body heat by clothing and creating a sheltered space to live. Building is an envelope which separates human from external climatic conditions. Building fulfills this requirement using heating and cooling units. Also this depends on how good thermal performance buildings have. Especially in old buildings it is observed that not enough attention is paid to thermal performance.

Factors affecting thermal comfort are environmental and constructional. The first group of factors includes local climatic conditions, which are outdoor temperature, relative humidity, solar radiation, geographical location and the effect of neighboring buildings etc. The second group of factors comprises materials of the building envelope, glazing type and size, orientation, thermal mass, surrounding vegetation, thermal insulation, ratio of transparent and opaque components, shading tools, building form etc. As can be realized, human have a chance to control and regulate the second group of factors in achieving better thermal comfort.

In recent years, depletion of conventional energy resources has forced people to explore alternative energy resources. This situation is worsening for buildings and their occupants, since more than half of the total energy consumption is used up by buildings. In view of these problems, architects should understand that they must design buildings which not only have minimum heating and cooling loads but also provide thermal comfort for their occupants. Moreover, it will be a logical approach for architects to pay attention to local climatic conditions during the design process. Thermal comfort mostly depends on making the right design decisions related to these factors during preliminary design stages.

2. AIM and SCOPE of STUDY

The aim of this study was to analyze the consequences of design elements on thermal comfort conditions in the Near East University Faculty of Architecture building located in Nicosia / Turkish Republic of Cyprus. In according to perform this study, heat and humidity measurement data from digital thermometer was recorded in previously selected classrooms from the case study building.

In the beginning of this research, our observations showed that Architecture Department Faculty building have some problems in terms of indoor climatic conditions, both in winter and summer. Hence, the most commonly used spaces in this building were selected to investigate the thermal behavior of classrooms. To analyze this behavior, temperature and humidity data had to be collected. On the other hand, it was clear that some design parameters had influenced the thermal conditions in the case study building.

3. RESEARCH METHODOLOGY

This study is focused on indoor and outdoor heat measurements at Architectural Department of Near East University in Nicosia / Turkish Republic of Cyprus.

Firstly temperature and humidity measurements were performed at two classes, each of them located on east and west façade of a building during the winter (11-25.03.2010) and summer (14-28.06.2010) periods for duration of 15 days. Architectural drawings of a building were obtained from Near East University's Design and Engineering Office. Exterior photos of a building were taken with it's surrounding. Also outdoor temperature measurements for the same periods provided by Meteorology Office of the Turkish Republic of Northern Cyprus were obtained as well (Meteorology Office of the Turkish Republic of Northern Cyprus).

The measurement days were not the hottest and coolest days during the year. Reason of choosing these periods was because of the maximum usage of the building during those days.

In the fnal stage of the study, all data collected from measurements were arranged in graphics and tables. According to that data analysis, evaluation and conclusions were made.

Chapter 2. COMFORT

2.1. Human thermal comfort - Thermal Comfort

The meaning of term 'comfort' should be considered on the historical ground; in the past and at present time depending on development of social, economical and cultural ground.

Level (rate) of comfort is different in periods of historical evolution of human.

In the Past (primitive age), comfort was obtained by shelters, where conditions were available for keeping out people from the natures conditions (weather changes-hot/cold/rain) and to be sheltered from enemies like animals. During ages people discovered how to use materials for their needs. Everything was about to keep their life safe and comfortable.

Nowadays comfort is related to basis of technical posibilities and income. In the world at different zones comfort relates to those two components.

In future the meaning of comfort may be related to those two componets again; but the formitive component will be a culture.

- Comfort is what Architecture is about; i.e. the purpose of Architecture is creation of Internal and External Comfort for people.
- Comfort is a state of conditions that are suitable for people and their needs.
- Comfort is a specific condition of the built environment. There are Natural Environment and Built Environment.
- Comfort is a complex essence which has the following characteristics or consistent : Physical, biological, psychological.
- Comfort is physical, biological and psychological response of human to conditions of environment where he/she is.

Where comfort is existent, human can perform all his activities in best way.

Comfortable space is a space where human responses are obtained in best way. When all these parameters are sufficient it can be said that an architectural space is comfortable.

2.2. Human Responses to the Thermal Environment

Thermal design is concerned with the heat transfer processes that take place within a building and between the building and its surroundings and the external climate, Table 1. It is primarily concerned with providing comfort and shelter for the building's occupants and contents. Thermal design therefore includes consideration of the

- Climate
- Building form and fabric
- Building environmental services, and
- Occupants and processes contained within the building.

It is also concerned with the energy used to provide heating, cooling and ventilation of buildings, and the local and global impact of energy use. The thermal design should be integrated with the visual and acoustic aspects of the design in order to achieve an overall satisfactory environmental solution (Table 1.) (Jones, 1999).

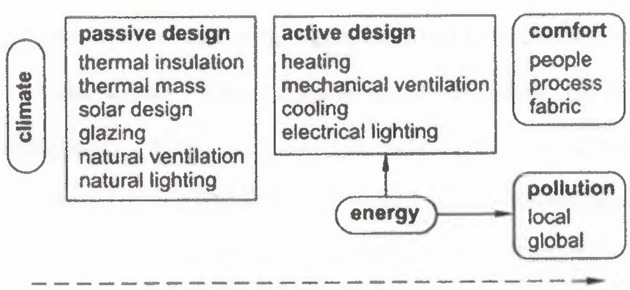


Table 1. Thermal design to achieve comfort for a given climatic condition. Passive design is related to building form and fabric. Active design is related to mechanical services, energy use and environmental impact (Jones, 1999).

The body produces heat by food metabolism and this heat is transferred to the environment by convection and radiation ("dry" heat loss). The dry heat exchange can be, of course, also positive (heat gain) when the air and/or temperatures of the surrounding surfaces are higher than that of the skin (about 34°C, 93°F). Some heat is lost by evaporation of water in the lungs, in proportion to the breathing rate which, in turn, is proportional to the metabolic rate. If the dry heat loss is not enough to balance the metabolic rate (and especially when the dry heat exchange is positive), sweat is produced at the skin glands and the evaporation of that sweat provides the additional required cooling (Jones, 1999).

The convection exchange depends on the ambient air temperature and the airspeed. The radiant exchange, in an indoor environment, depends on the average temperature of the surrounding surfaces (the mean radiant temperature). Outdoors, solar radiation is, of course, the major source of radiant heat gain. The rates of all the modes of heat exchange depend on the clothing properties.

The humidity does not play any role in the dry heat loss. It affects the rate of evaporation from the lungs but, contrary to common notions, ambient humidity does not affect the rate of sweat evaporation, except under extreme conditions. In fact, at higher humidity levels the sweat evaporation rate does not decrease, and may even increase. The reason is that in low humidity conditions the sweat evaporates within the skin pores, through a small fraction of the skin area. When the humidity is rising and the evaporative capacity of the environment decreases, the sweat is spread over a larger skin area. In this way the required evaporation rate can be maintained over a larger skin area at the higher humidity. Under certain conditions at high humidity the cooling efficiency of sweat evaporation decreases, when part of the latent heat of vaporization is taken from the ambient air instead of from the skin (Givoni 1976; Givoni and Belding 1962). In such cases the body produces, and evaporates, more sweat than in lower humidity in order to obtain the required physiological cooling (Jones, 1999).

The physiological research dealing with human responses to the thermal environment has covered the whole range of climatic conditions encountered by humans, from extreme cold to extreme heat. The main physiological human responses to changes in the thermal environment are the sweat rate, heart rate, inner body temperature, and the skin temperature. The comfort range is viewed as a certain limited range within the total range of thermal responses (Givoni, 1998).

Mathematical models predicting with reasonable accuracy these physiological responses-as functions of the climatic conditions, work (metabolic rate) and clothing properties, including acclimatization effect-have been developed and validated (Givoni, 1963; Givoni, 1976; Givoni and Belding, 1962; Givoni and Goldman, 1971, 1972, 1973).

The human sensory and physiological responses to the thermal environment are, to some extent, interrelated. The sensation of cold is associated with lower skin temperature, The sensation of heat, for resting or sedentary persons, is-correlated with higher skin temperature/higher sweat rate. Both responses reflect a higher thermal load on the body (Givoni, 1998).

2.2.1. The Thermal Sensation

As noted above, the main sensory thermal responses are the sensations of cold and heat and the discomfort from sensible perspiration.

The thermal sensation, over the whole range from very cold to very hot, is often graded (in comfort studies) along a seven-point numerical scale:

1 cold	3 slightly cool	5 slightly warm
2 cool	4 neutral (comfortable)	6 warm
		7 hot

A scale from minus 3 (cold) to +3 (hot) is sometimes used to express the same thermal sensations, with 0 stating neutral sensation. The range from slightly cool to slightly warm can be considered as designating acceptable conditions (Givoni, 1998).

2.2.1.1. Cold Discomfort

In dealing with cold discomfort a distinction should be made between "general" sensation of cold discomfort and "localized" discomfort (at the feet, the fingers, and so on). Localized discomfort is mainly experienced outdoors, when the overall insulation of the clothing is adequate but at certain specific points it is insufficient or that part of the body is exposed. Localized discomfort may be also experienced indoors when, for example, cold air "sinking" down large glass doors or windows accumulates near the floor; while the air at higher levels is at a higher temperature, the feet may feel too cold, but without the general sensation of cold. Persons sitting close to the glazing may feel localized discomfort only on the body side facing the glazing (Givoni, 1998).

A correlation exists between the subjective sensation of cold and the physiological response of the average skin temperature. The "general" thermal sensation of cold discomfort is experienced, under steady-state climatic conditions, when the average skin temperature is lowered below the lower level corresponding to the state of comfort, which under sedentary activity is about 32-33°C (90-92°F).

Thermal comfort in buildings in cold climates involves three aspects:

a.Providing comfortable indoor air and mean radiant temperatures of the interior surfaces of the external walls.

b.Prevention of directional radiative cooling, usually from large glazing areas.

c.Prevention of cold "drafts": discomfort resulting from localized cold air currents, usually from cracks between and around the sashes (wind penetration).

The actual level of the comfort zone, especially in winter, depends greatly on clothing. By wearing warmer clothing, it is possible to significantly lower the indoor temperatures and still remain comfortable. The acceptable indoor temperature at night, during the sleeping hours, is usually lower than during the daytime and evening hours (Givoni, 1998).

2.2.1.2. Heat Discomfort

The thermal sensation of heat discomfort is experienced, under steady-state conditions, when average skin temperature is elevated above the upper level corresponding to the state of comfort which, under sedentary activity, is about 33-34°C (91.4-93.2°F). However, the rate of elevation of the skin temperature when the ambient temperature rises above the comfort zone is much smaller than the rate of drop when the temperature falls below the comfort zone. The reason is that sweat evaporation reduces the rate of skin temperature rise.

The comfort skin temperature, T_s is *lowered* with increasing metabolic rate, M, (physical activity) as a result of a higher sweat-evaporation rate and a diversion of blood flow from the peripheral skin to the working muscles, a point discovered by Fanger (Givoni,1998).

2.2.1.3. Sensible Perspiration

Thermal comfort is also associated with a neutral state of skin moisture (absence of discomfort from a wet skin). While thermal sensation exists in both cold and hot conditions the perception of sensible perspiration exists only on the warm side of the comfort zone, in specific combinations of temperature, humidity, air motion, clothing, and physical activity. It is of special significance in hot-humid climates.

This sensation has two distinct limits. The lower limit is when the skin is completely dry and the upper limit is when the whole body and clothing are soaked with sweat. Between these two limits there are intermediate levels which can be defined quite clearly (Givoni, 1998).

When the evaporation rate is much faster than sweat secretion, the sweat evaporates as it emerges from the pores of the skin, without forming a liquid layer over the skin. The skin is then felt as "dry." Sensible-perspiration perception can be expressed by the following numerical scale:

0 Forehead and body completely dry

1 Skin clammy but moisture invisible

2 Moisture visible

3 Forehead or body wet (sweat covering the surface; formation of drops)

4 Clothing partially wet

5 Clothing almost completely wet

6 Clothing soaked

7 Sweat dripping off clothing

In several physiological studies (Givoni, 1963; Jennings and Givoni, 1959) the subjective sensation of sensible perspiration was recorded under controlled conditions over a wide range of climatic conditions.

Givoni has developed a mathematical model predicting the subjective response of sensible perspiration to the climatic conditions, clothing, and metabolic rate. It was found that the sensation of skin wetness (by the above scale) can be expressed as a function of the ratio E / E_{max}, where E is the required evaporative cooling, which equals to the physiological (total metabolic and environmental) heat stress, and E_{max} is the evaporative capacity of the air (Givoni, 1976)

S.P. = -0.3 + 5 (E/E/E_{max})

where: $E = (M - W) + (C + R)$

$E_{max} = p^{V0.3} x (35 - HR_a)$

M = Metabolic rate

W = Mechanical work performed by the body

C = Convective heat exchange

R = Radiant heat exchange

V = Airspeed over the body (m/s)

HR_a = Humidity ratio of air (gr/kg)

p = Coefficient depending on clothing type

All the energy units are in kilocalories per hour (Givoni, 1976).

2.2.1.4. Relationship Between Heat Sensation and Sensible Perspiration

These two types of discomfort may be experienced simultaneously or one of them experienced without the other. They can be affected by air velocity in opposite ways. Therefore, in different climatic types one or the other discomfort source is predominant. The following examples will illustrate such cases.

In a desert the humidity is very low, and wind speed is high. Discomfort is due exclusively to a feeling of excessive heat. The skin is actually too dry, although sweating is high (about 250 gr/hr, 0.55 lb/hr for a resting person). Evaporative potential far exceeds the rate of sweat secretion, so that sweat evaporation takes place within the skin pores. The skin's excessive dryness itself may become a source of irritation. Alleviation can be achieved by lowering the wind speed at the skin (e.g., by closing the openings) and, mainly, by lowering the ambient temperature (Givoni, 1998).

In contrast to the desert situation, discomfort in a warm-humid region, especially in still-air conditions, may be mainly due to excessive skin wetness. The air temperature in such regions is often below 26°C (79°F), and the rate of sweat secretion, at sedentary activity, is rather low (about 60 gr/hr, 0.13 lb/hr, per person). In spite of the low rate of sweating, the skin becomes wet because the evaporative potential of the still, humid air is very low. The physiological thermal balance is maintained, in spite of the lower evaporative potential, because the required evaporation rate is achieved over a larger wetted area of the skin. In practice, when the airspeed is suddenly increased, a sensation of chilliness may also accompany discomfort from the wet skin until the skin dries out sufficiently.

Alleviation of discomfort due to skin wetness is best achieved, in the absence of dehumidification, by maintaining a high-enough air velocity so that the required evaporation can be obtained with a smaller wetted area of the skin. Another option is to wear clothing of greater permeability (or to take off most clothes, as is common on a beach) (Givoni, 1998).

Chapter 3. THERMAL COMFORT VARIABLES

The body produces heat through metabolic activities and exchanges heat with its surroundings by conduction, convection and radiation (typically 75%), and evaporation (typically 25%). Thermal comfort is achieved when there is a balance between metabolic heat production and heat loss. It is mainly dependent on the thermal environmental conditions and the activity and clothing of the person in that environment (Jones, 1999).

3.1. Metabolic activity

The human body produces metabolic heat as a result of its muscular and digestive processes. It has to maintain a constant core temperature of 37°C. If the core body temperature is reduced by more than about 1°C hypothermia sets in; if it increases by more than about 1°C the person may suffer a heat stroke. The body must therefore lose the metabolic heat it generates in a controlled way. Clothing is one way of controlling heat loss. There are also physiological control mechanisms: for example, shivering when cold increases metabolic activity; the formation of 'goose-pimples' increases the body's surface resistance to heat loss; sweating when warm increases heat loss by evaporation. The heat generated by metabolic activity is measured in units of MET (1 MET = 58.2 W/m2 of body surface area; the average surface area of an adult is 1.8 m2. Typical values of MET for different activities are given in

Table 2.

Activity	MET	S(W)	L(W)
Seated at rest (theatre, hotel, lounge)	1.1	90	25
Light work (office, dwelling, school)	1.3	100	40
Standing activity (shopping, laboratory)	1.5	110	50
Standing activity (shop assistant, domestic)	2.2	130	105
Medium activity (factory, garage work)	2.5	140	125
Heavy work (factory)	4.2	190	250

Table 2. Metabolic heat generation for different activities at 20°C in MET and in watts (W) for sensible (S) and latent (L) heat loss (Jones, 1999).

3.2. Clothing

Clothing provides insulation against body heat loss. The insulation of clothing is measured in units of CLO (1 CLO = 0.155 m^2K/W; the units are those of internal resistance). Values of CLO for typical clothing ensembles are given in Table 3.

	CLO	(m2K/W)
Nude	0	0
Light summer clothes	0.5	0.08
Light working ensemble	0.7	0.11
Winter indoor	1.0	0.16
Heavy business suit	1.5	0.23

Table 3. Clothing resistance in CLO and thermal resistance (Jones, 1999).

3.3. Air Temperature

Air temperature is often taken as the main design parameter for thermal comfort. The CIBSE (The Chartered Institution of Building Services Engineers) recommended range for internal air temperature is between 19°C and 23°C in winter and less than 27°C in summer. The air temperature gradient between head and feet is also important for comfort; the temperature at feet should generally not be less than 4°C below that at head (Jones, 1999).

3.4. Radiant Temperature

Radiant temperature is a measure of the temperature of the surrounding surfaces, together with any direct radiant gains from high temperature sources (such as the sun). The ***mean radiant temperature*** is the area-weighted average of all the surface temperatures in a room. If the surfaces in a space are at different temperatures then the perceived radiant temperature in a space will be affected by the position of the person in relation to the various surfaces, with the closer or larger surface areas contributing more to the overall radiant temperature. Comfort can be affected by radiant asymmetry, and people are especially sensitive to warm ceilings (a 10°C radiant asymmetry from a warm ceiling can give rise to 20% comfort dissatisfaction). The ***vector radiant temperature*** is a measure of the maximum difference in a room between the radiant temperatures from opposite directions (Jones, 1999).

3.5. Relative Humidity (RH)

Relative humidity (RH) of a space will affect the rate of evaporation from the skin. The RH is a percentage measure of the amount of vapor in the air compared to the total amount of vapor the air can hold at that temperature. When temperatures are within the comfort range (19-23°C) the RH has little effect on comfort as long as it is within the range 40-70%. At high air temperatures (approaching average skin temperature of 34°C) evaporation heat loss is important to maintain comfort. Wet bulb temperature is a measure of the temperature of a space using a wetted thermometer. A 'dry bulb' temperature sensor will exchange heat with the surrounding air by convection. A wet bulb thermometer loses additional heat by evaporation and can be used in combination with a dry bulb, to obtain a measure of RH by referring to the psychrometric chart, **Plate**

1. An example of the use of this is shown in Figure 1, where a dry bulb temperature (dbt) of 19°C and a wet bulb temperature (wbt) of 14°C indicate a relative humidity (RH) of 60% (Jones, 1999).

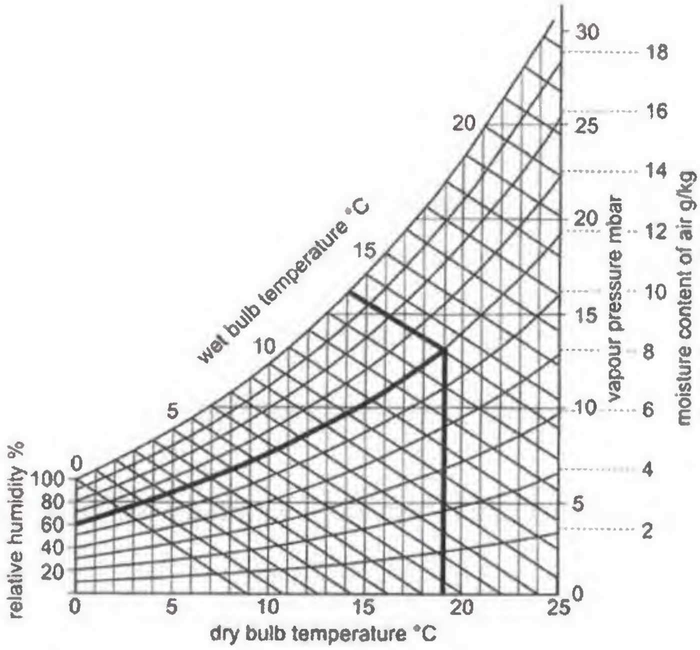


Plate 1. A psychrometric chart showing that a dry bulb temperature of 19°C and a wet bulb temperature of 14°C relates to an RH of 60% (Jones, 1999).

3.6. Air Speed

Air speed is a measure of the movement of air in a space. People begin to perceive air movement at about 0.2 m/s. Air speeds greater than 0.2 m/s produce a 20% and greater comfort dissatisfaction due to perceived draught. For most naturally ventilated spaces the air spced will be less than 0.1 m/s, away from the influence of open windows. For mechanically ventilated spaces, the air speed is generally greater than 0.1 m/s and could be greater than 0.2 m/s in areas close to air supply devices or where supply air jets are deflected by down stand beams or other geometric features of the space, and such speeds should be avoided. It is possible to counter draught discomfort to a certain extent by increasing air temperatures, as indicated in **Plate 2.** (Jones, 1999).

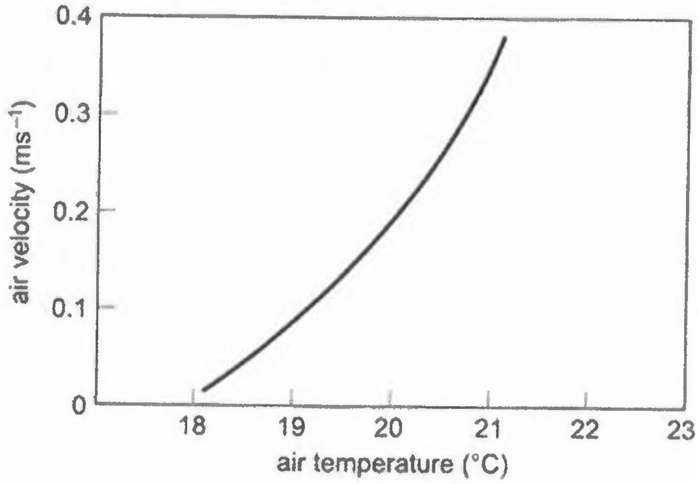


Plate 2. The interaction of air temperature and air movement of perceived comfort (Jones, 1999).

3.7. Thermal Comfort: Compensation and Adaption

The perception of thermal comfort is a function of the combination of the physical environment (air and radiant temperature, air movement and relative humidity) and the activity and clothing level of the person. To some extent these factors are compensatory. For example, during cool conditions, an increase in air movement can be compensated by an increase in air temperature, while in warm conditions; an increase in relative humidity can be compensated for by an increase in air movement. People can also adapt their clothing levels, activity levels and posture in response to the prevailing thermal conditions. In this way they are varying either their rate of metabolic heat production or their rate of body heat loss. Thermal indices use combinations of the comfort parameters in a compensatory way to provide a single measure of thermal comfort (Jones, 1999).

The ***resultant temperature***, sometimes called ***globe temperature***, is a combination of air temperature and mean radiant temperature, in a proportion comparable to that of the body's heat loss. At low air speeds (<0.1 m/s) the following relationship can be applied:

$$t_{res} = 0.5\ t_{mrt} + 0.5\ t_a$$

where t_{res} = resultant temperature (°C)

t_{mrt} = mean radiant temperature (°C)

t_a = air temperature (°C)

The resultant temperature can be measured at the centre of a black globe or 100 mm diameter (although globes between 25 mm and 150mm will give acceptable results).

The ***corrected effective temperature (CET)*** relates globe temperature, wet bulb temperature and air speed. It is equivalent to the thermal sensation in a standard environment with still, saturated air for the same clothing and activity. CET can be represented in monogram form as shown in **Plate 3**. (Jones, 1999).

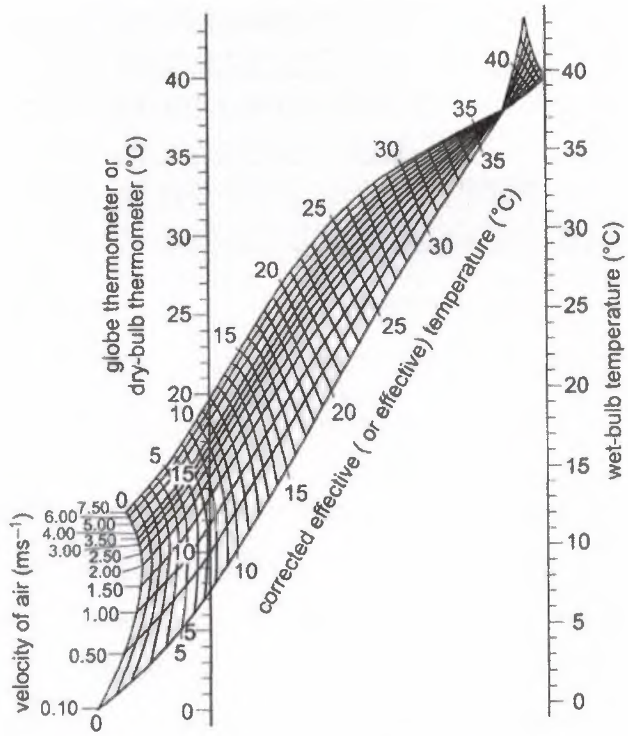


Plate 3. Nomogram for estimating corrected effective temperature (CET) (Jones, 1999).

3.8. Sick Building Syndrome

Sick building syndrome is a term used to describe a set of commonly occurring symptoms that affect people at their place of work, usually in office-type environments, and which disappear soon after they leave work. These symptoms include dry eyes, watery eyes, blocked nose, runny nose, headaches, lethargy, tight chest, and difficulty with breathing, typical percentage symptom reporting for air-conditioned offices is shown in **Plate 4** . The ***personal symptom index (PSI)*** is often used as a measure of the average number of symptoms per person for a whole office or zone (Jones, 1999).

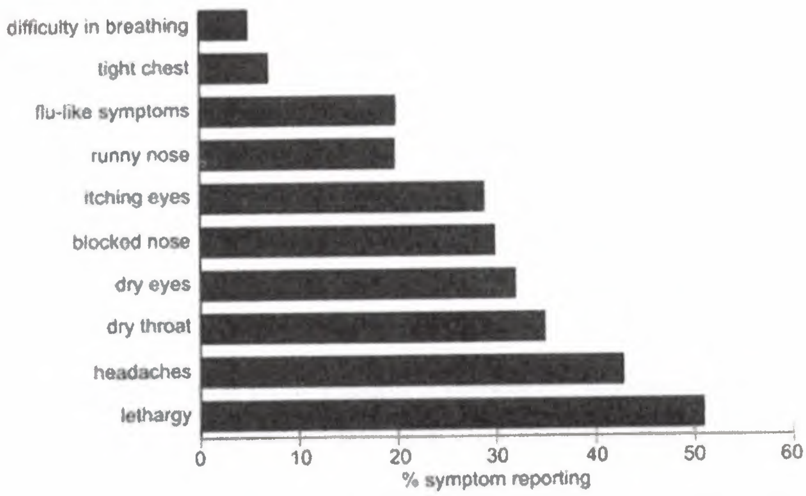


Plate 4. Sample percentage symptom reporting for air conditioned offices (Jones, 1999).

Workers who report high levels of symptoms also often report problems associated with thermal comfort, and in general perceive the air quality as stale, dry and warm. Studies have indicated that air-conditioned buildings appear to have a higher level of complaint than naturally ventilated buildings - possible reasons include cost cuts in their design, difficult to maintain and operate, difficult to keep clean (especially the air-distribution ductwork) and low ventilation effectiveness due to short-circuiting between supply and extract. Workers with a higher risk of symptoms are those in open-plan offices more than those in cellular ones, clerical workers more than managerial, women more than men, those in public sector buildings more than private, those in air-conditioned offices more than naturally ventilated ones, and those buildings where there is poor maintenance and poor operation of controls (Jones, 1999).

3.9. PMV and PPD

The ***predicted mean vote*** *(PMV)* is a measure of the average response from a large group of people voting on the scale below (Jones, 1999):

hot	+3
warm	+2
slightly warm	+1
neutral	0
slightly cool	- 1
cool	- 2
cold	- 3

The PMV can be calculated from ***Fanger's comfort equation*** which combines air temperature, mean radiant temperature, RH and air speed together with estimates of activity and clothing levels. The ***percentage people dissatisfied (PPD)*** provides a measure of the percentage of people who will complain of thermal discomfort in relation to the PMV. This is shown graphically in **Plate 5**. and can be calculated from:

$$\mathbf{PPD = 100 - 95 \exp (10.03353\ PMV^4 - 0.2179\ PMV^2)}$$

The implication of PPD is that there is no condition where everyone will experience optimum comfort conditions. It predicts that there will always be 5% of people who will report discomfort (Jones, 1999).

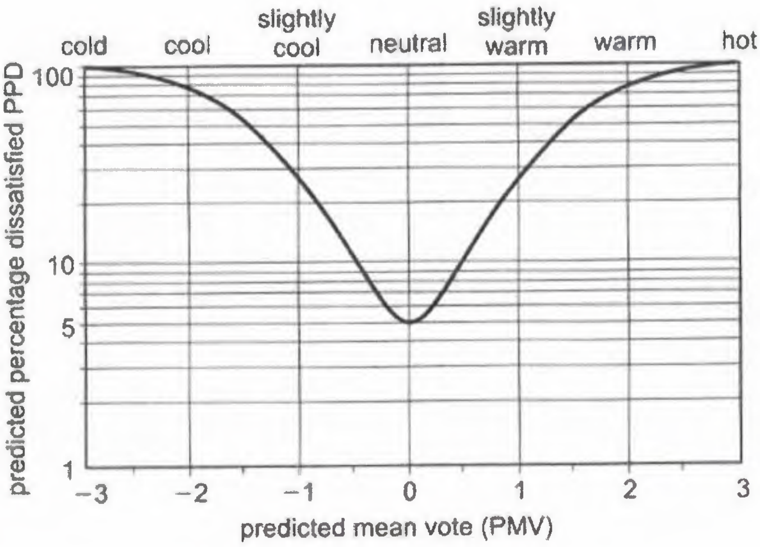


Plate 5. PPD as a function of PMV (Jones, 1999).

3.10. Ventilation

Ventilation is required to maintain good air quality for health and comfort. **Table 4.** to

Table 6. give recommended ventilation rates (Jones, 1999).

Type of building	Air t_{cl} °C	Ventilation İnfiltration rate (h^{-1})	Allowance (W/m^{2}°C)
Art galleries and museums	20	1	0,33
Assembly halls, lecture halls	18	½	0,17
Banking halls:			
Large (height > 4 m)	20	1	0,33
Small (height < 4 m)	20	1 ½	0,50
Bars	18	1	0,33
Canteens and dining rooms	20	1	0,33
Church and chapels:			
Up to 7000	18	½	0,17

Type of building	Air t_{cl} °C	Ventilation İnfiltration rate (h^{-1})	Allowance ($W/m^{2}°C$)
> 7000 m^3	18	¼	0,08
Vestries	20	1	0,33
Dining and banqueting halls	21	½	0,17
Exibition halls:			
Large (height > 4 m)	18	¼	0,08
Small (height < 4 m)	18	½	0,17
Factories:			
Sedentary work	19		
Light work	16		
Heavy work	13		
Fire stations, ambulance stations:			
Appliance rooms	15	½	0,17
Watch rooms	20	½	0,17
Recreation rooms	18	1	0,33
Flats, residences and hostels:			
Living rooms	21	1	0,33
Bedrooms	18	½	0,17
Bed-sitting rooms	21	1	0,33
Bathrooms	22	2	0,67
Lavatories and cloakrooms	18	1 ½	0,50
Service rooms	16	½	0,17
Staircase and corridors	16	1 ½	0,50
Entrance hall and foyers	16	1 ½	0,50
Public rooms	21	1	0,33
Gymnasia	16	¾	0,25
Hospitals:			
Corridors	16	1	0,33
Offices	20	1	0,33
Operating theatre suite	18-21	½	0,17
Stores	15	½	0,17
Wards and patient areas	18	2	0,67
Waiting rooms	18	1	0,33

Type of building	Air t_{cl} °C	Ventilation İnfiltration rate (h^{-1})	Allowance ($W/m^2 °C$)
Hotels:			
Bedrooms (standard)	22	1	0,33
Bedrooms (luxury)	24	1	0,33
Public rooms	21	1	0,33
corridors	18	1 ½	0,50
Foyers	18	1 ½	0,50
Laboratories	20	1	0,33
Law courts	20	1	0,33
Libraries			
Reading rooms (height > 4 m)	20	½	0,17
(height < 4 m)	20	¾	0,25
Stack rooms	18	½	0,17
Store rooms	15	¼	0,08
Offices:			
General	20	1	0,33
Private	20	1	0,33
Stores	15	½	0,17
Police Stations; Cells	18	5	1,65
Restaurants and tea shops	18	1	0,33
Schools and colleges:			
Classrooms	18	2	0,67
Lecture rooms	18	1	0,33
Studios	18	1	0,33
Shops and showrooms			
Small	18	1	0,33
Large	18	½	0,17
Department store	18	¼	0,08
Fitting rooms	21	1 ½	0,50
Store rooms	15	½	0,17
Sports pavillions: Dressing rooms	21	1	0,33
Swimming baths:			
Changing rooms	22	½	0,17

Type of building	Air t_{cl} °C	Ventilation İnfiltration rate (h^{-1})	Allowance ($W/m^{2}°C$)
Bath hall	26	½	0,17
Warehouses			
Working and packing spaces	16	½	0,17
Storage space	13	¼	0,08
The values quoted for rates of air infiltration in this table should not be used for the design of mechanical ventilation, air conditioning or warm air heating systems.			

Table 4. Recommended design values for internal environmental temperatures and empirical values for air infiltration and ventilation allowance (for normal sites and winter heating) (Jones, 1999).

Room or building		Recommended air change rates* (h^{-1})
Boilerhouses and engine rooms		15-30
Banking halls		6
Bathrooms, internal		6 ↑
Battery charging rooms		5↑'e kadar
canteens		8-12↕
cinemas		6-10↕
Dance halls		10-12↕
Dining and banqueting halls, restaurants		10-15↕
Drying rooms		Up to 5
Garages:	public (parking)	6↑ minimum
	repair shops	10↑ minimum
Hospitals:	treatment rooms	6
	operating theatre	15-17
	post-mortem room	5
Kitchens:	hotel and industrial	20-60↑
	local authority	10↑
Laboratories		4-6
laundries		10-15

Room or building		Recommended air change rates* (h^{-1})
Lavatories and toilets, internal		6-8↑
Libraries:	public	3-4↕
	book stacks	1-2
Offices, internal		4-6↕
Sculleries, and wash-ups, large-scale		10-15↑
Smoking rooms		10-15
Swimming baths:	bath hall	
	changing areas	10
Tiyatrolar		6-10

* the recommended air change rates do not apply in cases of warm-air heating, when the rate may be dictated by the heat requirements of the building or room.

↑ refers to extract ventilation

↕ ↕the supply air at the recommended rate will not neccessarily be all outdoor air, the required quantity of outdoor air must be checked against the number of occupants at a desirable rate per person.

Table 5. Mechanical ventilation rates for various types of building (Jones, 1999).

Type of space	Smoking	Outdoor air supply (litre/s)		
		Recommended	Minimum (Take greater of two)	
		Per person	Per person	per m^2 floor area
Factories * ↑	None			0,8
Offices (open plan)	Some			1,3
Shops, department stores and supermarkets	Some	8	5	-
Theatres*	Some			-
Dance halls*	Some			1,7
Hotel bedrooms ↑	Heavy			-
Laboratories	Some	12	8	1,3
Offices (private)	Heavy			-

Residences (average)	Heavy			-
Restaurants (cafeteria) ↑↕	Some			-
Cockail bars	Heavy			-
Conference rooms (average)	Some			-
Residences (luxury)	Heavy	18	12	-
Restaurants (dining rooms) ↑	Some			-
Board rooms, executive offices and conference rooms	Very heavy	25	18	6,0
Corridors	A per *capita* basis is not appropriate to these.			1,3
Kitchens (domestic) ↑				10,0
Kitcens (restaurant) ↑				20,0
Toilets*				10,0
* See statuotory requirements and local bye-laws				
↑ Rate of extract may be over-riding factor				
↕ Where queuing occurs in the space, the seating capacity may not be the appropriate total occupancy.				
For hospital wards, operating theatres, see Department of Health and Social Security Building Notes.				

Table 6. Recommended outdoor air supply rates for air-conditioned spaces (Jones, 1999).

3.10.1. Air Infiltration

Air infiltration is the term used to describe the fortuitous leakage of air through a building due to imperfections in the structure, such as:

- Cracks around doors, windows, infill panels
- Service entries, pipes, ducts, flues, ventilators and
- Through porous constructions, bricks, blocks, mortar joints (Jones, 1999).

3.10.2. Natural Ventilation

Natural ventilation is the movement of outdoor air into a space through intentionally provided openings, such as windows, doors and non-powered ventilators.

This is in addition to the ventilation due to air infiltration. In many cases, for much of the year infiltration alone will provide sufficient outdoor air to ventilate the building. However, it is uncontrollable, and if excessive, it can incur a high-energy penalty and/or make the building difficult to heat (or cool) to comfort levels (Jones, 1999).

3.10.3. Mechanical Ventilation

Mechanical ventilation is the movement of air by mechanical means to and/or from a space. It can be localized using individual wall or roof fans, or centralized with ducted distribution. It is controllable and can, for example, incorporate a heat-recovery system to extract heat from exhaust air and use it to pre-heat supply air (Jones, 1999).

3.10.4. Ventilation Effectiveness and Efficiency

The term *ventilation effectiveness* is used to describe the fraction of fresh air delivered to the space that reaches the occupied zone. It should ideally be 100%. However, if air short-circuits between supply and extract points then it could be greatly reduced, often down to as low as 50%, **Plate 6**. (Jones, 1999).

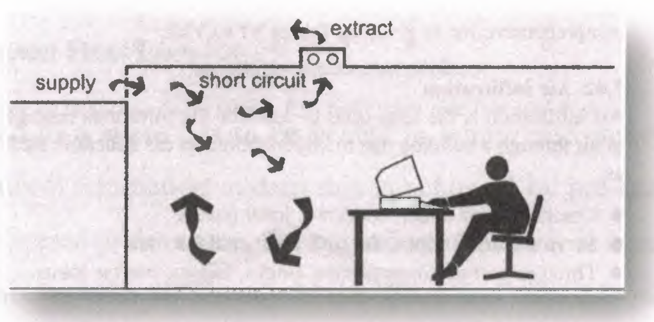


Plate 6. Short-circuiting of air between supply and extract reduces ventilation effectiveness and efficiency (Jones, 1999).

The term *ventilation efficiency* is used to describe the ability of a ventilation system to exhaust the pollutants generated within the space. For a specific pollutant, it is the mean concentration level of the pollutant throughout the space in relation to its concentration at the point of extract. The ventilation efficiency at a single location is the ratio of pollutant concentration at that location in the space to its concentration at the point of extract (Jones, 1999):

Ventilation efficiency $E = (Ce - Cs) / (Ce - Cs)$

where E = ventilation efficiency
Ce = concentration of pollutant at exhaust
Cs = concentration of pollutant in supply

If there is a significant level of the pollutant in the supply air then this should be subtracted from the internal and exhaust concentration levels (Jones, 1999).

3.10.5. Metabolic Carbon Dioxide as an Indicator of Air Quality

Metabolic carbon dioxide is often used as an indicator of air quality. For naturally ventilated spaces in winter when windows are closed, the carbon dioxide level may rise to typically 1500 ppm for offices, and 2500 ppm for school classrooms. For mechanically ventilated buildings the carbon dioxide level should not rise above 1000 ppm and will generally be less than 800 ppm. Metabolic carbon dioxide can also be used to estimate ventilation efficiency using the formula above (Jones, 1999).

3.10.6. Ventilation Heat Loss

The air supplied to a space has to be heated in winter and sometimes cooled in summer. In a mechanical ventilation system this is achieved by pre-heating or cooling the air before it is delivered to the space. For natural ventilation it is usually achieved by incoming fresh air mixing with air already in the space and then this mixture is heated by the heating system, for example by contact with 'radiator' surfaces.

The air that is exhausted from the space, through natural or mechanical means, contains heat energy. For a mechanical ventilation system this heat is sometimes recovered through a heat exchanger - otherwise it is wasted. The ventilation component of heat loss can be a significant and sometimes major proportion of the total building heat loss. It can also be very variable, especially in naturally ventilated buildings, as it depends on external wind velocity and air temperature (Jones, 1999).

The heat lost or gained through ventilation can be estimated from:

$$Qv = Va \times \text{volume} \times \Delta T \times \rho C/3600 \quad \text{or}$$

$$Qv = V_l \times \text{number of people} \times \Delta T \times \rho C/1000$$

where Qv = heat loss or gain in watts

Va = ventilation rate in air changes per hour (ac/h)

V_l = ventilation rate in litres per second per person (l/s/p)

pC = volumetric heat capacity of air = 1200 $Jm^{-3}K^{-1}$

ΔT = internal/external air temperature difference (^{O}C).

An increase in internal/external temperature difference causes an increase in ventilation rate and an increase in heat loss or gain.

When designing a heating system the ventilation rate used to calculate the design heat loss should correspond to a design ventilation rate. However, when estimating seasonal energy performance the ventilation rate will be the average ventilation rate over a heating season (Jones, 1999).

3.10.7. Natural Ventilation Design

Natural ventilation through leakage and purpose ventilation is a result of two processes, termed *stack effect* and *wind effect* (Jones, 1999).

3.10.8. Stack Effect

Stack effect occurs when there is a difference between the inside and outside air temperature. If the inside air temperature is warmer than the outside air it will be less dense and more buoyant. It will rise through the space escaping at high level through cracks and openings. It will be replaced by cooler, denser air drawn into the space at low level. Stack effect increases with increasing inside/ outside temperature difference and increasing height between the higher and lower openings. The neutral plane, **Plate 7.**, occurs at the location between the high and low openings at which the internal pressure will be the same as the external pressure (in the absence of wind). Above the neutral plane, the air pressure will be positive relative to the neutral plane and air will exhaust. Below the neutral plane the air pressure will be negative and external air will be drawn into the space (Jones, 1999).

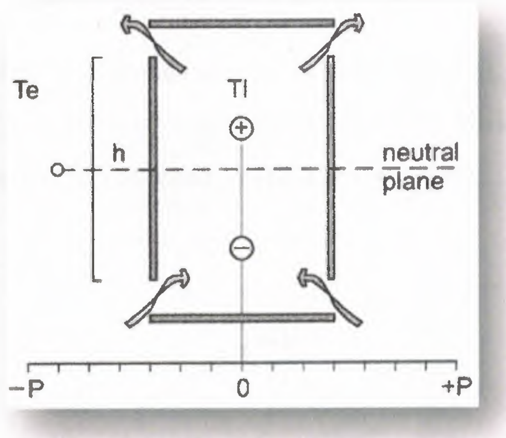


Plate 7. Pressure gradient due to slack effect, indicating the location of the neutral plane (Jones, 1999).

The pressure difference due to stack is estimated from (Jones, 1999):

$$Ps = -\rho \times T \times g \times h \times (1/Te - 1/Ti)$$

where Ps = pressure difference in pascals (Pa)
ρ = density of air at temperature T
g = acceleration due to gravity = 9.8 m/S2 h = height between openings (m)
Ti = inside temperature in kelvins, and
Te = external temperature in kelvins.

3.10.9. Wind Effect

Wind effect ventilation, sometimes referred to as *cross-ventilation,* is caused by the pressure differences on openings across a space due to the impact of wind on the external building envelope, **Plate 8.** Pressure differences will vary, depending on wind speed and direction and location of the openings in the envelope. The pressure at any point on a building envelope can be calculated for a given wind speed and direction if the pressure coefficient at the point is known. Pressure coefficients are usually derived from wind tunnel tests. The pressure difference across a building due to wind can be estimated from:

$$Pw = 1/2\ \rho v^2\ (Cp_1 - Cp_2)$$

where Pw = pressure difference across the building (Pa)

Cp_1 and Cp_2 = pressure coefficients across the building in relation to the wind speed (v) and air density (ρ) (Jones, 1999).

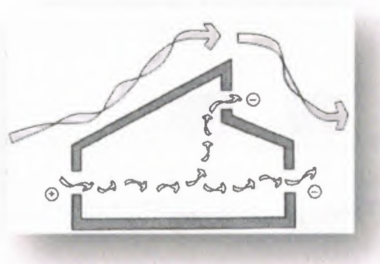


Plate 8. Wind driven cross-ventilation (Jones, 1999).

3.10.10. Ventilation Strategies

Plate 9. presents a range of natural ventilation strategies with depths limits for single-sided and cross-ventilated spaces. **Plate 10.** illustrates *passive stack ventilation (PSV)* used in domestic buildings and **Plate 11.** shows on typical domestic mechanical ventilation system.

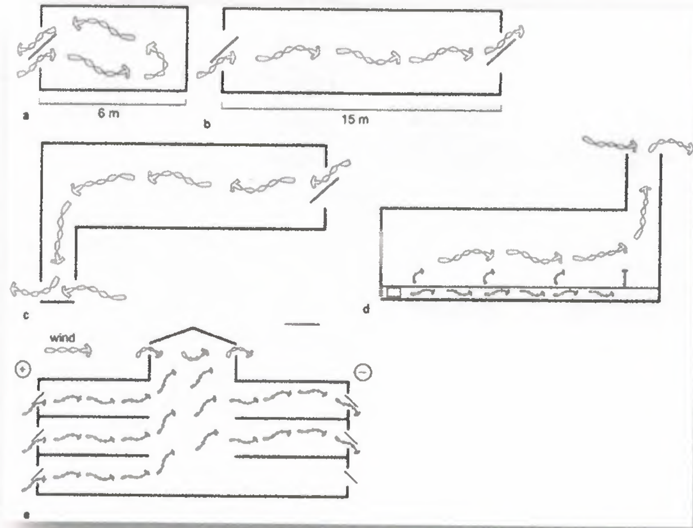


Plate 9. Natural ventilation strategies: a .Single-sided: b Cross-ventilation: c Cross-ventilation with chimney: d Cross-ventilation with underfloor supply: e Atrium: stack and wind effects (Jones, 1999).

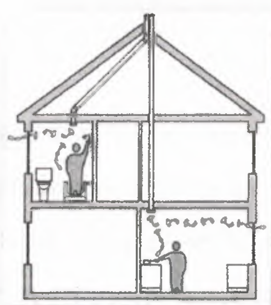


Plate 10. Passive stack ventilation (PSV) can be used instead of mechanical ventilation for local extract, for example in kitchens and bathrooms (Jones, 1999).

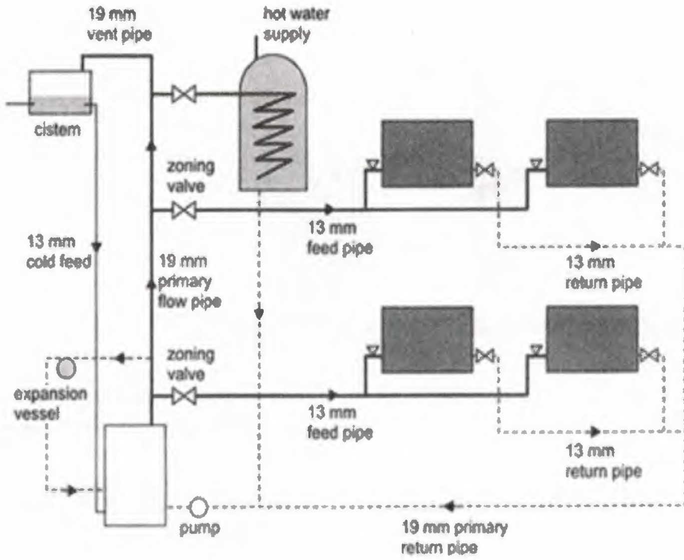


Plate 11. Domestic two pipe wet central heating system with flow and return to each radiator. The system can either be pressured using an expansion vessel (dotted circuit); or gravity feed, in which case it requires a header tank located above the top radiator (Jones, 1999).

3.11. Three stages to thermal design

Stage 1: Internal conditions for occupants or processes

The prime aim is to create spaces that are comfortable and healthy for their occupants,

Plate 12. People will typically spend 90% or more of their time in buildings. The environments people live and work in must promote a good quality of life. Thermal conditions should be within acceptable comfort limits and the indoor air quality should be free from any harmful pollutants. Buildings must also provide appropriate thermal conditions for their contents. Processes and for maintaining the building fabric itself. The required environmental conditions of all spaces should be clearly defined at the initial design stage in relation to the activities and contents of the space (Jones, 1999).

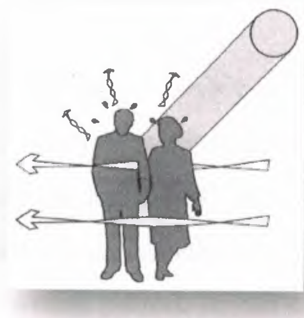


Plate 12. Thermal comfort is influenced by air temperature, air movement, relative humidity and the surrounding radiant environment (Jones, 1999).

Stage 2: *Climate modification through the building envelope*

Buildings can be designed to interact with the external environment in order to benefit from the natural energy of the sun and wind, **Plate 13.** The envelope of the building can be used to 'filter' or 'modify' the external climate to provide internal comfort conditions for much of the year without the use of fuel. The heat from the sun can be used to heat spaces in winter or to drive air movement for ventilation and cooling through buoyancy forces. The wind can also be used to provide ventilation and cooling. The fabric of the building can be used to insulate against heat loss or gain, and to stabilize the internal environment against extremes of external temperatures (hot or cold). The form, mass, orientation and construction of the building need to be designed in response to the climate and specific location (Jones, 1999).

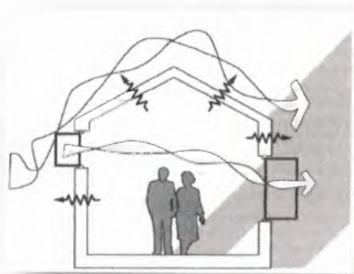


Plate 13. Climatic modification can be achieved through manipulation of a building's form and construction (Jones, 1999).

Stage 3: Mechanical services

If a building is designed to respond positively to the climate then its dependence on mechanical services to heat, cool and ventilate spaces will be minimized, **Plate 14.** However, there are few climates in the world where mechanical systems can be eliminated altogether. In temperate climates such as the UK a healing system will still generally be required during the winter period. In hot climates, mechanical cooling is often needed, sometimes the whole year round, for commercial buildings. These services should be provided in an energy-efficient way in order to minimize energy use from fossil fuels, and to reduce the impact that buildings have on polluting the environment. Wherever possible, renewable energy sources, such as wind power, photovoltaics and solar heating, should be considered. The mechanical systems and their controls should be designed to be able to respond to the specific needs of the occupants (Jones, 1999).

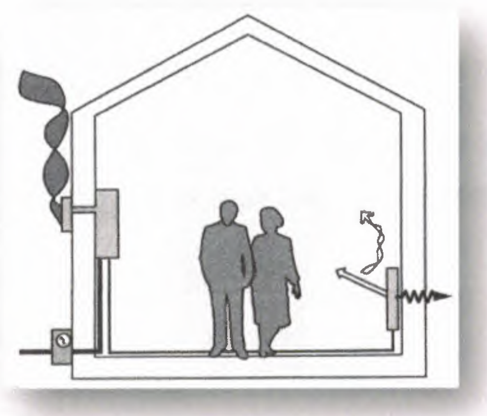


Plate 14. Mechanical services should he designed to minimize energy use and environmental impact (Jones, 1999).

Chapter 4. EFFECTS OF THE CLIMATE AND OTHER FACTORS OF HEAT DISCOMFORT

4.1. Architectural Features Affecting the Indoor Climate

Many architectural design features of a building affect the indoor climate. They do this by modifying four forms of interaction between the building and its environment (Givoni, 1998) :

a. The effective solar exposure of the glazed and opaque elements of the building's envelope (its wall and roof);

b. The effective solar heat gain of the building;

c. The rate of conductive and convective heat gain from, or loss to, the ambient air;

d. The potential for natural ventilation and passive cooling of the building.

The main relevant design features which affect some or all of the above mentioned interactions of the building with the environment are (Givoni, 1998) :

- The building's layout (shape)
- Orientation and shading conditions of the windows
- Orientation and colors of the walls
- The size and location of the windows from the ventilation aspect
- The effect of the ventilation conditions of a building on its indoor temperatures

In dealing with the subject of the building's orientation there are two separate effects of orientation: on the solar exposure of the building (orientation with respect to the sun) and on the ventilation potential (orientation with respect to the wind direction).

There are significant interactions between the effects of these design features, so that the quantitative effect on one feature (e.g., orientation) may greatly depend on the design details of other features (e.g., the shading of the windows and the color of the walls and the roof). Therefore, in discussing the effect of a given design feature, frequent back – and – forth references are made to this dependence on specific conditions of other features (Givoni, 1998).

4.2. Natural Ventilation

In all climatic regions of the world there are times when the outdoor temperature is pleasant and natural ventilation can be the simplest and most effective way to provide indoor comfort. Even in most hot regions there are months and times of the day when ventilation can provide comfort and, even in houses equipped with air conditioning, reduce the use for mechanical cooling. The role of ventilation is to maintain adequate indoor air quality and thermal comfort (Givoni, 1998).

Ventilating the building only at night can cool the interior mass of the building. By closing the windows during the daytime hours, the cooled mass reduces the rate of indoor temperature rise and thus may keep the indoor temperature significantly below the outdoor level. This strategy is termed nocturnal ventilative cooling. The effectiveness of nocturnal ventilation in lowering the indoor daytime temperature depends on the properties of the building materials, the shading conditions of the windows, and the external color of the building's envelope (Givoni, 1998).

Natural ventilation takes place mostly through windows, so that building design for ventilation means, to a great extent, decisions by the designer concerning the location, number, size, orientation, and design details of the windows.

The ventilation potential of a building depends on the wind speed around the building at the building's site. The site's wind conditions, in turn, depend on two factors: the urban wind approaching the site and the design details of the site's landscaping (Givoni, 1998).

4.3. Site and Climate

The site and climatic conditions have a major impact on the thermal design of a building, and should be considered in the early stages of design. Also, the building will modify the existing climate of the site to create a specific microclimate surrounding itself. Climate data is available for many parts of the world, often as hourly values compiled into a standard *Test Reference Year (TRY)* format (Jones, 1999).

The climate conditions that relate directly to thermal design include:

- Solar radiation, sun path and cloud cover.
- Wind speed and direction.
- Air temperature
- Relative humidity; and
- Rainfall and driving rain index.

4.4. Solar Radiation and Sun Path

Solar radiation impacts on the building in three forms, **Plate 15**. (Jones, 1999) :

- Direct radiation, from the position of the sun in the sky
- Diffuse radiation, from the whole of the visible sky; and
- Reflected radiation *(albedo)* from adjacent surfaces.

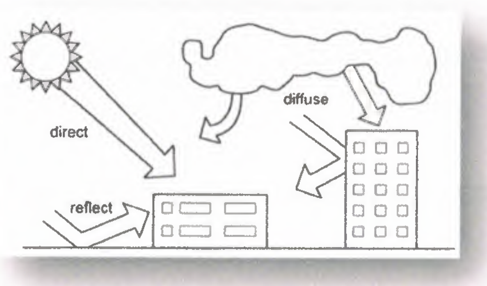


Plate 15. Direct, diffuse and reflected solar radiation (Jones, 1999).

All three components will vary according to time of day, time of year and cloud cover, and how much sky is seen by the building depending on natural and man-made obstructions. The solar path can be determined from the altitude and azimuth angles of the sun as in **Plate 16.** Typical values of solar radiation are given in **Table 7.** And **Table 8.** and the effect of sun angle and overshadowing in **Plate 17**. (Jones, 1999).

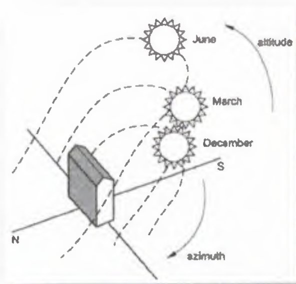


Plate 16. Sun angles indicating azimuth and altitude (Jones, 1999).

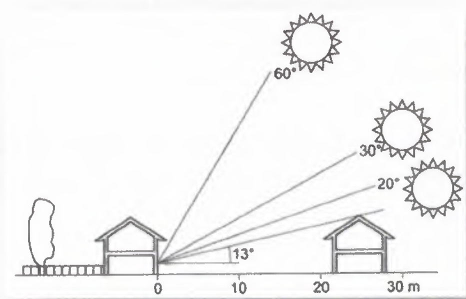


Plate 17. Sun angle and overshadowing (Jones, 1999).

The annual variation of possible hours of sunshine for the UK is presented in **Plate 18.** (Jones, 1999).

The main component is the direct radiation, but the reflected radiation can be significant where there arc hard light-colored reflective surfaces adjacent to the building, either from the built form itself or from existing buildings and landscaping. **Table 9.** contains data on reflected radiation for different angles and surfaces (the solar absorption of a surface is 1 - reflectance) (Jones, 1999).

Cloud cover is measured in octal on a scale of 0 to 8, with 0 being completely cloudless and 8 completely overcast. The diffuse radiation component will be higher for an overcast sky as shown in **Table 7.** Cloudiness *(C)* is a measure of the proportion of cloud in the sky. C is zero for a clear sky and 1 for an overcast sky (Jones, 1999).

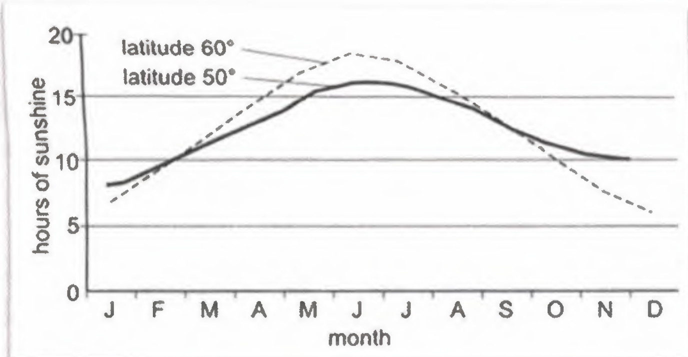


Plate 18. The annual variation of possible hours of sunshine for the UK. Northern regions receive more hours in summertime (Jones, 1999).

Month	Altitude	Direct Normal (W/m^2)	Diffuse (W/m^2)	
			Cloudy	**Clear**
June	0	900	310	100
July/May	4	895	295	100
August/April	2	865	255	95
September/March	40	815	195	85
October/February	29	700	140	75
November/January	20	620	90	60
December	7	560	75	50

Table 7. Solar altitude, and direct and diffuse solar radiation (cloudy and dear sky) al mid-day for South-east England (Jones, 1999).

Month	S	SE/SW	E/W	NE/NW	N	H	Diffuse
June	105	135	140	85	35	295	120/50
July/May	115	140	135	75	20	270	110/45
August/April	150	150	115	45	5	215	90/40
September/March	175	145	80	20	0	140	60/30
October/February	165	120	50	5	0	80	35/20
November/January	125	90	25	0	0	35	20/15
December	100	70	20	0	0	25	15/10

Table 8. Daily mean solar irradiances (W/m2) on vertical and horizontal surface. Diffuse radiation for cloudy/clear sky conditions (Jones, 1999).

Surface	Reflectance
Concrete	0,2 – 0,45 (weathered to clean)
Polished aluminium	0,7
White paint	0,6-0,75
Aluminium paint	0,45
Grass	0,33
Desert ground	0,25
Sand	0,18
Water	0,02-0,35 (for angle of incidence = 0-80°)

Table 9. Reflected radiation for different surfaces (Jones, 1999).

4.5. External Air Temperature

The external air temperature will affect the rate of transmission and convective heat loss from a building. It will typically vary over a 24-hour period (the diurnal variation) and over a year (seasonal variation). It will also vary with location. **Table 10.** presents the average monthly external air temperature for different locations within the UK. **Plate 19.** shows the typical diurnal temperature variations for southern England (Jones, 1999).

City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
Belfast	Max	5,8	6,5	9,0	11,8	14,7	17,4	18,1	18,0	16,0	12,9	8,9	6,7	12,1
	Min	1,3	1,1	2,4	3,9	6,1	9,2	10,7	10,5	9,3	7,2	3,9	2,5	5,7
	Mean	3,5	3,8	5,7	7,9	10,4	13,3	14,4	14,3	12,7	10,1	6,4	4,6	8,9
Glasgow	Max	5,5	6,3	8,8	11,9	15,1	17,9	18,6	18,5	26,3	13,0	8,7	6,5	12,3
	Min	0,8	0,8	2,2	3,9	6,2	9,3	10,8	10,6	9,1	6,8	3,3	1,9	5,5
	Mean	3,1	3,5	5,5	7,9	10,7	13,6	14,7	14,5	12,7	9,9	6,0	4,2	8,9
London	Max	6,1	6,8	9,8	13,3	16,8	20,2	21,6	21,0	18,5	14,7	9,8	7,2	13,0
	Min	2,3	2,3	3,4	5,7	8,4	11,5	13,4	13,1	11,4	8,5	5,3	3,4	7,0
	Mean	4,2	4,5	6,6	9,5	12,6	15,9	17,5	17,1	14,9	11,6	7,5	5,3	10,0
Cardiff	Max	6,8	6,9	10,0	13,2	16,2	19,2	20,4	20,1	18,0	14,5	10,2	8,0	13,0
	Min	1,5	1,5	2,8	5,0	7,7	10,7	12,3	12,3	10,7	8,0	4,7	2,7	6,0
	Mean	4,1	4,2	6,4	9,1	11,9	14,9	10,3	16,2	14,3	11,3	7,5	5,3	10,0

Table 10. UK average daily temperatures (1941-1970) (Jones, 1999).

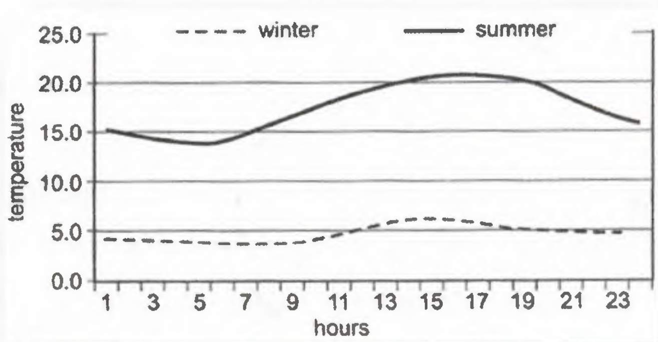


Plate 19. Diurnal UK variations for winter (January) and summer (June) for south-east England (Jones, 1999).

4.6. Sol-air Temperature

When solar energy is absorbed by an external wall it has the same effect, in relation to heat loss, as a rise in external air temperature. The sol-air temperature is the external air temperature which in the absence of solar radiation, would give rise to the same heat transfer through the wall as takes place with the actual combination of external temperature and incident solar radiation (Jones, 1999).

$$t_{sa} = (\alpha I_s + \varepsilon I_l) R_{so} + t_{ao}$$

where t_{sa} = sol-air temperature

t_{ao} = sol-air temperature

α = solar absorbtance

ε = long-wave emissivity

R_{so} = external surface resistance

I_s = solar irradiance (W/m2)

I_l = long-wave radiation loss *(W/m2)*

= 93-79 C (horizontal surfaces)

= 21-17 C (vertical surfaces)

C = cloudiness

4.7. External Relative Humidity

The external RH will vary with external air temperature and moisture content of the air. During periods of warmer weather, the RH may be relatively low due to the higher external air temperatures, although at night it will rise as the air temperature falls, **Plate 20.** During cold weather the external RH can rise typically to over 90%. **Plate 21.** presents seasonal average RH values (Jones, 1999).

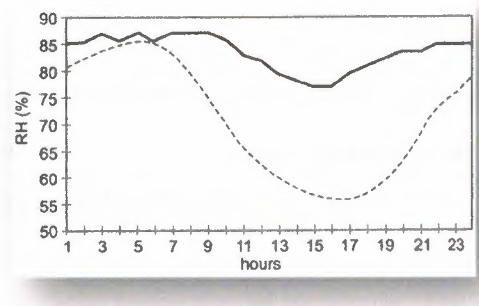


Plate 20. Diurnal RH variation for January (solid) and June (dotted) (Jones, 1999).

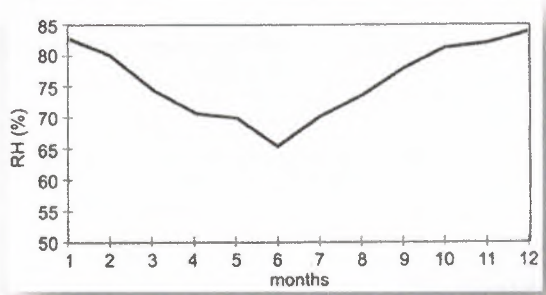


Plate 21. Seasonal average daily RH values for the UK (Jones, 1999).

Rainfall and Driving Rain Index

Rainfall can affect thermal performance. If an external surface is wet then it will lose heat by evaporation and this will reduce the external surface temperature, sometimes to below air temperature, increasing heal loss. Wind-driven rain ('driving rain') can penetrate some constructions, causing a reduction in thermal resistance. In areas of high incidence of driving rain, care must be taken to select constructions that provide protection against rain penetration (Jones, 1999).

4.8. Wind

The impact of wind on a building has two main consequences for thermal design. It affects the connective heat loss at the external surfaces, as well as the ventilation and infiltration rate and the associated heat loss (Jones, 1999).

Wind Speed and Direction

Wind speed is measured in m/s or sometimes in knots where 1 knot equals 0.4m/s. Wind direction is usually measured at eight points of the compass or, when required in more detail, in degrees clockwise from south. The wind speed and direction can be represented by a wind rose, **Plate 22.** , which indicates the relative frequency and speed of wind from different directions (Jones, 1999).

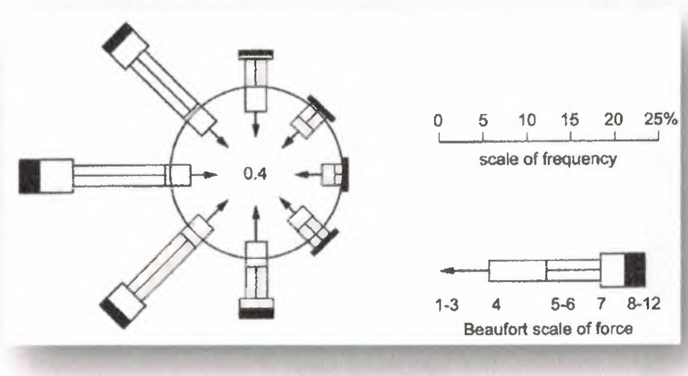


Plate 22. Standard wind rose (Jones, 1999).

Wind speed increases with height due to the frictional drag of the ground. The profile of variation with height is called the *boundary layer*, and it will vary from town to open country locations, as shown in **Plate 23.** and according to the relationship (Jones, 1999) :

$$v/v^r = k\ H^a$$

where v = mean wind speed (m/s) at height H (m)

v^r = mean wind speed (m/s) at height 10m

values of *k* and *a* from **Table** 11.

Terrain	k	a
Open country	0.68	0.17
Urban	0.35	0.25
City	0.21	0.33

Table 11. Values of coefficients for formula (Jones, 1999).

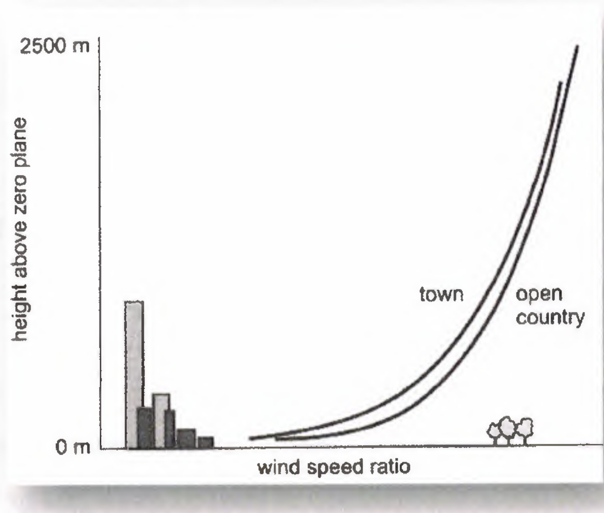


Plate 23. Boundary layer wind profile (Jones, 1999).

Dynamic and Static Wind Pressures

The static pressure *(Ps)* of the air is the pressure in the free-flowing air stream (as shown on the isobars of a weather map). Differences in static pressure arise from global thermal effects and cause wind- flow. The dynamic pressure *(Pd)* is the pressure exerted when the wind comes into contact with an object such as a building, **Plate 24.** The total or stagnation pressure *(Pt)* is the sum of the static and dynamic pressures. In most cases *P*s can be ignored in thermal design as it is usual to deal with pressure differences across a building, ie the difference in Pd. The dynamic wind pressure is related to the air density *(r)* and the square of the wind speed *(v)* (Jones, 1999).

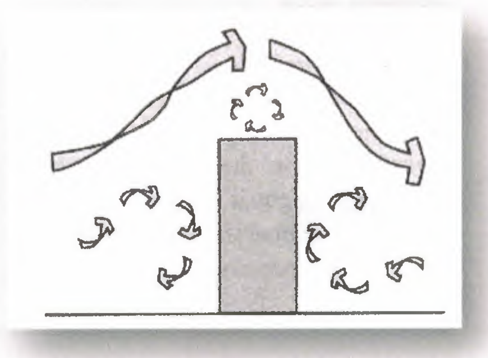


Plate 24. Typical wind flow pattern around a high-rise building (Jones, 1999).

Pressure Coefficients

The impact of wind on the building form generally creates areas of positive pressure on the windward side of a building and negative pressure on the leeward and sides of the building. The pressure coefficient is the relative pressure at a specific location on the building and it can be used to calculate the actual dynamic pressure for a given wind speed (Jones, 1999).

$$\boldsymbol{P\,\mathrm{d} = \mathrm{Cp} \times 0.5\ \mathrm{p}v^2\ (\mathrm{Pa})}$$

where ρ = density of the air (kg/m^3)
v = wind speed (m/s) at a reference height, h (m)
C_p = pressure coefficient measured with reference to the wind speed at the height h.

The pressure coefficients are dependent on general building form, as shown in the example in **Plate 25.** A scale model of the building can be placed in a wind tunnel to predict Cps. Building form is the main determinant of pressure distribution for a given wind direction. Openings should then be located to produce the required 'cross-ventilation' from pattern, **Plate 26.** (Jones, 1999).

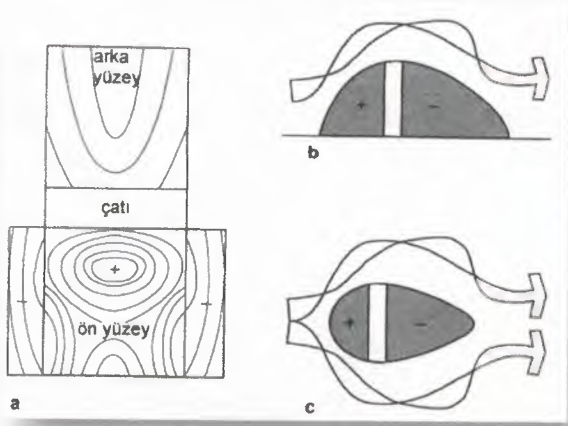


Plate 25. Wind pressure over a building envelope: a) Pressure distribution b) Section c) Plan (Jones, 1999).

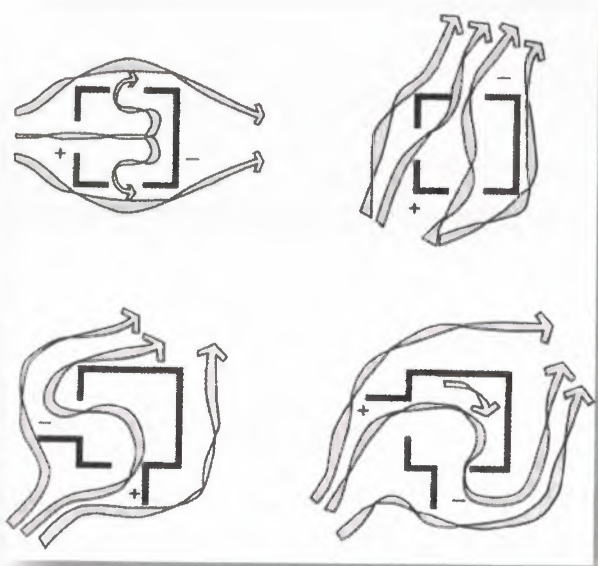


Plate 26. Pressure coefficients can be manipulated by the form of the building (Jones, 1999).

4.9. External Sheltered Areas

There are 'rules of thumb' which can be applied to estimate the impact of wind on buildings, in relation to creating external sheltered areas (for example, courtyards). These are shown in **Plate 27.** The figures show that distances between buildings should be less than about 3.5 times the building height, in order to create shelter from the prevailing wind (Jones, 1999).

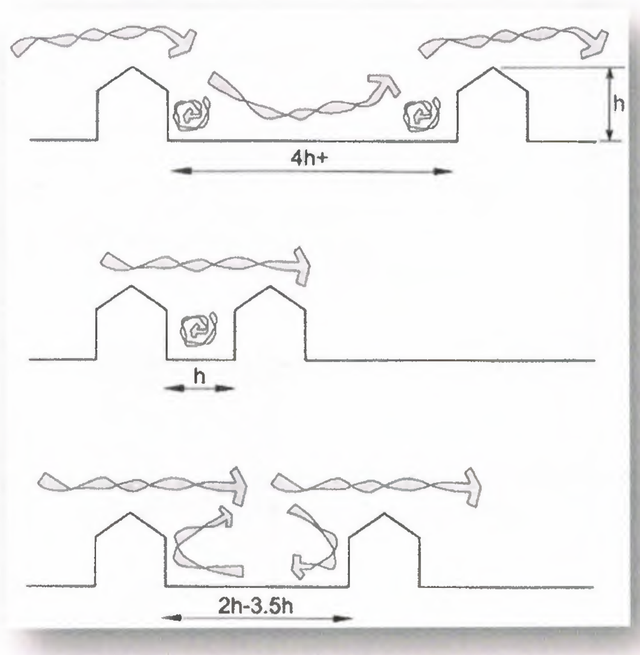


Plate 27. Building spacing and provision of sheltered external spaces (Jones, 1999).

Barriers can be used to reduce wind speed and create external sheltered areas. Porous barriers are often more suitable than 'hard' barriers as they reduce wind speed and do not induce counter wind flow areas as shown in **Plate 28.** High wind conditions can be created by downdraughts from tall buildings (as in **Plate 24.**), wind 'canyons' or acceleration around comers **Plate 29**. (Jones, 1999).

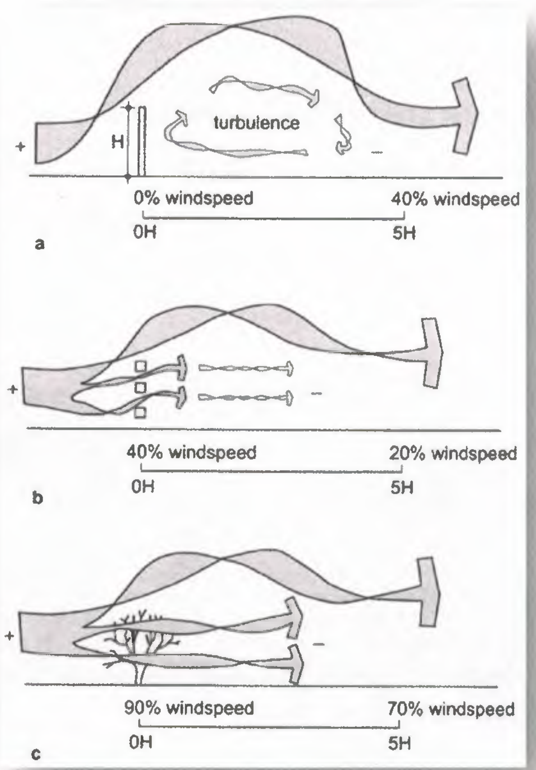


Plate 28. Barriers and their effect on wind flow: a) Dense barrier; b) Medium barrier; c) Lose barrier (Jones, 1999).

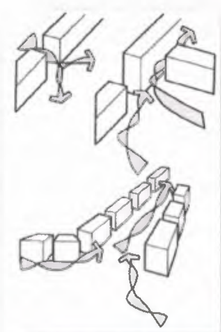


Plate 29. Localized high wind speeds can be caused by "canyon" effects and acceleration around corners (Jones, 1999).

Site Analysis

An overall site analysis should identify the prevailing wind, the seasonal sun paths, and existing shelter and obstructions, well as other aspects, such as noise sources and views, as in **Plate 30.** (Jones, 1999).

Plate 30. Example of environmental site analysis (Jones, 1999).

Chapter 5. THERMAL PERFORMANCE OF BUILDINGS

5.1. Heat Transfer Mechanisms

There are four types of heat transfer that relate to thermal environmental design, **Plate 31.** These are conduction, convection, radiation and evaporation. They are described below with examples of how they relate to building thermodynamics.

Heat is a form of energy, measured in joules *(J)*. The rate of energy use per second (s) is measured in watts (W), where (Jones, 1999) ;

1W = 1J/s (1 kW = 1000 J/s)

Another unit of energy is the kilowatt-hour (kWh), where:
1 kWh = 3600J (or 3.6MJ) and the therm, where:
1 therm = 29.3 kWh

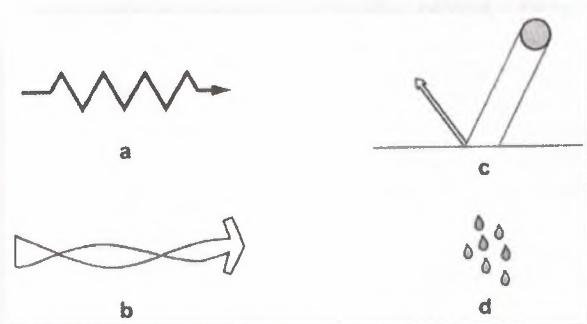


Plate 31. Heat is transferred by: a) Conduction; b) Convection c) Radiation d) Evaporation (Jones, 1999).

Conduction

Conduction normally applies to heat transfer through solids. It is the transfer of heat from molecule to molecule form relatively warm to cool regions. The rate of heat transfer through a solid is dependent on its thermal conductivity, or *k*-value. The k-value is closely related to the density of the material. Plate 32. (See Table I). High-density materials generally have high k-values - they are termed 'good conductors' of heat (e.g. high-density concrete, metals). Low-density materials have low k-values - they are termed 'good thermal insulators' (e.g. mineral fibre batts, low density concrete blocks). The thermal resistance of a given thickness of material in a construction is calculated by dividing its thickness by its k-value. The higher the resistance the better its insulation (Jones, 1999).

$$\boldsymbol{R = x/k}$$

where R = thermal resistance (m2.K/W)
X= thickness (m)
k = thermal conductivity (W/m.K)

The conductivity k of a material is the inverse of its resistivity r, that is, $k = 1/r$

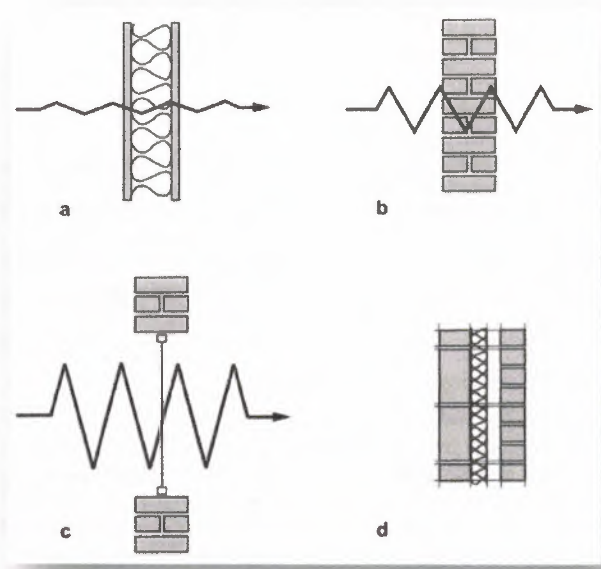


Plate 32. Comparison of thermal conduction properties of different constructions.

a) *Mineral wool has a low density* (25 *kg/m*^{3}) *and is a good thermal insulator* (k = *0.035 W/mK).* **b)** *Bricks have a relatively high density (1700kg/m*^{3}*) and a low thermal resistance* (k = *0.84 W/mK).* **c)** *Glazing has a relatively high density (1700kg/m*^{3}*) and a low thermal resistance* (k = *J .05 W/mK).* **d)** *Walls need to have structural and weatherproofing properties as well as thermal insulation properties. Most wall constructions are therefore composed of a number of layers, the resistances of which can be added to give an overall wall thermal resistance* (Jones, 1999).

Material	Density (kg/m^3)	Thermal conductivity (W/m.K)
Walls		
Brickwork (outer leaf)	1700	0.84
Brickwork (inner leaf)	1700	0.62
Cast concrete (dense)	2100	1.40
Cast concrete (lightweight)	1200	0.38
Concrete block (heavyweight)	2300	1.63
Concrete block (medium weight)	1400	0.51
Concrete block (lightweight)	600	0.19
Normal mortar	1750	0.80
Fiberboard	300	0.06
Plasterboard	950	0.16
Tile hanging	1900	0.84
Timber	650	0.14
Glass	1700	1.05
Surface finishes		
External Rendering	1300	0.50
Plaster (dense)	1300	0.50
Plaster (lightweight)	600	0.16
Calcium silicate board	875	0.17
Roofs		
Aerated concrete slab	500	0.16
Asphalt	1700	0.50
Felt/bitumen layers	1700	0.50
Screed	1200	0.41
Stone chippings	1800	0.96
Tile	1900	0.84
Wood wool slab	500	0.10
Floors		
Cast concrete	2000	1.13
Metal tray	7800	50.0

Material	Density (kg/m^3)	Thermal conductivity (W/m.K)
Screed	1200	0.41
Timber flooring	650	0.14
Wood blocks	650	0.14
Insulation		
Expanded polystyrene (EPS) slab	25	0.035
Mineral wool quilt	12	0.040
Mineral wool slab	25	0.035
Phenolic foam board	30	0.020
Polyurethane board	30	0.025

Table 12. Thermal conductivity and density of common building materials (Jones, 1999).

Example 1

Calculating the thermal resistance of a wall comprising 100mm brick, 50mm mineral wool slab insulation, 100mm medium-density concrete block:

Material	Thickness (m)	k-value (W/mK)	Resistance (m2K/W)
Brick	0.1	0.84	0.12
Insulation	0.05	0.055	1.43
Block	0.1	0.51	0.02
Total Thermal Resistance		1.73	

Notes: (1) Values for conductivity are from **Table 12.**

(2) The Thermal resistance of each layer is calculated according to formula 1: $R = x/k$.

(3) The main contribution to the total thermal resistance is from the mineral wool slab insulation (Jones, 1999).

Convection

Convection takes place in a fluid such as air or water. Once healed it becomes less dense and more buoyant. Fluids are normally heated by conduction from a warm surface such as the electric clement in a hot water cylinder, or the hot surface of a panel heater. A cold surface will conduct heat from the adjacent fluid, thereby cooling the fluid. This will make it denser and cause the fluid to become less buoyant, for example causing a downdraught under a cold window. For a typical room, the relatively warm and cool surfaces set up a series of interacting convective flow patterns. The convection of air in a room is an integral part of most heating systems (Jones, 1999) .

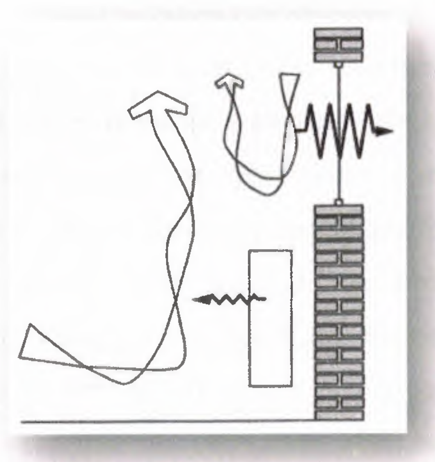


Plate 33. Typical convection patterns generated by relatively warm (panel heater) and cool (glazing) (Jones, 1999).

In the example, **Plate 33.**, heat is conducted from the air to the cooler surface of the glazing, causing a downdraught. Heat is conducted to the air from the warmer surface of the panel heater, causing an up draught. Although panel heaters are usually called radiators they mainly provide heat (typically 60-70%) through convection. The formula for convective heat transfer from a surface to air is (Jones, 1999):

$$Q_c = h_c x (t_a - t_s)$$

where Q_c = convective heat transfer (W)

h_c = convective heat transfer coefficient ($Wm^{-2}K^{-1}$)

t_a = air temperature (°C)

t_s = surface temperature (°C)

Heat flow upwards: $h_c = 4.3\ Wm^{-2}K^{-1}$

Heat flow downwards: $h_c = 1.5\ Wm^{-2}K^{-1}$

Heat flow horizontally: $h_c = 3.0\ Wm^{-2}K^{-1}$

Note: Values of h_c are at room temperature (21°C). They will increase with higher surface temperatures.

Radiation

Radiation is the transfer of heat between two surfaces. It is independent of the air between them. For example, heat travels by radiation from the sun to the earth through the vacuum of space. Radiant heat is in the infrared part of the electromagnetic spectrum (which includes X-rays, ultraviolet, visible light, infrared, micro- waves and radio, waves - which differ from each other by their wavelength and frequency). The sun emits radiation with wavelengths between 0.29 and 3.0 μm, which includes the visible spectrum (0.38 and 0.78 μm), **Plate 34.** The hotter the emitting body, the shorter the wavelength. Infrared radiation below a wavelength of 3.0 μm is termed short-wave; above this it is termed long-wave. The sun emits most of its heat energy as short-wave radiation, while lower-temperature surfaces, such as buildings, tend to emit only long-wave radiation (Jones, 1999).

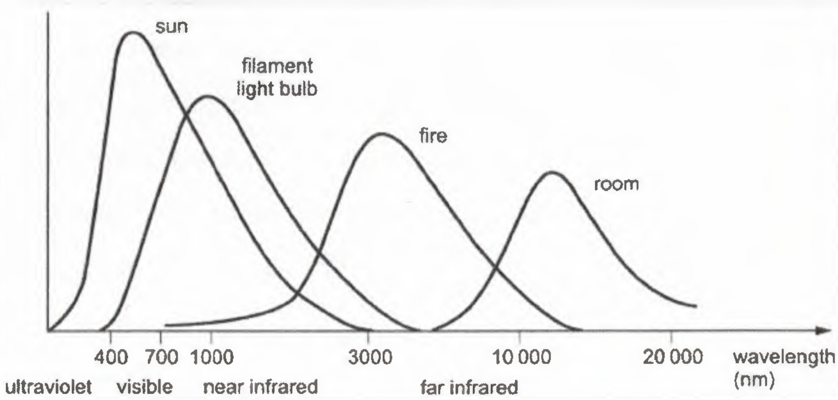


Plate 34. Spectrum of long-wave (low-temperature) and short-wave (solar) radiation; Vertical axis is not to scale (Jones, 1999).

Glass is relatively transparent to short-wave radiation while opaque to long-wave radiation. This is the principle of the 'greenhouse effect', **Plate 35.**, which is important in 'passive solar design'. The short-wave radiation from the sun passes through glass and warms up the internal surfaces, which in turn emit long-wave radiation which is 'trapped' within the space. The only heat loss therefore takes place through conduction (Jones, 1999).

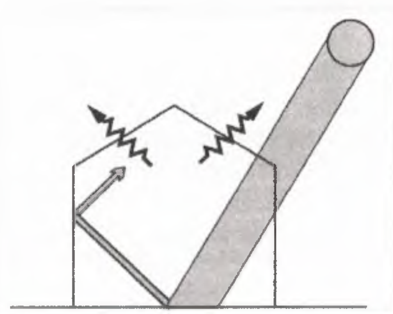


Plate 35. Heat transfer Process in a greenhouse, which forms the basis of passive solar design (Jones, 1999).

Solar radiation incident on solid walls will heat up the external wall surface, **Plate 36.** This heat is conducted through the wall where it will result in a rise in the internal surface temperature. The internal surface will then radiate long-wave radiation in proportion to its surface temperature and emissivity (see below). Glazing, however, is transparent to 'short-wave' solar radiation and radiative heat is transmitted directly through the glass, **Plate 37.** (Jones, 1999).

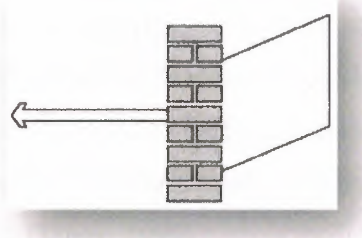


Plate 36. Radiation absorption and emission at surfaces (Jones, 1999).

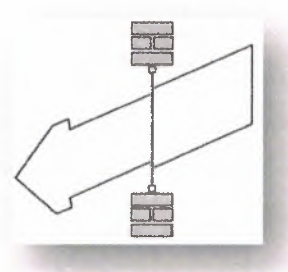


Plate 37. Radiation transmission through glass (Jones, 1999).

The Stefan-Boltzmann law

The amount of radiation emitted by a surface is related to its temperature and emissivity according to the Stefan-Boltzmann law (Jones, 1999) :

$$Q_r = (5.673 \times 10^{-8}) \times S \times T^4$$

where $Q_r =$ radiation emitted by the surface

E = surface emissivity

T = surface temperature (^{O}C)

5.673×10^{-8}= Stefan-Boltzmann constant $(W/m^2$ K$^4)$

Emissivity and absorbtance

The emissivity of a surface is the amount of radiation emitted by the surface compared to that radiated by a matt black surface (a 'black body') at the same temperature. The best emitters are matt dark surfaces and the worst are silvered surfaces (although they are good reflectors of radiation). The emissivity of a surface varies between 0 and 1, with most common building materials, such as bricks and plaster, having an emissivity of about 0.95. The absorbtance is the amount of radiation absorbed by a surface compared to that absorbed by a black body. For low-temperature surfaces the absorbtance and emittance are the same, **Table** 13. (Jones, 1999).

Finish	Thermal absorbtance and emittance
Aluminium paint	0.55
Aluminium polished	0.08
Asbestos cement, aged	0.95
Black mall	0.95
Chromium plate	0.20
Galvanised iron, aged	0.28
Grey paint	0.95
Light green paint	0.95
Limestone	0.95
Red clay brick	0.94
White marble	0.95
White paint	0.89
Wood, pine	0.95

Table 13. Surface emissivities / absoprtivities (Jones, 1999).

Evaporation

Evaporation takes place when a liquid such as water changes state to a vapor. A vapor is a mixture of gases which exerts a vapor pressure. The water molecules that escape from the liquid tend to have higher energy content than those left behind and so the average energy content of the liquid is reduced, and therefore its temperature is also reduced. In order for evaporation to take place, the vapor pressure of water (in the form of droplets or a wetted surface) must be greater than the partial pressure of the water vapor in the surrounding atmosphere. The lower the relative humidity of the air, the greater the evaporation that will take place. The evaporation rate can be calculated as follows (Jones, 1999):

$$\mathbf{W = \underline{8.3 \times 10^{-4}}\, h_c \times (p_{va} - p_s)}$$

W = Tale of evaporation from the surface

h_c = convective heat transfer coefficient

P_{va} = vapor pressure in air

P_s = saturation vapor pressure at surface temperature

Evaporation produces local cooling on wetted surfaces. This can be used to advantage in hot countries where roof ponds, cooled by evaporation, can be used to cool the roof construction. The tradition in some hot dry countries is to simply spray the floors of courtyard with water to cool the floor surface. Air passed over wetted surfaces is cooled and its moisture content rose. The rate of evaporation increases with increased liquid temperature, reduced vapor pressure of the surrounding atmosphere, or increased air movement across the wetted surface (Jones, 1999).

Condensation is the reverse of evaporation and takes place when air comes into contact with a relatively cold surface. The air adjacent to the cold surface is cooled and becomes saturated and the vapor condenses into a liquid forming droplets on the surface (Jones, 1999).

Thermal capacity

The thermal capacity of a material is a measure of its ability to store heat from the surrounding air and surfaces. Generally, the more dense a material, the greater its capacity to store heat (Table III). Therefore, high-density materials, such as concrete, will store more heat than low-density materials, such as mineral wool. The thermal capacity of a material can be calculated from the formula (Jones, 1999) :

Thermal capacity = volume (m3) X density (kg/m3) (J/K.m3) x specific heat (J/kg.K)

Dense masonry materials have 100 times the thermal capacity of lightweight insulating materials, **Table 14.**

Material	Density (kg/m^3)	Specific heat (J/kg.K)	Thermal capacity (J/K.m^3)
Granite	2600	900	2340 x 10^3
Brick	1700	790	1343 x 10^3
Concrete (dense)	2100	820	1722 x 10^3
Concrete (light)	500	1000	500 x 10^3
Mineral fibre	25	960	24 x 10^3
Polystyrene board	15	1400	21 x 10^3

Table 14. Density, specific heat and thermal capacity of common materials (Jones, 1999).

Thermal capacity and response

Lightweight buildings will respond quickly to heat gains, from either internal sources (people, lights, machines) or external sources (solar radiation, high external air temperatures). They have a relatively low thermal capacity. The internal air will therefore warm up quickly as the mass of the building will have a relatively low capacity to absorb internal heat. They will also cool down quickly when the heat source is turned off, as there is little residual heat in the construction to retain air temperatures. They are more likely to overheat during warm weather and be cool during colder weather. They therefore require a more responsive heating/cooling system, and are more suited to intermittent occupancy (Jones, 1999).

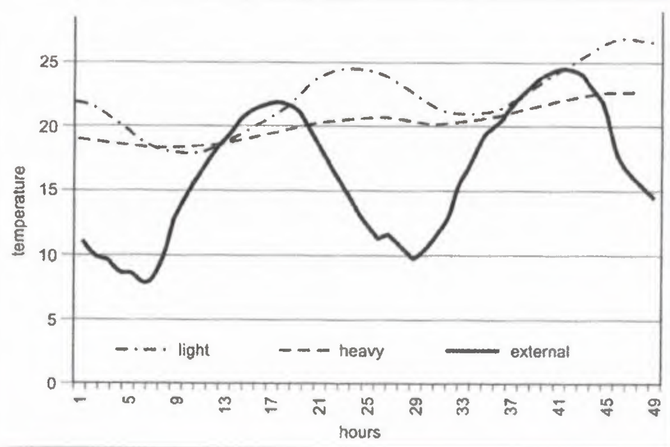


Plate 38. Thermal responses of lightweight and heavyweight buildings against external temperature over a two-day period (Jones, 1999).

Heavyweight buildings are slower to respond to extremes of temperature, **Plate 38.**, and therefore have the potential to maintain a more stable internal environment. Buildings constructed of heavyweight materials will have a high thermal capacity. They will be slow to heat up as the mass of the building will absorb heat from the space. However, they will also be slow to cool down and are able to retain relatively high internal air temperatures between heating periods. Heavyweight buildings can maintain relatively cooler internal environments in warmer weather by absorbing peaks in heat gains. Typical cooling effects may be up to 3°C reduction in internal air temperature peaks due to thermal mass effects. In addition, the mean radiant temperature will be lower due to the lower surface temperatures (Jones, 1999).

The thermal mass effect is related to the exposed surface area of material and its thickness and heat capacity. Surface area is relatively more important than thickness of material. For example, for absorbing short-term (diurnal) peaks in heat gain the thermal mass thickness need only be about 40 mm (Jones, 1999).

5.2. Building Fabric

The building fabric is a critical component of any building, since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, floor slabs, walls, windows, and doors, the fabric controls the flow of energy between the interior and exterior of the building.

The building fabric must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site. Fabric design is a major factor in determining the amount of energy a building will use in its operation. Also, the overall environmental life-cycle impacts and energy costs associated with the production and transportation of different envelope materials vary greatly.

5.3. *U*-values

The *U*-value of the wall, roof or floor element of a building can be used to provide an estimate of its heat loss. The *U*-values of typical construction types are given in**Table 15.** The *U*-value of a wall construction can be calculated using the following procedure (Jones, 1999) :

1 Calculate the resistance of the individual layers of the construction (see Section 2 and refer to *k*-values in **Table 12.**) (Jones, 1999).

$$\mathbf{R_{1,2,3....}} = x/k$$

where $R_{1,2,3....}$ = thermal resistance of element 1.2.3... ($m^2K.W^{-1}$)

x = thickness (m)

k = thermal conductivity ($W.m^{-1}.K^{-1}$)

2 Select the appropriate values for the internal and external surface resistances *(Rsi* and Rse) by referring to standard tables (**Table 16.** and **Table 17.**).

3 Select the appropriate resistance of any air cavities (R_{cav}) by referring to the standard **Table 18.** (Jones, 1999).

4 Calculate the total thermal resistance (R_{total}) of the wall using the following formula:

$$\mathbf{R_{total} = R_1 + R_{su} + R_3 + \ldots + \mathit{R_{si}} + R_{se} + R_{cav}}$$

5 Calculate the *U*-value, that is, the conductance, of the wall using the following formula:

$$\boldsymbol{U}\textbf{-value} = \mathbf{\mathit{1}/ R_{total}}$$

The heat loss *(Q_f)* associated with an element of the construction of area *(A)* and with a temperature difference (D_T) across it can be estimated as follows (Jones, 1999) :

$$\boldsymbol{Q_f = U} \textbf{ x area x temperature difference}$$

Example 2

U-*value calculation*

Calculate the U-value of the insulated cavity wall construction shown in **38.35** for an exposed site. Estimate the rate of heat loss through 10 m^2 of the fabric for a 20°C temperature difference across the wall (Jones, 1999).

The calculation is carried out in **Table 19.**; giving a total resistance of 2.96m2K/W.

Hence *U*-value = 1/2.96 = 0.34 W/m^2K

and heat loss Q_f = 0.34 x 10 x 20 = 68 W

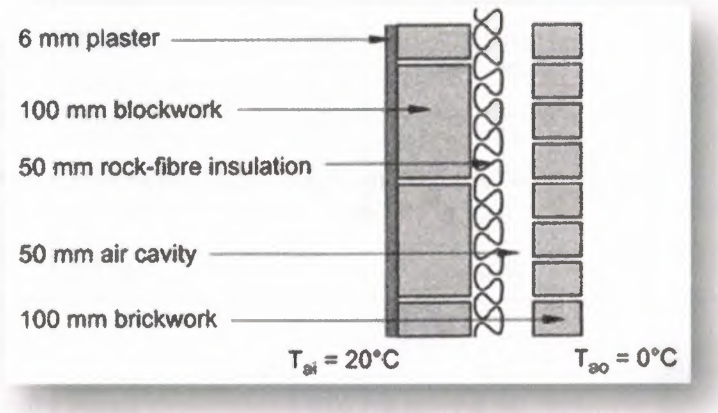


Plate 39. Construction of wall in Example 2. (Jones, 1999).

5.4. Thermal Insulation

A high standard of thermal insulation in buildings in a temperate climate such as in the UK has the following benefits:

• It reduces the rate of heat loss, and therefore buildings use less energy to maintain comfortable internal thermal conditions. This also means that people are more able to afford to heat their buildings to comfortable condition and

• It raises internal surface temperatures and therefore reduces the risk of surface condensation (Jones, 1999).

Construction type	Element	x	k	R	Drawing
Cavity wall construction with lightweight block	Ri	-	-	0,123	
	Plaster	0,06	0,16	0,38	
	Block work	0,1	0,15	0,67	
	Cavity	0,05	-	0,18	
	Brickwork	0,01	0,84	0,12	
	Ro	-	-	0,055	*U*-Value =0.65 W/m^2K
	TOTAL			1,53	

Cavity wall with 50 mm cavity filled with insulation		-	-	0,123	
	Plaster	0,06	0,16	0,38	
	Block work	0,1	0,15	0,67	
	Insulation	0,05	0,035	1,43	
	Brickwork	0,1	0,84	0,12	
	Ro	-	-	0,055	*U*-Value = 0.36 W/m^{2}K
	TOTAL			2,78	

Cavity wall construction with 20 mm insulating block	Ri	-	-	0,123	
	Plaster	0,06	0,16	0,38	
	Blockwork	0,22	0,15	1,37	
	Cavity	0,05		0,18	
	Brickwork	0,1	0,84	0,12	
	Ro	-	-	0,055	*U*-Value = 0.45 W/m^{2}K
	TOTAL			2,23	

Timber frame construction with 100 mm insulation	Ri	-	-	0,123	
	Plasterboard	0,06	0,16	0,38	
	Insulation	0,10	0,035	2,86	
	Cavity	0,05		0,18	
	Brickwork	0,1	0,84	0,12	
	Ro	-	-	0,055	U-Value = 0.27 W/m^{2}K
	TOTAL			3,7	

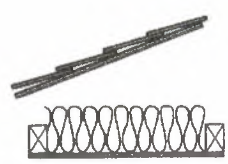
Construction type	**Element**	x	k	R	**Drawing**
Cavity wall construction with 100 mm insulation	Ri	-	-	0,104	
	Plasterboard	0,06	0,16	0,38	
	Insulation	0,10	0,035	2,86	
	Cavity	0,05		0,18	
	Ro	-	-	0,055	
	TOTAL			3,52	U-Value = 0.28 W/m^{2}K

Table 15. Table XIV Typical construction and their U-values (Jones, 1999).

Walls	0,123
Floors or ceilings	
upward heat flow	0,104
Downward heat flow	0,148
Roofs	0,104

Table 16. Internal Surface resistance (m2K.W-1) (Jones, 1999).

	Sheltered	Normal	Exposed
Walls	0,08	0,055	0,03
Roofs	0,07	0,045	0,02

Table 17. External surface resistance (m2K.W-1) (Jones, 1999).

	Width (mm)	Resistance (m^2K.W-1)
Sealed	6	0,11
Reflective surface	6	0,18
	>19	0,18
Reflective surface	>19	0,35

Table 18. Wall cavity resistance (Jones, 1999).

Element	Thickness (mm)	K-value (W/mK)	Resistance ($m^2K/W-1$)
Ri	-	-	0,123
Plaster	0,06	0,016	0,38
Block work	0,1	0,15	0,67
insulation	0,05	0,035	1,43
Cavity	0,05		0,18
Brickwork	0,1	0,84	0,12
Ro	-	-	0,055
Total			2,96

Table 19. Calculation for example 2. (Jones, 1999).

5.5. Types of insulation

Most thermal insulating materials have k-values of 0.3-0.4 *W/m.K.* The most common types are:

• **Mineral fibre** - this can be glass fibre or rock fibre and is available in lower-density roll form or higher-density batt form. The roll form is usually used to insulate roofs, while the batt form is often used in walls where, because of its greater rigidity, it is more appropriate to vertical fixing. Mineral fiber insulation forms a good attachment to the inner skin of the construction, leaving no air gap. It is often used in wall and roof industrial cladding type constructions. Mineral fiber may also be in a lose form that can be 'blown' into a cavity, to 'cavity fill' an existing or new construction (see below).

• **Rigid board** - this is usually made from foamed plastic or foamed glass. k-values are typically 0.037 W/m.K. It can be gas filled to give lower k-values, although boards which use ozone- depleting gases should be avoided. If rigid board insulation is used, it is essential to achieve a good attachment to the inner skin of the construction in order to avoid airflow between the inner skin and the insulation layer, which will detract from its U-value performance. The cavity should be kept clean and mortar 'snobs' and other sources of blockage on the inner skin should be eliminated before the insulation is fixed.

Rigid board insulation is often used in composite 'factory made' cladding system constructions, where it is installed between two layers of metal sheeting.

- **Blown insulation cavity fill**, including mineral or cellulose fibers or plastic granules. Insulation is blown into the cavity after completion of construction. Care is needed in installing blown insulation in order to avoid any voids in the insulation in areas where the insulation has difficulty in penetrating, for example, blocked areas of the cavity. This method of cavity insulation has the advantage that it can be applied to existing constructions.

- **Recycled paper insulation**, such as *'Warmcel'.* This is produced from 100% recycled newspaper, and has very low embodied energy compared to most other insulation materials. It has a k-value of 0.035 W/m.K. It can be applied in a 'breathing wall' construction, where sufficient vapor resistance is provided by the materials on the inside of the construction to prevent the risk of interstitial condensation. Materials in the middle and outside have low vapor resistance to allow moisture to freely transfer to the outside, or

- **Low-density concrete blocks**. Blocks with densities down to 480 kg/m^3 give thermal insulation with k-values of 0.11 W/m.K. Such blocks are normally 210 mm in thickness and are used for the inner skin of a construction; this may be an infill panel or a load bearing wall. They contribute to the thermal insulation of cavity construction, especially when the cavity needs to be left empty for weather resistance in exposed locations. Lightweight block work requires sufficient expansion joints to avoid cracking.

Some constructions might use a combination of insulating materials to achieve its required U-value **Plate 40.** and **Plate 41.** In addition, thermal insulation may need to be integrated with a thermal mass layer to provide the required thermal performance, **Plate 42.** (Jones, 1999).

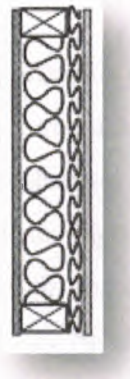


Plate 40. A combination of low-density insulation in a timber frame construction with a higher density insulation applied outside with an external render (Jones, 1999).

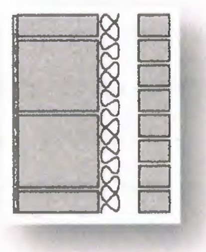


Plate 41. A combination of insulating block inner skin with part-filled cavity insulation (Jones, 1999).

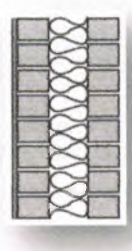


Plate 42. A construction with a heavyweight inner skin to provide thermal stability (Jones, 1999).

5.6. Thermal bridging

Thermal bridging takes place through details of construction that have a relatively low thermal resistance to heat flow; they have a high *U*-value in comparison with the rest of the construction. Common areas of thermal bridging are around windows, doors and structural elements. Heat will flow from high to low temperatures by conduction along the path of 'least thermal resistance'. In the case of jambs, sills, lintels and floor edges, the least resistance path will generally be along the highly conductive materials such as metal and dense concrete. Heat loss at thermal bridges can be reduced by adding insulation and thermal breaks, and ensuring that the insulation is continuous over the building envelope. If thermal bridging occurs it will result in increased heat loss and increased risk of condensation. The heat loss through floors is a specific case where heat will follow the three-dimensional line of least thermal resistance as shown in **Plate 43.** The *U*-value of floors is therefore taken as an average value accounting for the high 'edge losses' and slab dimensions (Jones, 1999).

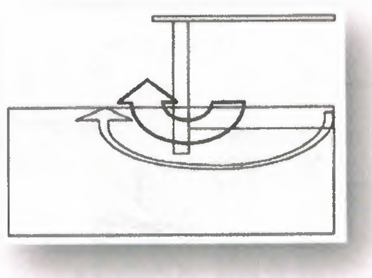


Plate 43. The edge losses are dominant in floor heat loss (Jones, 1999).

5.7. Installation of insulation

The following guidelines should be followed when designing an insulated construction:

• Insulation should always be located on the "warm and dry side" of a ventilated cavity (unless informed otherwise, it is usual to assume that all cavities are ventilated). If a cavity or air gap is ventilated on the warm side of the insulation this could provide a "short circuit" for heat loss as indicated in **Plate 44.** (Jones, 1999).

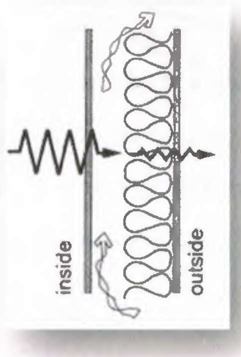


Plate 44. Insulation on the cold side of a ventilated cavity has considerably reduced effect due to the cavity's convective heat loss (Jones, 1999).

• Avoid air infiltration through or around the insulation material as indicated in **Plate 45.** Ensure continuity of insulation at design details, eg eaves and floor junctions.

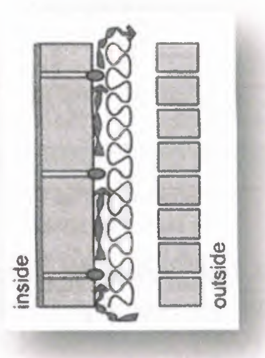


Plate 45. Mortar snobs may distance the insulation from the inner skin introducing airflow on the warm side of the insulation and short-circuiting the heat flow through convective losses (Jones, 1999).

• Ensure that there is a vapor barrier on the warm side of the insulation 10 guard against negation of its insulation property by moisture penetration from condensation,

Avoid compression of low-density insulation (Jones, 1999).

5.8. Glazing

Glass is the main material used for glazing. It is available in a wide range of configurations with different thermal properties (Jones, 1999).

Thermal performance of glass

Glass is transparent to short-wave infrared radiation and opaque 10 long-wave radiation (see para 2.04). It is also a good conductor of heat. Although glass transmits the short-wave infrared part of the solar radial ion spectrum, it will also reflect and absorb a proportion of the radiation as shown in **Plate 46.** (Jones, 1999).

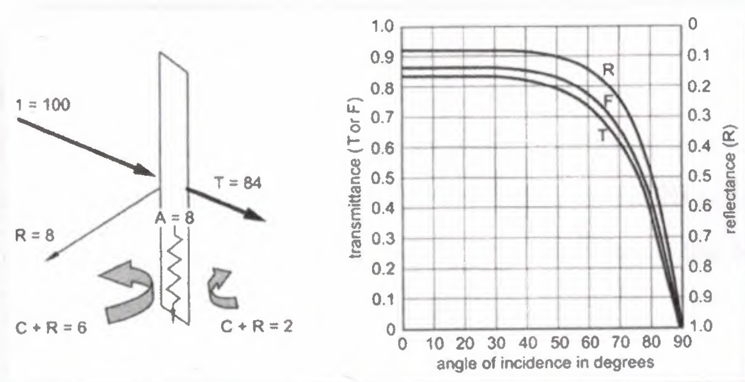


Plate 46. Transmitted, reflected, absorbed and re-emitted solar radiation as a percentage of incident value for 4 mm single glazing, and graph indicating variation of solar transmittance with angle of incidence (Jones, 1999) :

Incident (I) = 100%

Reflected (R) = 8%

Transmitted (T) = 84%

Absorbed (A) = 8%

Convected and radiated inside (C+R) = 2%

Convected and radiated outside (C+R)= 6%

U-Value of glass

The main thermal resistance in glass results from the surface resistances. The glass material itself has practically no thermal resistance.

Example 3

Calculate the U-value of a single layer of glass

Total resistance (R) = 0.118 m^2K/W

Internal surface resistance is 0.123

External surface resistance is 0.055

k-value of glass is 1.05 thickness 6 mm

$R = 0.123 + 0.006/1.05 + 0.055$

Total resistance *(R)* = 0.1837 m^2K/W

U-value is $1/R = 5.4$ W/m^2K

Adding layers of glass will improve the insulating properties of glazing due to the resistance of the trapped layer of air (or another gas). The thermal resistance of an air- or gas-filled cavity increases in proportion to its width up to about 20 mm and remains constant up to 60 mm, after which it decreases slightly. Increasing the layers of glass will reduce the solar transmittance by about 80% per layer (see

Table 20.) (Jones, 1999).

The glazing frame can provide a thermal bridge, which will increase the overall *U*-value of the glazing system. Other properties of glazing systems are given in **Table 21.**

	Transmission	Total heat gain	Light
6 mm clear glass (x1)	84	86	87
6 mm clear glass (x2)	64	73	76
6 mm Spectrafloat (x1)	56	66	49
6 mm Antisun (x1)	45	60	75
6 mm Solarshield (x1)	9	22	16
Insulight Gold (x2)	14	22	26
6 mm clear glass + blind (x1)	9	47	-
6 mm clear glass + blind between layers of glass (x2)	8	24	-

Table 20. Solar transmission, total heat gains and light transmission for different glazing systems (Jones, 1999).

	U-value (w/m^{3}K)			
	wood	**metal**	**PVC-U**	**Thermal break**
Single glazing	4,7	5,8	4,7	5,3
Double glazing	3,3	4,2	3,3	3,6
Double glazing, argon fill	3,1	4,0	3,1	3,4
Double glazing, low- E	2,6	3,4	2,6	2,8
Triple glazing	2,6	3,4	2,6	2,9

Table 21. *U*-values of different glazing systems (Jones, 1999).

Glazing treatment

The transmission of solar radiation can be reduced by different glazing treatment or the use of blinds or solar shading. Internal blinds convert short-wave radiant heat gains 10 convective and long-wave radiant heat gains. Blinds located externally **Plate 47.** or between layers of glass (provided the cavity is ventilated) are more effective in reducing solar heat gains (Jones, 1999).

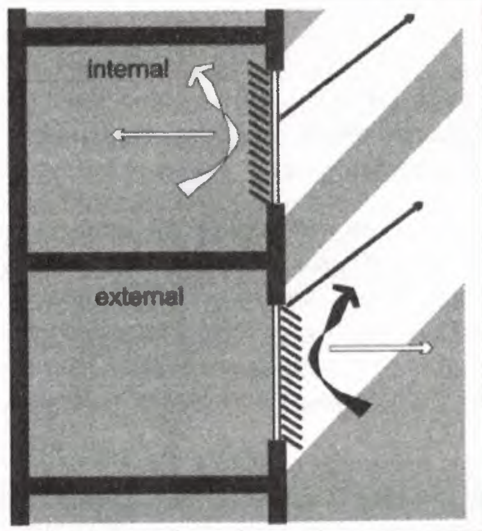


Plate 47. Comparison of heat gains through external and internal shading. Solar gain of 12% for external white louvers,and 46% for internal white louvers (Jones, 1999).

Low-emissivity glass

A coating of metal oxide can be applied to a glass surface to reduce its emissivity .This will reduce its long-wave radiation loss, which will reduce the overall transmission loss by about 30%. The low- emissivity coating is usually applied to the inside surface of the inner pane of a double-glazed unit (Jones, 1999).

Matrix glazing systems

Matrix glazing systems are designed to make maximum use of daylight, while at the same time controlling solar heat gain. They usually consist of a reflective matrix located between two layers of glass. The blades of the reflector are angled to respond to the particular orientation of the glass and the requirement accepting or rejecting the solar heat gains, **Plate 48.** (Jones, 1999).

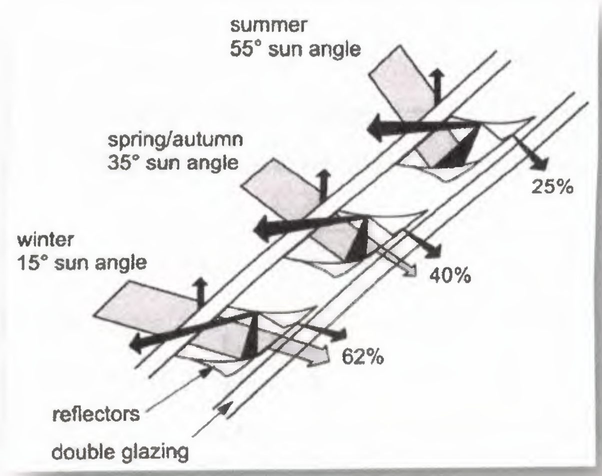


Plate 48. Matrix glazing system (Jones, 1999).

Transparent insulation material (TIM)

This can be applied to the face of an opaque south-facing facade to provide insulation while at the same time allowing the passage of solar gains to the solid wall behind, **Plate 49.** It can also be installed between two layers of glass where light but not view is required (Jones, 1999).

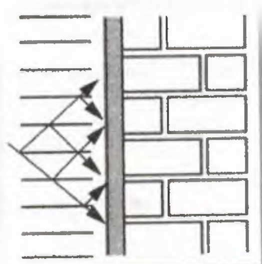


Plate 49. Transparent insulation material (TIM) (Jones, 1999).

Condensation

Condensation occurs when moist air meets a relatively cool surface. Water condenses out of the air and is deposited on the cool surface. It can result in dampness, surface mould growth, and deterioration of the building fabric (Jones, 1999).

Terminology

- The amount of water vapor that the air can contain is limited and when this limit is reached the air is said to be *saturated.*
- The saturation point varies with temperature. The higher the air temperature, the greater the amount of water vapor it can contain.
- Water vapor is a gas, and in a mixture of gases such as air, the water vapor contributes to the total vapor pressure exerted by the air.
- The ratio of the vapor pressure in any mixture of water vapor and air to the vapor pressure of saturated air at the same temperature is the *relative humidity* (RH).
- If air is cooled it will eventually reach saturation point, that is, 100% RH, and any further cooling will cause the vapor to condense. The temperature at which condensation occurs is called the *dew point* temperature (Jones, 1999).

5.9. Surface condensation

When air with a relatively high RH comes into contact with a cold surface condensation can take place. The risk of surface condensation depends on:

- Air and surface temperature, and
- Moisture content of the air (Jones, 1999).

Mould growth

Surface condensation can cause mould growth. Mould spores can germinate at RH ins above 80%. If the RH is generally greater than 70% for long periods mould will spread (Jones, 1999).

Estimating surface temperature

The following formula can be used to estimate the surface temperature:

Temperature drop between the air and the surface $= \Delta T \times U \times Rsi$ where

ΔT = inside/outside air temperature difference

U = wall U-value

Rsi = internal surface resistance

Surface temperature and U-value

The internal surface temperature is affected by the U-value of the construction element **Plate 50.** The higher the U-value, the lower the internal surface temperature for a given heat input to the space. Thermal bridging constitutes a localized increase in U-value which will result in a lower surface temperature. High U-value elements at risk include single glazing and thermal bridging (Jones, 1999).

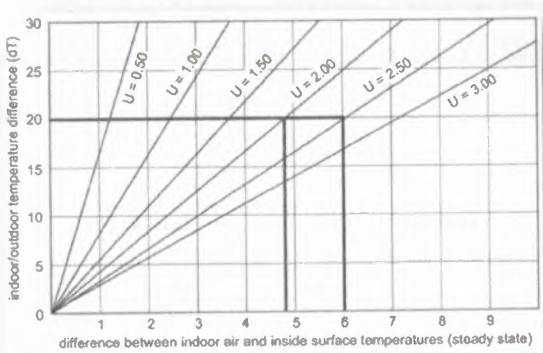


Plate 50. Internal air-to-surface temperature versus inside/outside temperature difference for different U-values (Jones, 1999).

Moisture content of the air

Moisture is contained in the external air and this is added to by various building use activities, **Table 22**. The main moisture sources are (Jones, 1999) :

External air: external air enters the building through ventilation. Its RH will depend on its moisture content and temperature. For example, on a typical winter's day external air at 90% RH and 5°C will contain about 5 g/kg (dry air) of water vapor. Saturated air at 0°C will contain 3.8 g/kg.

	kg/kg dry air
Dwelling	0,0034
Offices, shops, classrooms	0,0017
Catering	0,0068

Table 22. Moisture addition to internal air (Jones, 1999).

Drying out: building materials contain moisture, **Table 23** . A building could take a year to dry out after construction. A new house might contain 4000 liters of water which will be released during the drying-out period.

Material	**Water content (litres/m^2)**
105 mm brickwork	33
100 mm blockwork	40
150 mm in-situ concrete	30

Table 23. Moisture content of materials (Jones, 1999).

Occupants: moisture is produced as a result of occupants' activities, **Table 24**. On average, 3.4 g/kg of moisture is added to the air by internal activities in a house.

Source	**Litres per 24-hour period**
4 person asleep (8 hours)	1,0 – 2,0
2 person active (16 hours)	1,5 – 3,0
Cooking	2,0 – 4,0
Bathing, dishwashing, etc	0,5 – 1,0
Drying clothes	3,0 – 7,5
Pariffin Heater	1,0 – 2,0
Daily total	5,0 – 10,0 max 10-20

Table 24. Moisture emission rates (four-person house) (Jones, 1999).

Causes of surface condensation

Minimizing the risk of surface condensation requires a balanced approach to heating, ventilation and insulation, together with minimizing moisture production:

Heating: inadequate heating can result in low air temperatures and higher levels of RH. It also means colder surface temperatures. Intermittent heating can result in the fabric and surface temperatures significantly cooler than the air temperature (during warm-up). Warm moist air coming into contact with cool surfaces can then result in condensation. Partial heating of a house can result in warm, moist air convecting to cooler rooms with cooler surfaces. Surface areas shielded from heating (eg behind wardrobes) will be more at risk (Jones, 1999).

Ventilation: low ventilation rates will result in a build-up of moisture in the air causing higher RHs. Too much ventilation could give rise to lower internal air temperatures which will again increase the RH, and also reduce surface temperatures. Ventilation should therefore be balanced as illustrated in **Plate 51.** (Jones, 1999).

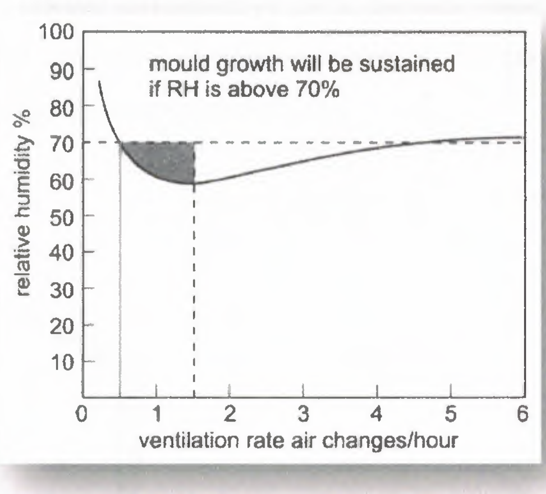


Plate 51. Ventilation rate versus RH, indicating that low and high rates can give rise to higher RHs (Jones, 1999).

Estimating risk of surface condensation

The risk of surface condensation can be estimated if the RH and air and surface temperatures are known.

Example

Predict the risk of surface condensation using the psychrometric chart **Plate 52.**

- The outdoor dry-bulb air temperature is 0°C and contains 3.8 g/kg of moisture, which gives an RH of 100% (point A).
- On entering the building the air warms to 20°C. If its moisture content remains the same, its RH will reduce to 27% (point B).
- Internal activities are assumed to generate additional moisture of 7 g/kg, increasing the RH to 70% (point C).
- The dew point temperature for air at 70%RH is 15°C (point D).

This means that condensation will occur if the air comes into contact with a surface at a temperature of 15°C or less. Referring to the graph in **Plate 50.** for an internal/external air temperature difference of 20°C, surface condensation will occur if the U-value is greater than 2 W/m^2K, in which case the internal surface temperature will be 15°C, ie 5°C less than the air temperature (Jones, 1999).

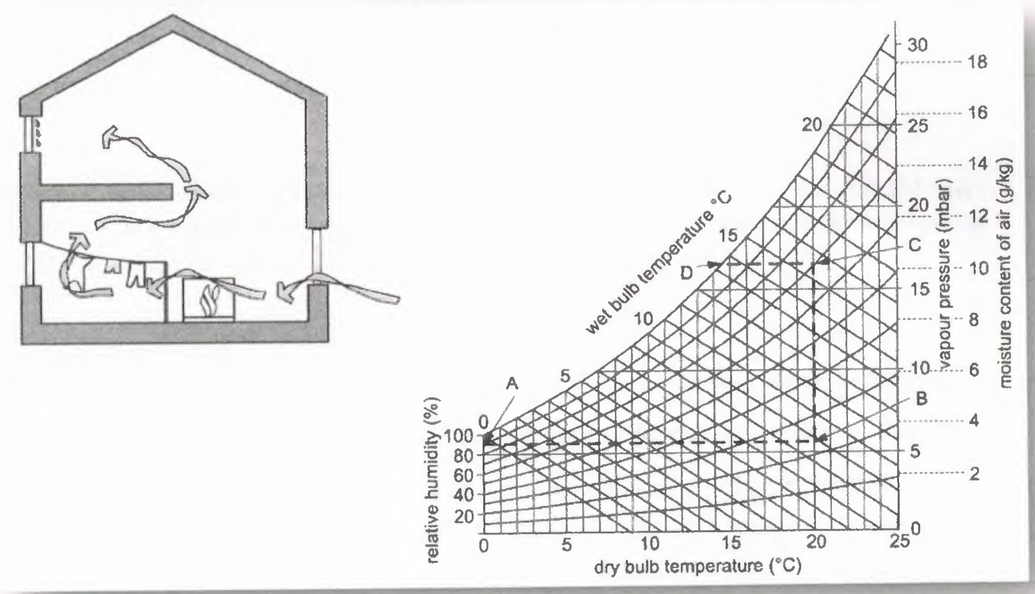


Plate 52. Illustration to Example: predicting the risk of surface condensation using a psychrometric chart (Jones, 1999).

Interstitial condensation

Condensation can occur within a construction. The dew point temperature profile of a wall can be predicted. If the actual temperature at any point within the construction falls below the dew point temperature then there is a risk of interstitial condensation taking place, as shown in **Plate 53.** (Jones, 1999).

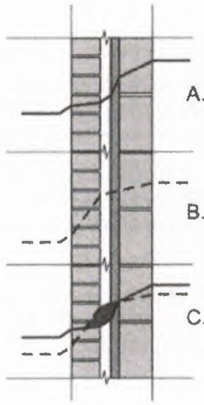


Plate 53. Set of three diagrammatic representations of: A. Temperature profile through wall, B. Dew point temperature profile, and C. Overlap of these two profiles indicating area of interstitial condensation risk (Jones, 1999).

A material will resist the passage of vapor depending on its vapor resistivity or vapor resistance (**Table 25.** and **Table 26.**) (analogous to thermal resistivity). The vapor resistance of a given thickness of material within a construction is (Jones, 1999) :

$$\mathbf{V_r = \mathit{x} \ x \ \mathit{v}_r}$$

where v_r = vapor resistivity (Ns/kg.m)
x = thickness of material (m)
V_r = vapor resistance (Ns/kg)

Material	**K-value (W/mK)**	**Vapor resistivity (MNs/gr)**
Brickwork	0,84	25 – 100
Concrete	1,4	30 – 100
Render	1,3	100
Plaster	0,5	60
Timber	0,14	45 – 75
Plywood	0,14	1500 – 6000
Fibreboard	0,07	15 – 60
Hardboard	0,14	450 – 750
Plasterboard	0,17	45 – 60
Compressed strawboard	0,1	45 – 75

Wood-wool slab	0,11	15 – 40
Expanded polystyrene	0,04	20 – 30
Glass wool (open cell)	0,04	15 – 40
Glass wool (closed cell)	0,02	30 – 1000
Expanded ebonite	0,03	1000 – 6000

Table 25. K-value and vapor resistivity and resistances (Jones, 1999).

Membranes	Vapor resistance (MNs/g)
Average gloss paint	7,5 – 40
Polythene sheet	110 – 120
Aluminium foil	4000

Table 26. Vapor resistance of membranes (Jones, 1999).

5.10. Vapor pressure

The vapor pressure can be estimated from the moisture content using a psychrometric chart. The dew point temperature for a given vapor pressure will be the dry bulb temperature at 100% RH. The drop in vapor pressure across a given thickness of material in a construction is (Jones, 1999) :

$$\mathbf{d}V\mathbf{p} = (V_r/V_R) \times \mathbf{dV_p}$$

where dVp = drop in vapor pressure across a given thickness of material (kPa)

Vr = vapor resistance of material (Ns/kg)

V_R = vapor resistance of construction (Ns/kg)

dVp = vapor drop across construction (kPa)

Building 'design heat loss'

The *design heat loss* of a building is its heating demand for a given external air temperature, which will vary for different parts of the UK. It can be estimated as follows (Jones, 1999) :

Fabric heat loss rate Q_f (W/ °C)

Ventilation heat loss rate Q_v (W/ °C)

Total heat loss rate $Q = Q_f + Q_v$ (W/ °C)

Design internal air temperature T_i (°C)

Design external air temperature T_e (°C)

Design heat loss $= Q \times (T_i - T_e)$ *(W)*

5.11. Seasonal energy use

The seasonal energy use can be calculated from the design heat loss, but using some form of seasonal temperature instead of a design temperature. Also, an allowance has to be made for system efficiency and incidental heat gains. The seasonal temperature can be in the form of a heating season average temperature or *degree days* (

Table 27.). If average temperature is used, then some accounts of seasonal heat gains are required. Degree days already assume some level of useful heat gains in relation to a *base temperature;* which is the temperature below which heating is required. The standard base temperature is 15.5°C, which takes account of typical internal heat gains (Jones, 1999).

Seasonal energy design temperatures Region	**Seasonal verage temperature T_{sa} (°C)**	**Annual Degree Days**
Thames Valley	7,5	2120
South Eastern	6,7	2427
Southern	7,8	2265
South Western	8,3	1949
Severn Valley	7,2	2211
Midland	6,7	2507

West Pennines	6,7	2362
North Western	6,4	2532
North Eastern	5,9	2510
East Pennines	6,6	2373
East Anglia	6,7	2451
Borders	6,1	2709
West Scotland	5,8	2585
East Scotland	6,0	2719
North-east Scotland	5,5	2886
Wales	7,2	2244
Northern Ireland	6,4	2522

Table 27. Seasonal energy design temperatures (Jones, 1999).

5.12. Heat gains

There will be heat gains from internal activities and solar effects (**Table 28.**). For domestic buildings, the internal gains can be estimated depending whether the household has high, medium or low activities (**Table 28.**). Not all the internal gains will usefully supplement the heating. Some may cause overheating and some may occur where or when they are not required (Jones, 1999).

Months	Single glazing			Double		
	S	SE/SW	E/W	S	SE/SW	E/W
January	14	12	6	12	10	5
February	19	16	11	16	13	9
March	35	31	23	30	26	19
April	35	34	30	29	29	26
May	42	44	42	35	37	35
June	41	45	46	35	38	39
July	39	43	42	33	36	35
August	40	41	37	34	34	31
September	39	36	29	33	30	24
October	31	27	18	26	22	15
November	19	16	9	16	13	7
December	14	12	5	12	10	4

Table 28. Solar heat gains (Jones, 1999).

Heat source	**Total heat gain (kWh/day)**	
	low	**high**
Occupants	4,02	5,46
Lighting	2,17	2,50
Cooker	2,89	4,25
Refrigerator	1,44	1,44
Television	0,45	0,54
Hot water	3,70	4,70
TOTAL	14,67	18,89

Table 29. Domestic internal heat gains (Jones, 1999).

5.13. Environmental temperature

It is more accurate in cases where the radiant temperature is significantly different from air temperature to calculate the heat transfer to the internal surface of a wall using the *environmental temperature* which combines air temperature and mean radiant temperature:

$$t_{ei} = 2/3\, t_{mrt} + 1/3\, t_{ai}$$

where t_{ei} = environment temperature

t_{mrt} = mean radiant temperature, and

t_{ai} = air temperature.

Plate 54. illustrates the use of resultant temperature, environment temperature and sol-air temperature (Jones, 1999).

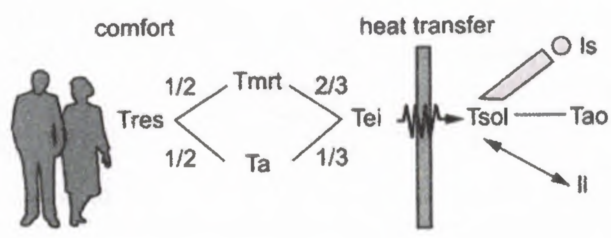


Plate 54. Resultant temperature, environmental temperature and sol-air temperature (Jones, 1999).

5.14. Seasonal energy use *(E)*

To calculate the seasonal energy use for space heating; firstly using average temperature:

$E = ((Q_f + Q_v) \times (T_i - T_{sa})$ x number of hours – seasonal heat gains x *eff*

Where E = the seasonal energy use (W)

Q_f = fabric heat loss

Q_v = ventilation heat loss

T_i = average internal temperature

T_{sa} = seasonal average temperature (Table 22.)

Eff = efficiency of heating system

Using degree days:

$$E = (Q_f + Q_v) \times \text{degree-days} \times 24 \times eff$$

Carbon dioxide emissions

Table 30. gives the carbon dioxide emissions associated with fuel use (Jones, 1999).

Fuel	Mass or carbon dioxide	
	Kg/Gj	Kg/kWh
Gas(mains)	52	0,0144

Liquid petroleum gas (LPG)	76	0,0211
Heating oil	75	0,0208
House coal	83	0,0231
Anthracite	90	0,0250
Smokeless solid fuel	116	0,0322
Electricity	188	0,0522

Table 30. Carbon dioxide emissions associated with fuel use (Jones, 1999).

5.15. Mechanical ventilation

Mechanical ventilation may be required in buildings as an alternative or in addition to natural ventilation. Specific applications include:

- Deep plan spaces which cannot be ventilated from the side by natural means
- Spaces with a high occupancy or high heat gain
- Spaces with high source levels of pollution, including industrial processes and moisture in kitchens and bathrooms
- Where the external air quality may be poor and so the external air needs to be filtered or taken in at high level and
- Where high ventilation rates are required in winter, mechanical ventilation (with pre-heated air) can be used without incurring cold draughts (Jones, 1999).

Mechanical extract

Local mechanical extract can be used to exhaust pollutants at source (for example, in kitchens, bathrooms and toilets; and locally for industrial processes such as solder baths and welding booths) (Jones, 1999).

Mechanical supply

Mechanical supply systems can be used in situations where a positive flow needs to be established between a space and its surroundings. Examples are:

- In a house or apartment to maintain a minimum ventilation rate and reduce condensation risk
- Mechanical induction systems where high velocity warm air is supplied to a space, and extract is through natural leakage and
- Mechanical supply to an office and extract naturally, perhaps through an atrium or chimney/tower (Jones, 1999).

Balanced supply and exhaust

Mechanical ventilation systems in larger buildings usually have a balanced supply and extract, **Plate 55.** This allows:

- Control of higher ventilation rates
- Heating and/or cooling of incoming air
- Filtration of incoming air
- Humidity control of air and
- Heat recovery from exhaust to supply air.

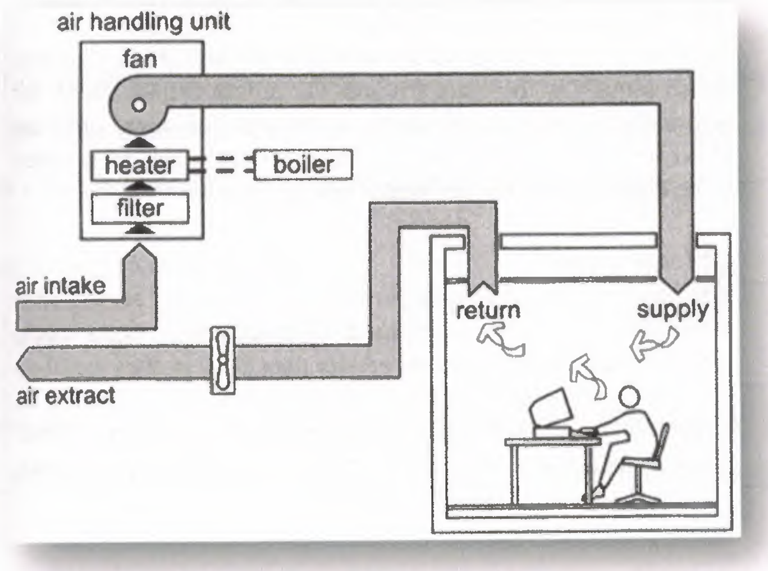


Plate 55. Components of one type of balanced supply and extract mechanical ventilation system (Jones, 1999).

Air supply rates

If the air supply is for ventilation, then the volume flow rate can be estimated from the number of occupants in the space. This will be typically 8 litres/second person unless there is smoking, in which case it will be 16 or 32 l/s/p for light and heavy smoking respectively. If air is required as the sole source of heating then the volume flow rate can be estimated from the following formula (Jones, 1999) :

Volume flow rate = design heat loss/$((T_{su} - T_{ex}) \times C_p))$

T_{su}= supply air temperature

T_{ex} = extract air temperature, and

C_p = volumetric specific heat of air

Air distribution

Air is distributed from the air handling unit (AHU) to the space through a system of ducts, **Plate 56.** The cross-section area of the AHU and ducts depends on the air speed for a given volume now rate, and can be calculated from (Jones, 1999) :

***csa* = volume now rate/air speed**

where *csa* is the cross-sectional area in m^2

The velocity through the AHU would typically be 2 m/s. The velocity through the main riser ducts will vary from 3 m/s (low velocity) to 7 m/s (medium velocity)

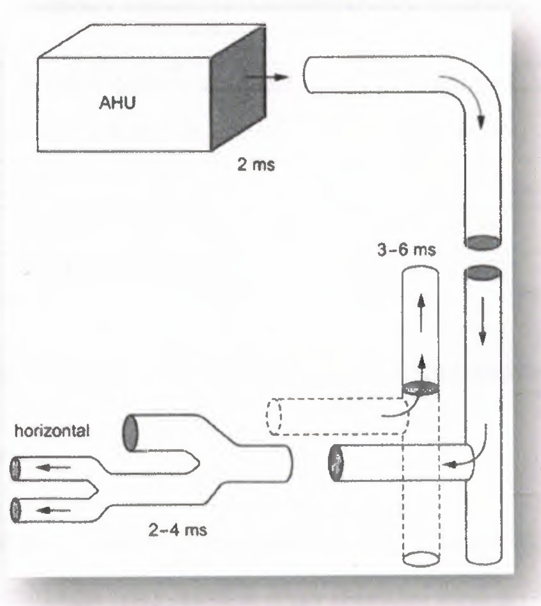


Plate 56. Ducted air distribution system indicating velocity ranges (Jones, 1999).

Fan power

The fan power required to supply the air through the ducted system depends on the volume flow rate and the pressure drop in the system, which are related to the air speed. For an energy-efficient mechanical ventilation system with low duct velocity, the *specific fan power* could be less than 1 kW/m^3 of air supply. This compares to about 4 kW/m^3 of air supply in standard systems (Jones, 1999).

Heat-recovery systems

An advantage of mechanical ventilation is that it can use heat recovery. This can be applied at all scales of building from domestic to large-scale commercial. It is especially appropriate to maintaining energy efficiency in full fresh-air systems. Heat recovery is only worth while if the recovered heat is useful and is greater than the energy used due to the increase in fan power from the increase pressure drop of the heat-recovery equipment.

Table 31. lists the efficiency ranges of heat-recovery systems (Jones, 1999).

Heat recovery systems	Efficiencies
Plate heat exchangers	% 40 and %60
Thermal wheels	% 79 – 82
Run-around coils	% 45 and 60
Double accumulators	% 85 - 95

Table 31. Heat recovery systems and typical efficiencies (Jones, 1999).

5.16. Cooling systems

Some buildings require cooling in addition to what can be achieved from ventilation alone. Such buildings may have a high internal heat gain, where mechanical ventilation will not provide sufficient cooling, especially during warm weather. The building itself may be designed for a hot climate, where air-conditioning with cooling and humidity control is necessary. Cooling of air is achieved by passing the air over cooling coils in the AHU (Jones, 1999).

Heat gains

The main reason for mechanical cooling is in response to heat gains from people, office machinery, lighting, solar gains and high external air temperatures. Solar gains have been discussed in para 4.01. Internal gains from lighting and machines can be high (Table 32.), but they are often overestimated, which can result in over capacity of the system design (Jones, 1999).

Factor	**Heat gain W/m^2)**
People	10
Equipment (computers, copiers, etc)	15 – 20
Lighting	10 – 25
TOTAL	35 – 60

Table 32. Internal heat gains for a typical office (Jones, 1999).

Room air delivery

Chilled air can be delivered to the space, either in a mixing mode or a displacement mode (Jones, 1999).

Mixing mode of air delivery

The air supplied to the space is typically about 13°C at the design cooling load. The air is jetted into the space such that it mixes with air already in the space by entrainment and when the air enters the occupied zone it is at the appropriate temperature, speed and RH for comfort, **Plate 57.** Air may be supplied from the perimeter, the ceiling or even the floor (Jones, 1999).

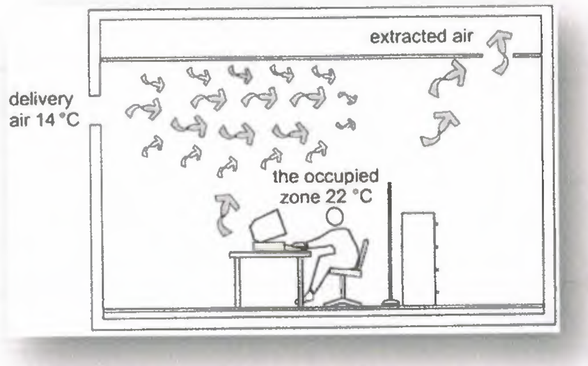


Plate 57. Mixing mode of air delivery (Jones, 1999).

Coanda effect

Ceiling systems often rely on the *coanda effect,* **Plate 58.a**, to ensure that the cool supply air remains at high level ('sticks' to the ceiling) until it is mixed. The coanda effect does not work at low jet velocities and the jet becomes' unstuck' and can cause cold air 'dumping', **Plate 58.b** (Jones, 1999).

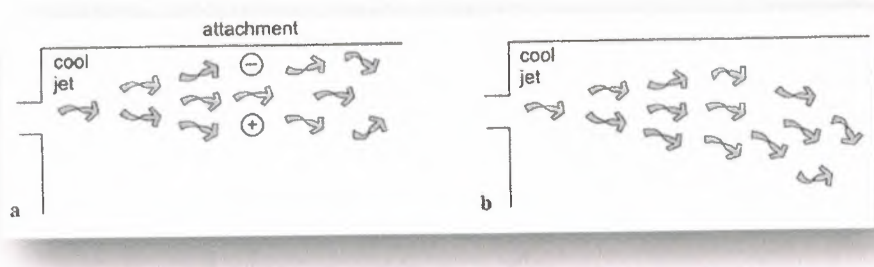


Plate 58. Coanda effect (Jones, 1999).

Displacement air delivery

Air is supplied to the space at a low velocity such that it displaces the air already in the space towards the ceiling extract, **Plate 59.** Air is usually supplied at the floor or through low-level diffusers. However, some floor systems, that use *swirl* diffusers, are assumed to be displacement but are really mixing systems (Jones, 1999).

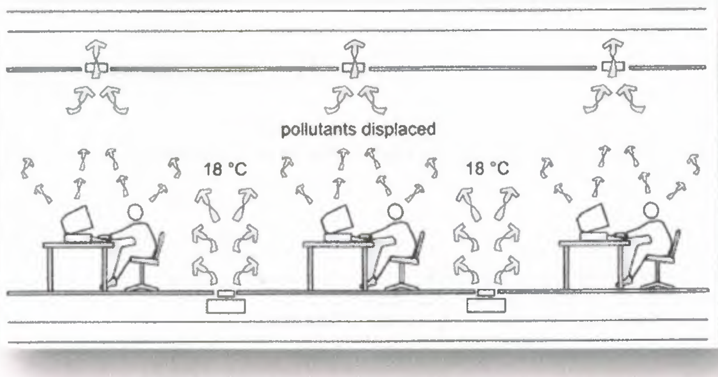


Plate 59. Air displacement system (Jones, 1999).

5.17. Air supply

The temperature and volume flow rate of the supply air will often determine the type of system used. Displacement systems should have air delivery temperatures greater than 18°C or they are likely to cause cool draughts. So if low-temperature supply is needed for a high heat load, then mixing systems are usually more suitable, **Plate 60.** shows the relationship between air supply temperature, volume flow and internal heat gains (Jones, 1999).

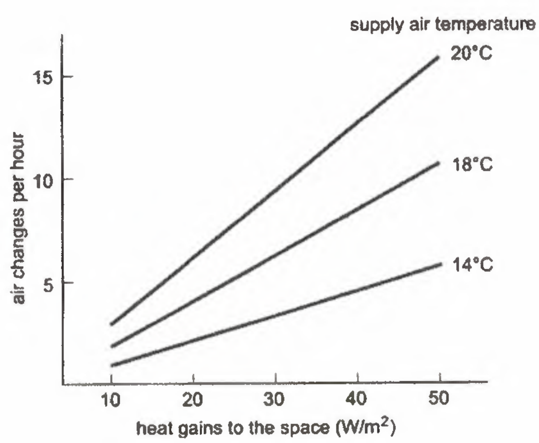


Plate 60. Relation between volume flow, supply air temperature and cooling load (Jones, 1999).

5.18. Central air-conditioning systems

Plate 61. illustrates a typical central air-conditioning system layout (Jones, 1999).

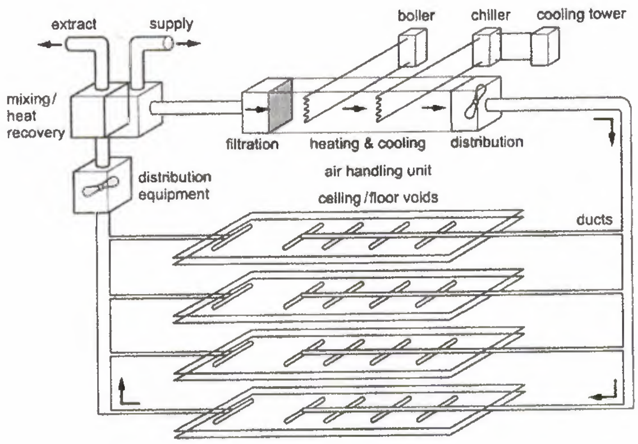


Plate 61. Layout of a central air conditioning system (Jones, 1999).

Variable air volume (VAV)

In this system the volume of air is controlled in response to the cooling load. As the cooling load is reduced the volume of air is also reduced until a minimum air supply is reached, after which the supply air temperature is increased (Jones, 1999).

Constant air volume (CAV)

With this the air is supplied at a constant volume and the temperature of the air is varied in response to the space cooling or healing load (Jones, 1999).

Localized systems

Localized systems are usually either fan coil units or heat pump units. They can be located around the perimeter of a space or in the ceiling void, **Plate 62.** A Space may have multiple units, or one unit may supply a single floor. They need access to outside air, which can either be supplied directly to the unit from outside or be ducted separately from a central unit which only supplies ventilation air requirements and not heating and cooling requirements. Fan coil units are served by hot and cold water systems that supply the main heating and cooling load (Jones, 1999).

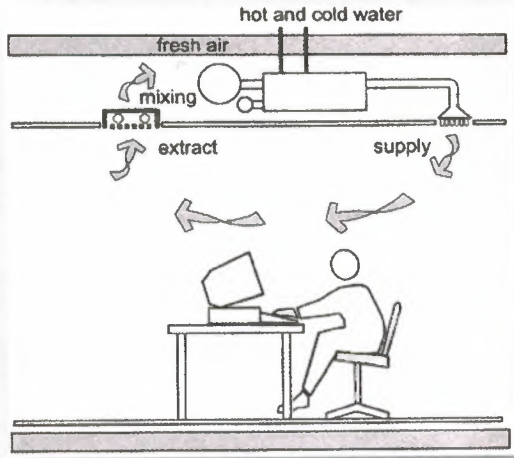


Plate 62. Ceiling fan coil system (Jones, 1999).

5.19. Passive cooling systems

Passive cooling is achieved by means of introducing chilled surfaces in a room, the opposite of radiators for heating, **Plate 63.** These surfaces absorb heat from the space by convection/conduction and radiative heat exchange. Passive cooling devices can be in the form of fins, panels or beams. Sometimes the whole surface is cooled. Surface temperatures are about 15°C and cooling loads of typically up to 40 W/m^2 can be achieved. To avoid the risk of condensate forming on the chilled surfaces in situations of high relative humidity, sensors can be incorporated into the design to raise the surface temperatures. Alternatively, if mechanical ventilation is used the ventilation air can be dehumidified at the AHU (Jones, 1999).

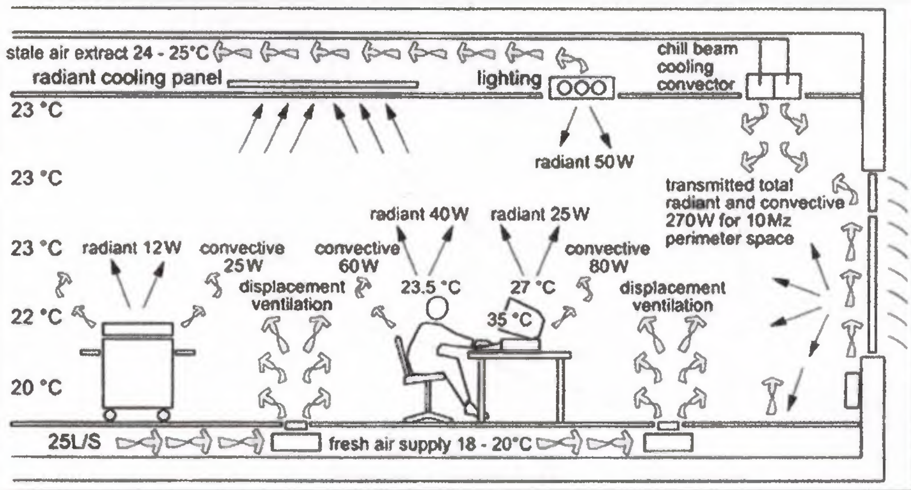


Plate 63. Passive cooling systems (chilled beams or panels) can be combined with displacement ventilation (Jones, 1999).

Refrigeration

Cooling systems require some form of refrigeration equipment in order to extract heat from the cooling fluid that flows in the cooling coils in the air handling unit, or in the passive cooling system. A standard heat pump circuit is shown in **Plate 64.** and an absorption circuit in **Plate 65.** (Jones, 1999).

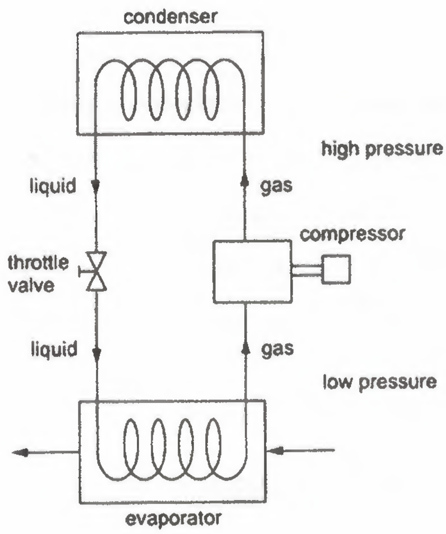


Plate 64. Diagrammatic heat pump circuit. The refrigerant is in a liquid state as it enters the evaporator where it absorbs heat and changes state to gas. It is compressed to a hot gas and enters the condenser where it gives out heat and returns to liquid state. In reverse operation it can be used to cool (Jones, 1999).

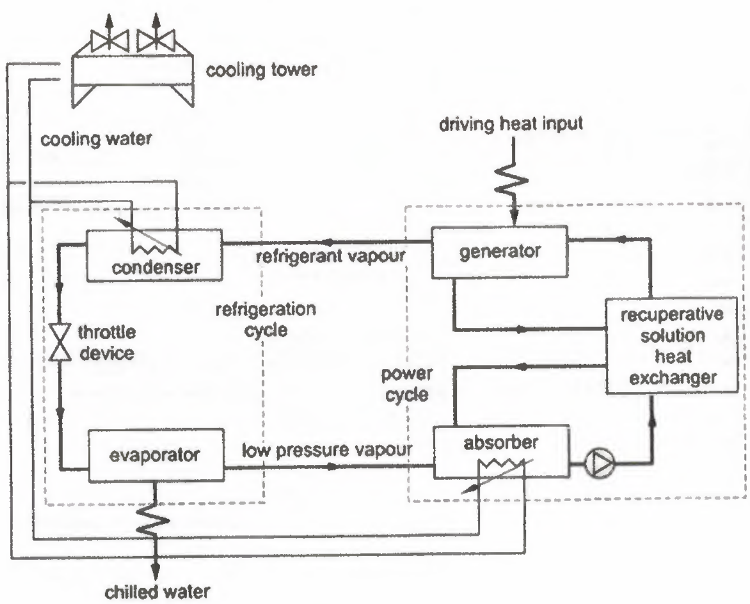


Plate 65. Schematic diagram of an absorption cooling system. Refrigerant vaporised in the generator passes to the condenser where it rejects heat and condenses, its pressure (and temperature) is then reduced by a throttling device before it enters the evaporator, here it absorbs heat from the chilled water circuit and becomes a low-pressure vapor. It then returns to the absorber (Jones, 1999).

5.20. Hybrid systems

Hybrid, or mixed-mode, systems combine mechanical and natural ventilation in either a spatial or a seasonal mix. Seasonal hybrid buildings may be naturally ventilated in summer and mechanically ventilated in winter. Spatial hybrid buildings may have spaces that are both naturally ventilated (say, at the perimeter) and mechanically ventilated (say, in the depth of space).

Space for services

The space requirements for the location of mechanical services and their distribution systems can be considerable: typically 2-15% depending on building type, and must be considered early in the design process (

Table 33.) (Jones, 1999).

	Natural ventilation	Mechanical ventilation	Air conditioning
AHU's	-	2	4
Boilers	1,5	1,5	1,5
Chillers	-	-	2
TOPTAL	1,5	3,5	7,5

Table 33. Typical space requirements for different systems for an office building as a percentage of total floor space (Jones, 1999).

Prediction and Measurement

There are a number of prediction and measurement techniques now available that the designer can use to help achieve a good thermal design. Prediction techniques can be used during the design to inform the design process. Measurement techniques can re applied after construction, during the 'hand-over' period, in order to check the thermal design performance (Jones, 1999).

5.21. Building energy models

Computational dynamic building energy models can be used to predict the time-varying thermal performance of a building. They are able to predict the dynamic performance of a building and can account for the thermal capacity of the structure as well as time-varying response to internal heat gains and solar radiation. They will predict on a regular time interval (usually hourly) the following parameters (Jones, 1999) :

- Internal air temperature
- Internal mean radiant temperature
- Internal relative humidity
- Energy used for space healing or cooling and .
- Temperature profiles through the construction

These values can be predicted for each space in the building over any time period (eg day, week, year). The models require the following input data:

- Meteorological data: temperature, solar, wind. This is available in standard *test reference year (TRY)* format for various sites
- Construction data: k-values, density, specific heat capacity, and dimensions for materials used
- Building geometry: areas and locations of walls, floors, etc . Occupancy patterns: hours of use, energy use, activities and
- Heating, ventilating and cooling operation: times of use, system and control details.

Examples of available building energy models include HTB2, **Plate 66.** , ESP, EASICALC and SERIRES (Jones, 1999).

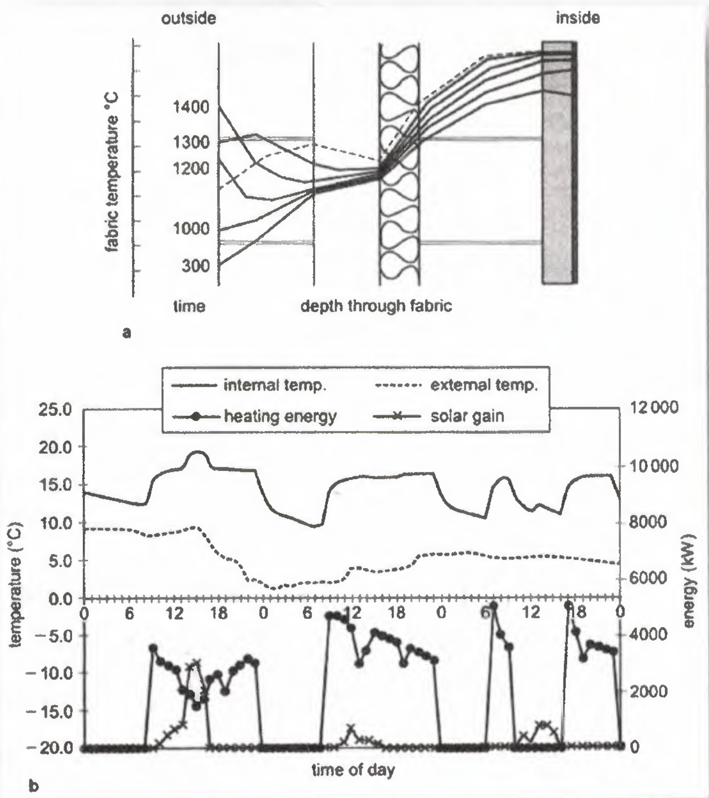


Plate 66. Example of the results of the building energy model HTB2: a) Predicting the temperature profile through a wall over time; b) Forecasting, the internal air temperature and energy use as they vary with external temperature and solar gain over a three-day period (Jones, 1999).

5.22. Ventilation and airflow models

Network models

Network or *zonal* models can be used to calculate the flow of air between one or more zones in a building and between the spaces and outside. They are computer based and calculate the flows between pressure nodes both within and outside the building. Their main advantage is that they can be used to calculate inter-zone flows and therefore air change rates, ventilation heat transfer and the transfer of contaminants. They can be used to study new building forms, can handle a wide range of opening and crack types and can predict the interaction of buoyancy and wind-driven effects (Jones, 1999).

Computational fluid dynamics (CFD) models

CFD can be used to predict the internal airflow patterns driven by the combination of the external forces of wind and stack and the internal forces from buoyancy (warm or cold surfaces) and momentum (air jets) sources, **Plate 67.** It can also be used to predict the ventilation rate and the dispersal of a pollutant through the space or smoke movement in the event of a fire. CFD can be used to predict the external wind flow around a building and the resulting pressure field from which the pressure coefficients (Cp) can be calculated. It is therefore an extremely versatile and useful technique in the field of ventilation and air quality prediction. It is, however, highly complex and requires a level of skill and understanding of ventilation design, building physics and computational numerical techniques in order to obtain credible solutions. However, models are becoming easier to use by the non-specialist and the need to use such models in ventilation design will eventually result in their widespread use (Jones, 1999).

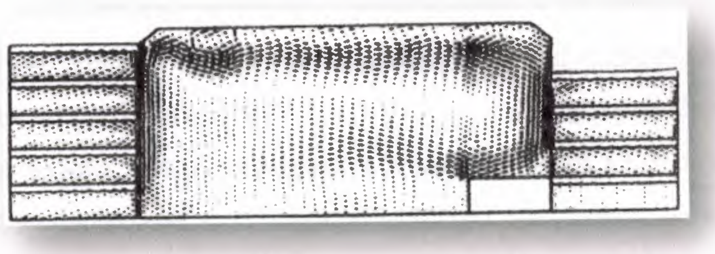


Plate 67. Example of the use of computational fluid dynamics (CFD) to predict air movement in an atrium (Jones, 1999).

Wind tunnel modeling

A physical model of a building and its surroundings can be constructed and placed in a wind tunnel, **Plate 68.** where it is subjected to a controlled wind flow. Pressure sensor taps can be installed at various points on the building envelope, corresponding to ventilation openings. The pressure at each opening can be measured. This can then be related to the free wind pressure, at a point of known height above the surface, in order to obtain the Cp value (Jones, 1999).

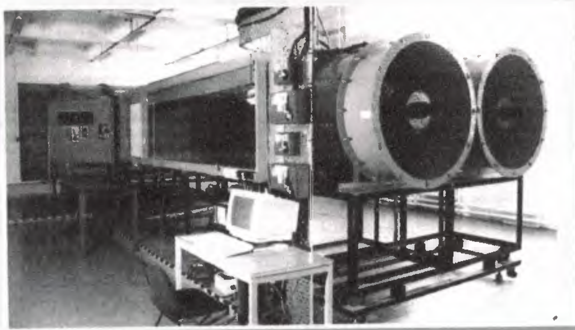


Plate 68. Boundary layer wind tunnel and model at the Welsh School of Architecture used for measuring Cps. (Jones, 1999).

5.23. Thermographic surveys

All objects emit heat energy (ie infrared radiation), the amount being dependent on the surface temperature and its emissivity. *Thermography* is the term used to describe the process of making this heat energy visible and capable of interpretation. An infrared camera can be used to scan the surfaces of a building and produce a 'live' heat energy picture that can be viewed. The picture appears in color or grayscale. The differences in color or tones of grey correspond to differences in surface temperature across the surface being viewed. Surface temperature differences of the order of 0.5°C can be identified. Areas of defective or missing insulation can be detected by identifying locally warm (viewed from the outside) or cool (viewed from the inside) surface areas. If there is air leakage into a building it can produce a locally cooled area on the internal surface which can be detected by the camera. If there is air leakage to the outside this can produce a locally heated area. **38.73** presents some examples of Thermographic images (Jones, 1999).

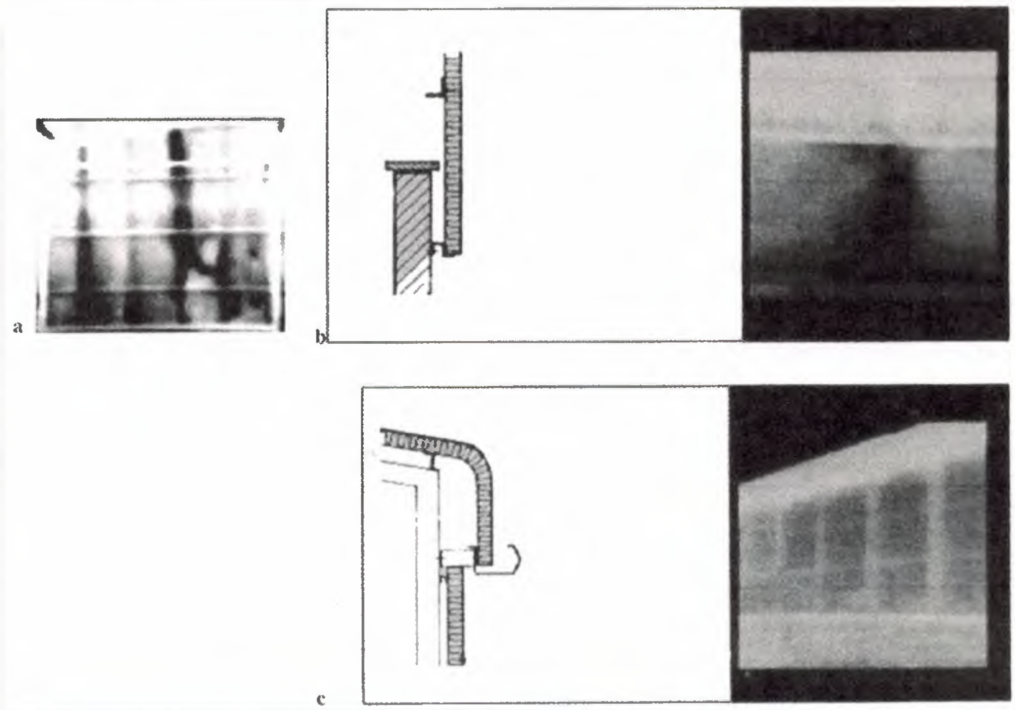


Plate 69. Examples of thermographic images: a) Finding missing insulation; b) Showing air leakage when viewed from inside; c) Air leakage viewed from outside (Jones, 1999).

5.24. *U*-value measurement

The *U*-value of a construction can be estimated from measurements of internal and external surface temperature and heat flux. These measurements need to be carried out over a period of time to minimize the effects of thermal capacity. For lightweight cladding constructions an estimate of the *U*-value can be achieved in about eight hours. In heavyweight masonry construction a period of a week to ten days may be needed. Measurements should be carried out on a north-facing wall or roof to avoid interference from solar gains (Jones, 1999).

Air leakage measurements offer a means of assessing the relative air tightness of different buildings by comparison with standard values. The air leakage of a building can be measured by pressurizing the building using a fan and measuring the volume flow of air needed to maintain a fixed pressure difference between inside and outside.

Air leakage rate standards are normally specified either for whole buildings (in air changes per hour) or in normalized form relating to envelope area ($m^3.s^{-1}$ per m^2 of envelope area).

Table 34. presents typical design air leakage values (Jones, 1999).

If there is air leakage into a building it can produce a locally cooled area on the internal surface which can be detected by the camera. If there is air leakage to the outside this can produce a locally heated area.

	$m^3/h/m^2$ @ 50 Pa
Domestic	7
Commercial	
Natural ventilation	10
Air conditioning	5
Industrial	15
Stores	5

Table 34. Air leakage standards, for 50Pa internal/external pressure difference of 50Pa (from BSRIA) (Jones, 1999).

Chapter 6. CASE STUDY

6.1. Introduction

In order to explore temperature and humidity differences (thermal comfort) properly and objectively - since the building is set in North-South direction - two classrooms at the Near East University's Architecture Department were selected for the experiment. Classrooms are situated at the eastern and western sides of the building.

Indoor and outdoor temperature and indoor humidity measurements were made for both facade classes. Because of the external thermal climate influences (there is no heat insulation at ground floor and roof) the classes placed at the middle floor of building were selected.

Thermal data of the classrooms were obtained in two periods throughout the year. One of them was at winter 11.03.2010-25.03.2010 and the other one was at summer 14.06.2010-28.06.2010. There was not any mechanical heating or cooling during these measurement periods. Three measurements were made: morning (8:00am), noon (12:00am) and afternoon (5:00pm) every day.

The measurement days were not the hottest and coolest days during the year. Reason for choosing these periods was because of the maximum usage of the building during those days. During the measurements, there were no students in the classrooms.

6.2. Building Design, Structure and Features of Classrooms

Faculty of Architecture consists of 4 floors (ground + three floors) and is located in Nicosia - North Cyprus - 35°13'33.83"N; 33°19'33.32"E (**see appendix I.**).

Before choosing the building it was analyzed with its surrounding. During the survey it was noticed that there is a thermal discomfort in the building.

Building was constructed at 1994. Aim of the building was to create a space for students of Architecture Department. Because of the limited time for construction period heating and insulating necessities were not implemented. Building has a structure of reinforced concrete and hole brick walls of 20cm thickness. There is no heating, nor moisture insulation for walls and roof. Windows are made of 4mm single glazed glass layer. Window and door frames are made of wood thick 5cm. Mosaic floor covering is used for all floors. There is no solution for heating and cooling in the classrooms. Because of these structural properties of the building mentioned above a thought of thermal discomfort appeared. Thus we chose this building as a case study.

The building consists of four stories, where each floor has five classes, eleven rooms for teaching staff, the dean's office, the secretary, the kitchen and WCs. The fourth floor is designed as an open space atelier and workshop area.

The classes of study are located at the east and the west facades of the third floor of the building (**see appendix I. for plans**). Classes on the east and west facades were selected with purpose to be able to make a comparison of the temperature and humidity measurements between the two facades of the building. Because the remaining floors in the building are not typical by function and there are other external influences such as heat loss and gain from the floor and the roof. Thus, the middle floor was chosen instead of ground and upper floors.

To simplify the experiment, radiant temperature and air movement speed measurements were omitted. Also metabolic and clothing activity variables were not included since there were no students during measurements. During the measurements in winter, both the windows and the doors were closed while in summer period measurements they were open.

The study will also give us a scope of view for planning the building if reconstruction will be planned by identifying and revealing the thermal and psychological disturbances.

Plate 70. East Facade of Architecture Department.

Plate 71. Northwest Facade of Architecture Department.

6.3. Technical Specifications of Measurement Tools

Consistent of inside measurement device and outside measurement device Hama Electronic Weather Station Thermometer was purchased from Turkey. Both devices had humidity measurement sensors; so with those devices there was an opportunity to measure the temperature and the humidity at the same time. There were no opportunities to obtain devices to measure the radiant temperature and the air speed. For more exact results it would be better to use those four devices, but in this case air temperature and air humidity measurements gave us an approximate idea of variables for thermal comfort in classrooms of Architecture Department of the Near East University.

Calibration of device was made in the classrooms by resetting the device. Also, measurements were made with a dry bulb thermometer and compared with the digital ones. So, we decided that the measurements will be accurate.

Plate 72. Hama Electronic Weather Station
(for **technical specifications see appendix III.**)

6.4. Simultaneous Indoor and Outdoor Heat and Humidity Measurements at Winter and Summer

Simultaneous heat measurements for fifteen continuous days were made at the selected classes in the building's eastern and western facades. Measurements include internal temperature, indoor humidity and indoor - outdoor temperatures at morning (8:00am), noon (12:00am) and afternoon (5:00pm) for periods of summer and winter.

Periods of measurement for winter were 11.03.2010-25.03.2010; and for summer 14.06.2010-28.06.2010. Those periods were not the coolest and hottest days of the year. The sense of choosing those periods was because these days were the hottest and coolest days during the lecturing period of the year.

For indoor measurements the thermometer was placed in the middle of the classroom and for outside measurements in front of the classroom's window (Plate 73.). The device let us measure indoor and outdoor temperature and indoor humidity. Outdoor humidity measurements were obtained from the Office of Meteorology at Turkish Republic of Northern Cyprus.

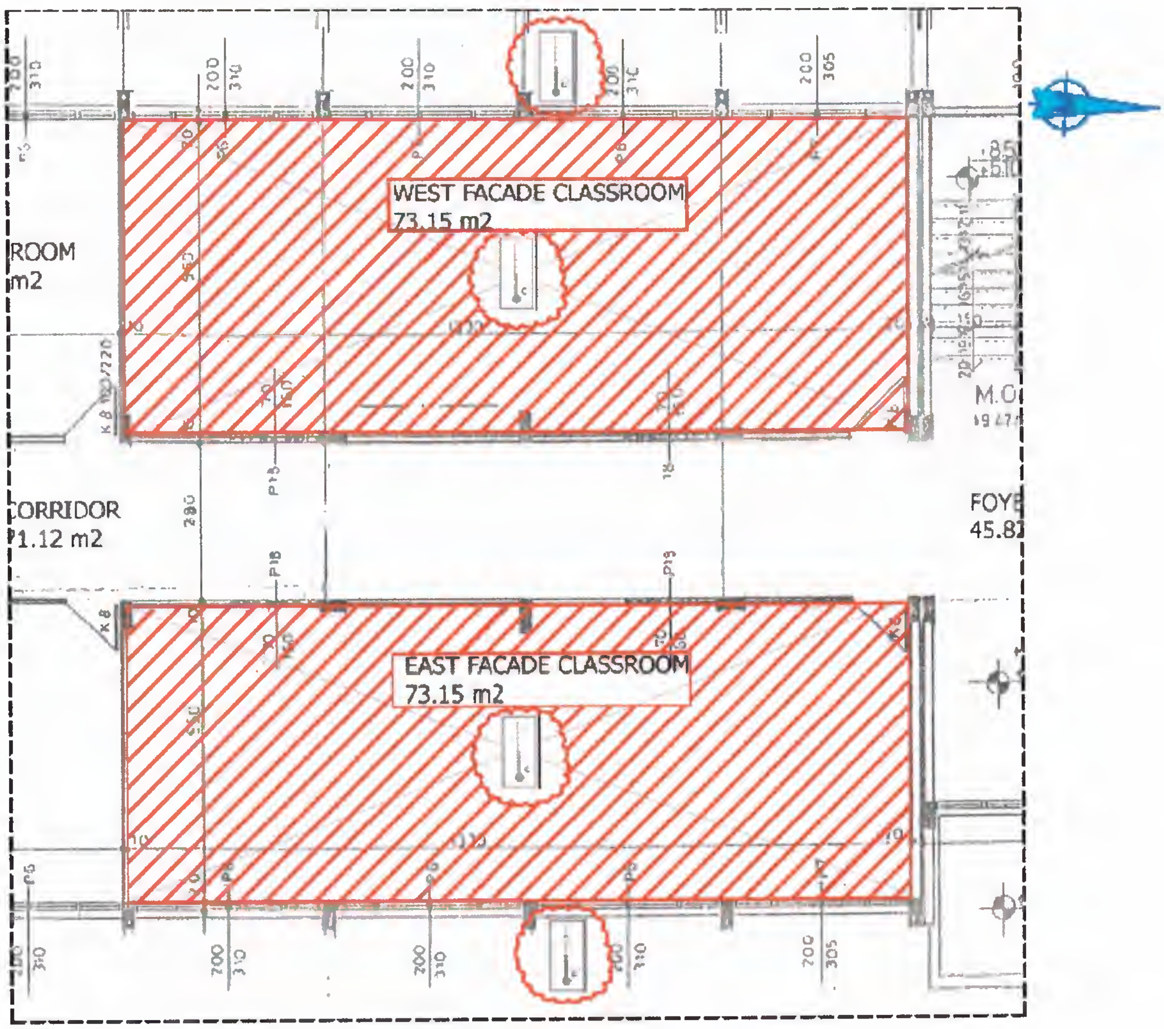


Plate 73. Placement of thermometer.

6.4.1. Simultaneous Indoor and Outdoor Heat and Humidity Measurements at Winter

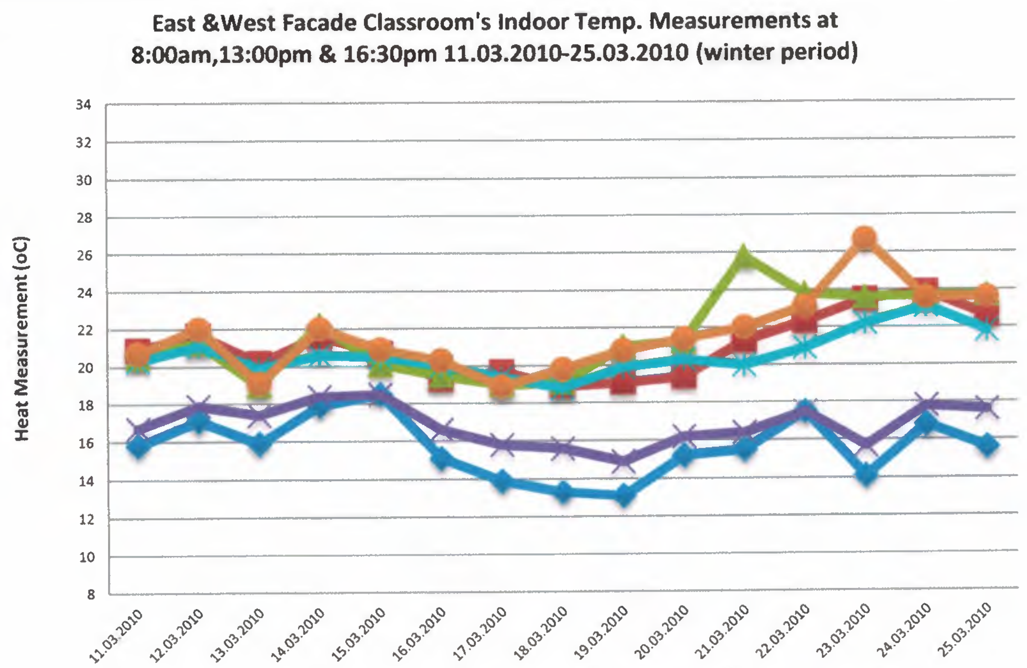
Heat measurements made during 11.03.2010-25.03.2010 are listed at Table 35.

Date	Hour	Ind. Temp.(°C)	Ind. Humidity (%)	Outdoor Temp. (°C)	Ind.Temp-Out.Temp.
11.03.2010	7:57	15,8	72%	15,2	0,6
	12:51	20,9	66%	21,9	-1
	16:17	20,5	64%	20,2	0,3
12.03.2010	07:50	17,1	75%	17,4	-0,3
	12:52	21,7	67%	23,6	-1,9
	16:43	21,3	57%	18,8	2,5
13.03.2010	07:52	15,9	71%	15,6	0,3
	12:48	20,2	68%	21	-0,8
	16:33	19,0	64%	19	0
14.03.2010	09:00	17,9	70%	20,5	**-2,6**
	12:57	21,6	63%	23,4	-1,8
	15:32	22,2	59%	21,9	0,3
15.03.2010	07:54	18,5	63%	16,6	1,9
	12:54	20,7	62%	21,8	-1,1
	16:30	20,1	59%	18,3	1,8
16.03.2010	07:55	15,1	72%	14,3	0,8
	12:52	19,3	61%	19,9	-0,6
	16:29	19,5	49%	16,6	2,9
17.03.2010	7:55	13,9	61%	11,7	2,2
	12:53	19,7	49%	19,7	0
	16:30	19,0	47%	17	2
18.03.2010	07:50	13,3	58%	10,7	2,6
	12:53	18,9	52%	17,5	1,4
	16:44	19,1	42%	14,3	4,8
19.03.2010	07:55	13,1	54%	11,7	1,4
	13:03	19,1	41%	17,3	1,8
	16:25	21,0	35%	15,1	5,9
20.03.2010	07:53	15,2	51%	12,8	2,4
	13:17	19,4	38%	18,8	0,6
	16:26	21,3	27%	17	4,3
21.03.2010	08:45	15,5	50%	14,7	0,8
	12:54	21,3	34%	21	0,3
	16:20	25,8	39%	18,5	7,3
22.03.2010	07:53	17,5	45%	15,3	2,2
	12:54	22,3	29%	20,5	1,8
	16:27	23,8	29%	19,8	4
23.03.2010	07:53	14,1	66%	13,3	0,8
	12:54	23,5	23%	23,8	-0,3
	16:40	23,6	38%	21,4	2,2
24.03.2010	07:54	16,8	54%	16,7	0,1
	12:57	23,9	27%	24,2	-0,3
	16:20	23,7	29%	21,5	2,2
25.03.2010	07:55	15,6	66%	14,6	1
	12:45	22,6	45%	24,5	-1,9

Table 35. Indoor and Outdoor Heat and Humidity Measurements for East Facade at Winter

Date	Hour	Ind. Temp.(°C)	Ind. Humidity (%)	Outdoor Temp. (°C)	Ind.Temp-Out.Temp.
11.03.2010	08:10	16,7	71%	15,7	1,0
	13:02	20,3	66%	24,2	-3,9
	16:30	20,7	65%	22,4	-1,7
12.03.2010	08:02	17,9	74%	17,2	0,7
	13:03	21,1	63%	25,5	-4,4
	16:33	22,0	57%	25,9	-3,9
13.03.2010	08:08	17,4	70%	14,8	2,6
	13:05	19,9	66%	27,8	-7,9
	16:44	19,1	63%	21,6	-2,5
14.03.2010	09:15	18,4	68%	17,3	1,1
	13:17	20,6	63%	25,8	-5,2
	15:45	22,0	60%	28,2	-6,2
15.03.2010	08:05	18,5	64%	16,8	1,7
	13:07	20,5	63%	22,9	-2,4
	16:43	20,9	60%	20,7	0,2
16.03.2010	08:08	16,6	68%	14,7	1,9
	13:05	20,0	58%	18,7	1,3
	16:41	20,3	49%	17,3	3,0
17.03.2010	08:06	15,8	58%	9,4	6,4
	13:06	19,4	49%	19,3	0,1
	16:45	18,9	47%	16,8	2,1
18.03.2010	08:05	15,6	55%	12,7	2,9
	13:06	18,8	49%	17,2	1,6
	16:30	19,8	44%	20,6	-0,8
19.03.2010	08:08	14,9	52%	11,5	3,4
	12:55	19,9	42%	16,2	3,7
	16:41	20,8	37%	20,5	0,3
20.03.2010	08:06	16,2	49%	11,7	4,5
	12:57	20,3	38%	18,7	1,6
	16:42	21,4	28%	22,9	-1,5
21.03.2010	09:02	16,4	46%	12,5	3,9
	13:20	20,0	37%	18,5	1,5
	16:45	22,0	35%	19,3	2,7
22.03.2010	08:07	17,5	44%	11,1	**6,4**
	13:08	20,9	32%	24,7	-3,8
	16:41	23,1	31%	25,1	-2,0
23.03.2010	08:08	15,7	62%	13,0	2,7
	13:07	22,2	29%	26,7	-4,5
	16:25	26,7	30%	22,1	4,6
24.03.2010	08:07	17,8	51%	12,3	5,5
	13:15	23,1	28%	31,5	**-8,4**
	16:34	23,6	30%	22,0	1,6
25.03.2010	08:10	17,6	62%	12,5	5,0
	13:07	21,8	47%	23,2	-14

Table 36. Indoor and Outdoor Heat and Humidity Measurements for West Facade at Winter.



	11.03.2010	12.03.2010	13.03.2010	14.03.2010	15.03.2010	16.03.2010	17.03.2010	18.03.2010	19.03.2010	20.03.2010	21.03.2010	22.03.2010	23.03.2010	24.03.2010	25.03.2010
08:00 east	15,8	17,1	15,9	17,9	18,5	15,1	13,9	13,3	13,1	15,2	15,5	17,5	14,1	16,8	15,6
13:00 east	20,9	21,7	20,2	21,6	20,7	19,3	19,7	18,9	19,1	19,4	21,3	22,3	23,5	23,9	22,6
16:30 east	20,5	21,3	19	22,2	20,1	19,5	19	19,1	21	21,3	25,8	23,8	23,6	23,7	23,7
08:00 west	16,7	17,9	17,4	18,4	18,5	16,6	15,8	15,6	14,9	16,2	16,4	17,5	15,7	17,8	17,6
13:00 west	20,3	21,1	19,9	20,6	20,5	20	19,4	18,8	19,9	20,3	20	20,9	22,2	23,1	21,8
16:30 west	20,7	22	19,1	22	20,9	20,3	18,9	19,8	20,8	21,4	22	23,1	26,7	23,6	23,6

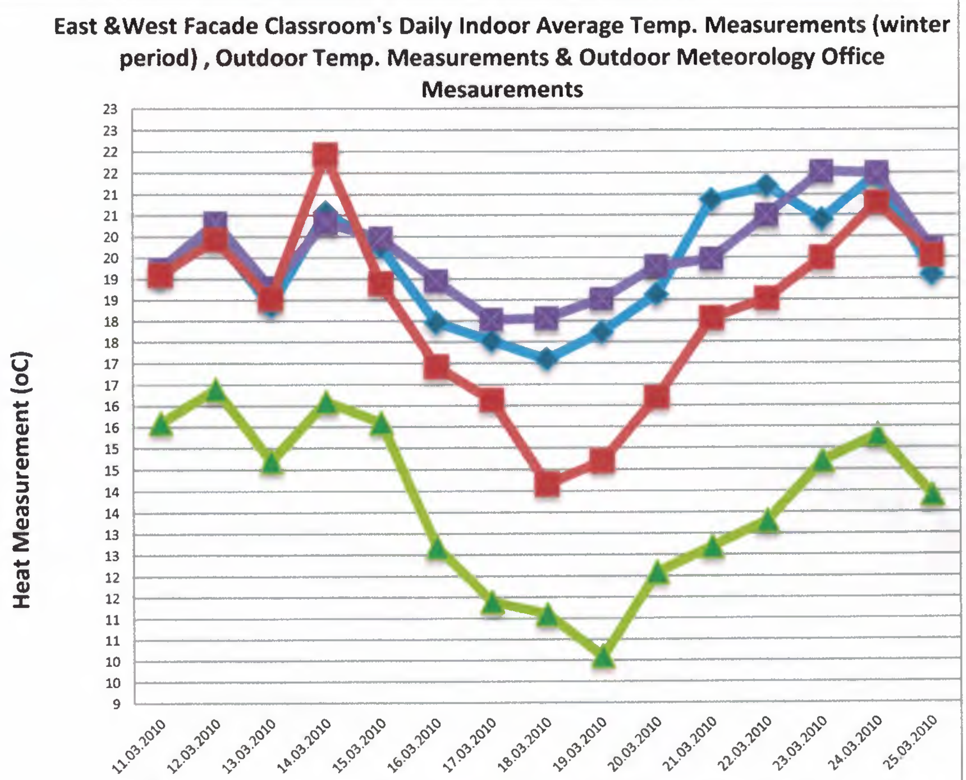
* EFC: East Facade Classroom; WFC: West Facade Classroom

Plate 74. Graphical Display of East and West Facade Classroom's Indoor Temp. Measurements at 8:00 am,13:00 and 16:30 11.03.2010-25.03.2010 (winter period).

In the winter mornings, the eastern facade of the building begins the day with 13°C and the western façade begins with 15°C indoors. Western façade temperature measurements show that indoor temperatures are always higher than outdoor temperatures (max +6.4 °C). West facade classrooms temperature difference is closer to outdoor temperature (max +2.6 °C) and some days is lower (12.03.2010 and 14.03.2010, max -2.6 °C). This difference on two façade classrooms is large because of western facades longer daily sun exposure time. This shows that there is an effect of radiant temperature.

During the day, the indoor temperature is expected to increase while the outdoor air temperature increases because the building has no insulation. Eastern façade measurements prove this fact but western façade indoors measurements for some days are lower than outdoors. This may be because of the fact that people tend to wear thicker clothes during the winter and they open the windows after feeling warm later in the day. This situation is observed at noon and afternoon temperature measurements.

The last temperature measurement of the day is between 18.9°C and 26.7°C. The first measurement of the next day is between 14.9°C and 18.5°C. This means that the building loses heat during the night.

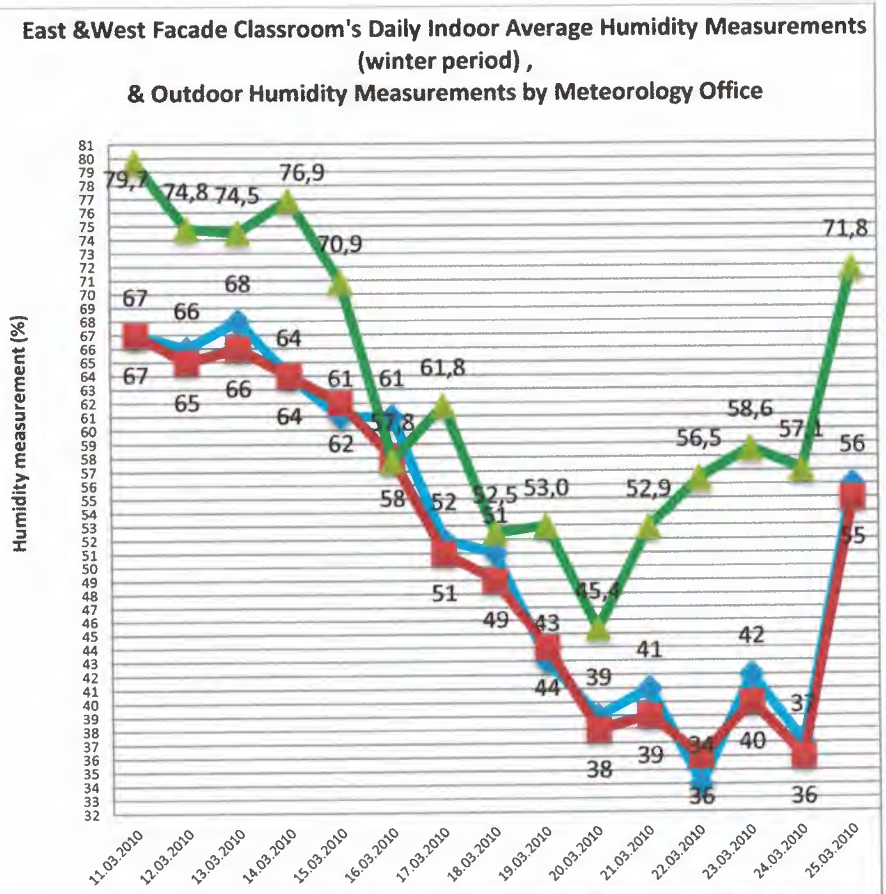


	11.03.2010	12.03.2010	13.03.2010	14.03.2010	15.03.2010	16.03.2010	17.03.2010	18.03.2010	19.03.2010	20.03.2010	21.03.2010	22.03.2010	23.03.2010	24.03.2010	25.03.2010
EFC* daily interior avg.temp.	19,1	20,0	18,4	20,6	19,8	18,0	17,5	17,1	17,7	18,6	20,9	21,2	20,4	21,5	19,1
WFC* daily interior avg.temp.	19,2	20,3	18,8	20,3	20,0	19,0	18,0	18,1	18,5	19,3	19,5	20,5	21,5	21,5	19,7
Outdoor Average temp.	19,1	19,9	18,5	21,9	18,9	16,9	16,1	14,2	14,7	16,2	18,1	18,5	19,5	20,8	19,55
temp measured by meteorology office	15,6	16,4	14,7	16,1	15,6	12,7	11,4	11,1	10,1	12,1	12,7	13,3	14,7	15,3	13,9

Plate 75. Graphical Display of East and West Facade Classroom's Daily Indoor Average Temp. Measurements (winter period) , Outdoor Temp. Measurements and Outdoor Meteorology Office Measurements.

Humidity level of comfort for indoor is around 45%. In case study measurements winter humidity fell below limit of comfort (min measurement: 71% humidity). Also it can be observed that when outdoor humidity level increases, the indoor humidity level increases too. That shows that there is a humidity exchange between interior and outdoor. Apparently this difference occurs because of opening windows and doors for ventilation even during the winter.

In comparison with the perceived temperature of comfort acceptance, the conditions in winter shows that sensible heat falls below the limits of comfort (3-5°C).



	11.03.2010	12.03.2010	13.03.2010	14.03.2010	15.03.2010	16.03.2010	17.03.2010	18.03.2010	19.03.2010	20.03.2010	21.03.2010	22.03.2010	23.03.2010	24.03.2010	25.03.2010
EFC* daily avg.interior humidity	67	66	68	64	61	61	52	51	43	39	41	34	42	37	56
WFC* daily avg.interior humidity	67	65	66	64	62	58	51	49	44	38	39	36	40	36	55
outdoor avg.hum. by meteorology office	79,7	74,8	74,5	76,9	70,9	57,8	61,8	52,5	53,0	45,4	52,9	56,5	58,6	57,1	71,8

Plate 76. Graphical Display of East and West Facade Classroom's Daily Indoor Average Humidity Measurements (winter period) , and Outdoor Humidity Measurements by Meteorology Office

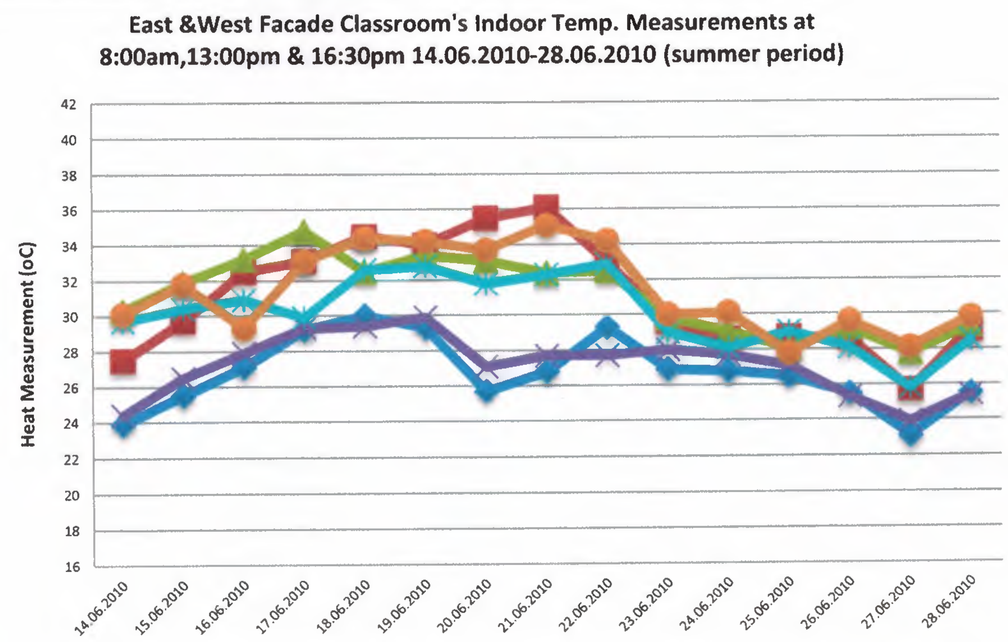
6.4.2. Simultaneous Indoor and Outdoor Heat and Humidity Measurements at Summer.

Date	Hour	Ind. Temp.(°C)	Ind. Humidity (%)	Outdoor Temp. (°C)	Ind.Temp-Out.Temp.
14.06.2010	08:05	23,9	69%	22,1	1,8
	13:25	27,5	46%	33,0	-5,5
	17:40	30,3	35%	28,0	2,3
15.06.2010	08:02	25,5	67%	24,4	1,1
	13:28	29,7	43%	35,2	-5,5
	17:30	31,9	34%	30,9	1,0
16.06.2010	08:00	27,1	60%	27,7	-0,6
	13:05	32,5	31%	36,2	-3,7
	17:30	33,2	25%	34,6	-1,4
17.06.2010	08:03	29,2	36%	30,3	-1,1
	13:04	33,1	30%	40,3	-7,2
	17:35	34,8	20%	35,4	-0,6
18.06.2010	08:18	30,0	40%	30,6	-0,6
	13:00	34,5	24%	38,8	-4,3
	18:03	32,5	25%	35,0	-2,5
19.06.2010	08:00	29,3	41%	29,6	-0,3
	13:02	34,0	24%	39,8	-5,8
	17:40	33,4	27%	34,2	-0,8
20.06.2010	08:50	25,7	55%	28,1	-2,4
	13:00	35,5	25%	38,2	-2,7
	18:05	33,1	27%	36,1	-3,0
21.06.2010	08:01	26,8	64%	27,1	-0,3
	13:20	36,1	21%	39,2	-3,1
	18:10	32,4	28%	32,6	-0,2
22.06.2010	08:20	29,3	44%	27,4	1,9
	13:02	33,0	25%	35,7	-2,7
	18:10	32,5	27%	32,7	-0,2
23.06.2010	08:01	26,9	46%	25,4	1,5
	13:20	29,6	36%	30,9	-1,3
	18:10	29,8	38%	28,6	1,2
24.06.2010	08:02	26,8	50%	26,6	0,2
	13:12	28,6	42%	29,8	-1,2
	17:40	29,0	37%	27,2	1,8
25.06.2010	08:05	26,5	53%	26,1	0,4
	13:02	28,7	46%	32,3	-3,6
	18:00	28,1	50%	24,5	3,6
26.06.2010	08:04	25,5	58%	24,7	0,8
	13:05	28,6	43%	32,1	-3,5
	18:00	29,2	47%	27,1	2,1
27.06.2010	08:30	23,1	60%	22,2	0,9
	13:10	25,7	50%	27,5	-1,8
	18:00	27,8	47%	25,1	2,7
28.06.2010	08:03	25,5	56%	24,2	1,3
	13:25	29,1	34%	30,7	-1,6
	18:00	29,3	39%	28,5	0,8

Table 37. Indoor - Outdoor Heat and Humidity Measurements for East Facade at Summer.

Date	Hour	Ind. Temp.(°C)	Ind. Humidity (%)	Outdoor Temp. (°C)	Ind.Temp-Out.Temp.
14.06.2010	08:20	24,4	65%	23,8	0,6
	13:08	29,7	45%	34,2	-4,5
	18:05	30,1	37%	30,7	-0,6
15.06.2010	08:15	26,5	63%	24,1	2,4
	13:04	30,4	43%	36,1	-5,7
	18:00	31,8	34%	32,1	-0,3
16.06.2010	08:17	27,9	59%	27,6	0,3
	13:29	30,9	34%	35,2	-4,3
	18:05	29,3	35%	32,4	-3,1
17.06.2010	08:16	29,3	33%	31,0	-1,7
	13:20	29,9	25%	38,3	**-8,4**
	18:03	33,1	23%	32,0	1,1
18.06.2010	08:03	29,4	41%	28,7	0,7
	13:23	32,6	24%	35,8	-3,2
	17:32	34,4	24%	39,2	-4,8
19.06.2010	08:25	29,9	40%	27,4	2,5
	13:22	32,8	26%	39,0	-6,2
	18:07	34,2	24%	35,9	-1,7
20.06.2010	09:10	27,1	60%	25,1	2,0
	13:20	31,8	22%	37,2	-5,4
	18:25	33,7	23%	36,1	-2,4
21.06.2010	08:15	27,7	61%	24,7	3,0
	13:05	32,3	32%	37,0	-4,7
	17:40	35,1	26%	36,8	-1,7
22.06.2010	08:01	27,7	47%	25,6	2,1
	13:20	32,9	26%	33,1	-0,2
	17:40	34,2	25%	36,1	-1,9
23.06.2010	08:20	28,0	42%	24,4	3,6
	13:04	29,0	38%	31,3	-2,3
	17:40	30,0	37%	28,1	1,9
24.06.2010	08:20	27,7	47%	24,0	3,7
	13:00	28,1	43%	29,9	-1,8
	18:15	30,1	37%	27,0	3,1
25.06.2010	08:22	27,1	48%	24,4	2,7
	13:25	29,0	43%	31,8	-2,8
	17:40	27,8	52%	27,5	0,3
26.06.2010	08:22	25,3	48%	22,5	2,8
	13:23	28,1	44%	32,6	-4,5
	17:30	29,6	38%	30,0	-0,4
27.06.2010	09:00	23,9	50%	21,7	2,2
	13:30	25,8	47%	26,1	-0,3
	18:30	28,1	43%	27,2	0,9
28.06.2010	08:20	25,4	55%	21,9	3,5
	13:05	28,5	32%	34,9	-6,4
	18:00	29,8	38%	29,9	-0,1

Table 38. Indoor - Outdoor Heat and Humidity Measurements for West Facade at Summer.



	14.06.2010	15.06.2010	16.06.2010	17.06.2010	18.06.2010	19.06.2010	20.06.2010	21.06.2010	22.06.2010	23.06.2010	24.06.2010	25.06.2010	26.06.2010	27.06.2010	28.06.2010
08:00 EFC*	23,9	25,5	27,1	29,2	30	29,3	25,7	26,8	29,3	26,9	26,8	26,5	25,5	23,1	25,5
13:00 EFC*	27,5	29,7	32,5	33,1	34,5	34	35,5	36,1	33	29,6	28,6	28,7	28,6	25,7	29,1
17:30 EFC*	30,3	31,9	33,2	34,8	32,5	33,4	33,1	32,4	32,5	29,8	29	28,1	29,2	27,8	29,3
08:00 WFC*	24,4	26,5	27,9	29,3	29,4	29,9	27,1	27,7	27,7	28	27,7	27,1	25,3	23,9	25,4
13:00 WFC*	29,7	30,4	30,9	29,9	32,6	32,8	31,8	32,3	32,9	29	28,1	29	28,1	25,8	28,5
17:00 WFC*	30,1	31,8	29,3	33,1	34,4	34,2	33,7	35,1	34,2	30	30,1	27,8	29,6	28,1	29,8

Plate 77. Graphical Display of East and West Facade Classroom's Indoor Temp. Measurements at 8:00 am,13:00 and 16:30 14.06.2010-28.06.2010 (summer period).

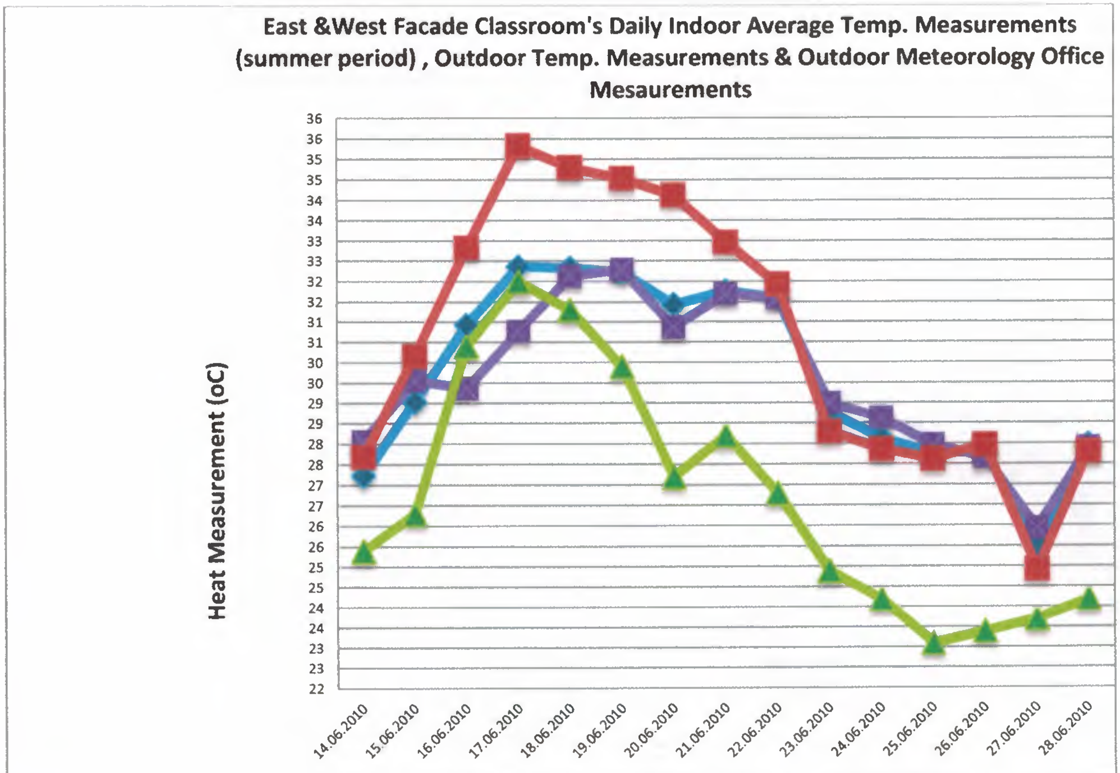
At summer, when outdoor air temperature increases, interior heat temperature increases too. In the morning, indoor-outdoor temperature differences varies between +0,7°C; -1,7°C. This shows that building also loses heat in a short time. There is no isolation at windows nor at walls. At noon the temperature difference between outdoor and classrooms becomes 8,4°C.

Mornings, because of the sun's motion east façade's classroom temperature becomes higher than west façade classroom (+0,3;-4,8°C). Noon temperature difference differs from day to day. Some days east classrooms temperature is higher than west classrooms; some days west classrooms temperature is higher than east classrooms temperature. This means that there is an effect of radiant temperature. Building gains heat easily. Also starting the day with high temperature (29°C) this is not good for the beginning of the day. Because of emissivity of buildings materials, building will continue to gain heat during the day.

Evenings, classrooms temperature became higher than outdoor temperature. This means that there is a big absorption of heat.

All this data shows that building heats fast, and cools fast too.

At summer for cooling, doors of classrooms opens manually. Thus, by providing air flow classrooms get cooler.

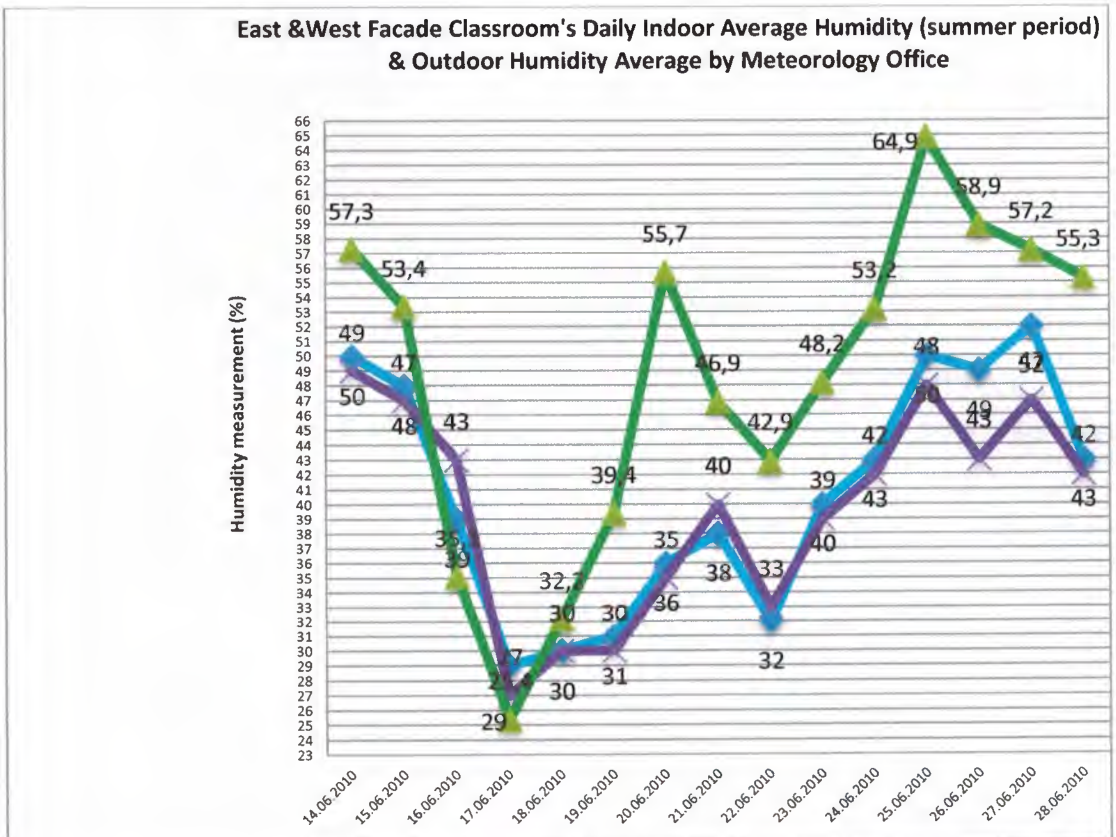


	14.06.2010	15.06.2010	16.06.2010	17.06.2010	18.06.2010	19.06.2010	20.06.2010	21.06.2010	22.06.2010	23.06.2010	24.06.2010	25.06.2010	26.06.2010	27.06.2010	28.06.2010
EFC* daily interior avg.temp.	27,2	29,0	30,9	32,4	32,3	32,2	31,4	31,8	31,6	28,8	28,1	27,8	27,8	25,5	28,0
WFC* daily interior avg.temp.	28,1	29,6	29,4	30,8	32,1	32,3	30,9	31,7	31,6	29,0	28,6	28,0	27,7	25,9	27,9
outdoor avg.temp.	27,7	30,2	32,8	35,3	34,8	34,5	34,1	33,0	31,9	28,3	27,9	27,6	28,0	24,9	27,8
temp measured by meteorology office	25,4	26,3	30,4	32,0	31,3	29,9	27,2	28,2	26,8	24,9	24,2	23,1	23,4	23,7	24,2

Plate 78. Graphical Display of East and West Facade Classroom's Daily Indoor Average Temp. Measurements (summer period) , Outdoor Temp. Measurements and Outdoor Meteorology Office Measurements.

Humidity level for indoor is around 45 percent. In case study measurements, summer humidity falls below the limit of comfort (min measurement: 23%low). Because no mechanical heating and cooling is available, humidity level is controlled only by opening windows.

In comparison with the perceived temperature of comfort acceptance, the conditions in summer showed that sensed temperature rises up from limits of comfort (max 12,5°C of difference; i.e. interior temp. is 35,5 °C).



	14.06.2010	15.06.2010	16.06.2010	17.06.2010	18.06.2010	19.06.2010	20.06.2010	21.06.2010	22.06.2010	23.06.2010	24.06.2010	25.06.2010	26.06.2010	27.06.2010	28.06.2010
EFC* daily avg. interior humidity	50	48	39	29	30	31	36	38	32	40	43	50	49	52	43
WFC* daily avg. interior humidity	49	47	43	27	30	30	35	40	33	39	42	48	43	47	42
outd.avg.hum.by meteorology office	57,3	53,4	35,1	25,4	32,2	39,4	55,7	46,9	42,9	48,2	53,2	64,9	58,9	57,2	55,3

Plate 79. Graphical Display of East and West Facade Classroom's Daily Indoor Average Humidity (summer period) and Outdoor Humidity Average by Meteorology Office.

6.5. Evaluation of Classrooms from Point of View of Thermal Comfort

Temperature measurements showed that materials used in buildings construction and improper placement of building caused an unacceptable thermal comfort limits (thermal comfort heat limits: 21°C-23°C). That means that classrooms are not suitable for their purpose.

To preserve the sustainability of building preventive architectural precautions, such as reducing window area, solar shading elements, heat insulation etc. could be taken. Also mechanical heating and cooling systems can be installed and with evaluating the solar energy that system can be supported.

6.6. INSPECTION AND FINDINGS

A difference of 5-6°C is noticeable between outdoor temperature measurements of the Department of Meteorology and the case study classes for both summer and winter. A reason may be the fact that our measurement location was different from the location of the weather stations of the Department of Meteorology. Nevertheless, the overlaid temperature measurement graphics show us that measurements are parallel. This makes us sure that our outdoor temperature measurements are accurate.

The eastern facade is the first to get exposed to the sun in the summer. The western facade doesn't get sunshine till noon. But we observed higher temperatures of up to 1.4°C in the western facade classrooms. Even though the facade is not exposed to sun this difference means that the construction materials emit radiant heat. Mornings we observed 30°C of indoor temperature on some days and only two days 23°C in this period (thermal comfort range: 21°C-23°C). So that the temperature will rise during the day and will exceed the thermal comfort levels.

When outdoor and indoor temperature measurements of the eastern and western facade classrooms are compared, a maximum of 2oC difference is seen. They are almost the same. This property, also observed in winter, indicates to construction materials of poor insulation quality and a necessity for insulation .

Till noon sun rays reaches their highest level of radiation. Because of noninsulated walls and single glazed windows indoor temperatures reaches 30°C on average. So this shows that classrooms are not favorable for use because of exceeding thermal comfort levels.

During measurement periods it is observed that the doors and windows were kept open during lectures in order to maintain airflow as practiced in real life.

With high temperature differences evening measurements shows that building absorbs a lot of heat during the day. Namely; indoors are now warmer than outdoors. This is more clearly observed in the eastern facade classroom. Even though expections were towards the western facade classroom to be warmer than outdoors because of longer exposure to the sun, but it is found that eastern facade classroom is warmer. This makes one think that the cause may again be radiant heat from the building itself accumulating for a longer time.

Indoor humidity tends to fall below comfort levels (27% in the western facade classroom, 29% in the eastern facade classroom). With no air conditioning this will cause the nasal mucosa to dry and increase sensitivity to germs causing respiratory illnesses such as asthma, allergies and lung diseases in classrooms.

6.7. CONCLUSIONS AND RECOMMENDATIONS

This study was performed in order to benefit construction factors in today's buildings which use traditional construction materials with no insulation. Also determining the benefits of raising a healthy society by respecting human sensitivity. Buildings built without considering the needs of inhabitants with insufficient insulation are determined to have thermal problems.

This study was focused on indoor and outdoor heat measurements at Architectural Department of Near East University in Nicosia / Turkish Republic of Cyprus. Temperature and humidity measurements were performed at two classes, each of them located on east and west façade of a building during the winter (11-25.03.2010) and summer (14-28.06.2010) periods for duration of 15 days. Architectural drawings of a building were obtained; exterior photos of a building were taken with it's surrounding. Also outdoor temperature measurements for the same periods provided by Meteorology Office of the Turkish Republic of Northern Cyprus were obtained as well.

Finally, all data collected from measurements were arranged in graphics and tables. According to that data analysis, evaluation and conclusions were made.

Human health is key to sustainable environment. Living spaced protected from the influence of by environmental problems generates healthy people. Healthy people mean healthy societies. Therefore, healthy societies perform at highest levels in their every activity.

During the design process, buildings have to be designed with correct structures and materials. Proper wall thickness, proper heat and humidity insulation materials should be chosen, correct window sizes and shading devices should be designed.

Assigning the thermal comfort standards for educational buildings a solution to this common problem can be brought. Therefore, healthy buildings will keep healthy bodies and will provide healthy generations.

National Educational Institution in TRNC have to conduct a solution for educational buildings with inadequate thermal comfort by determining this problem.

For healthy future generations, negatively affecting human health circumstances should be eliminated from residential, business and educational buildings.

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APPENDICES

I. Architectural Plans of Faculty of Architecture

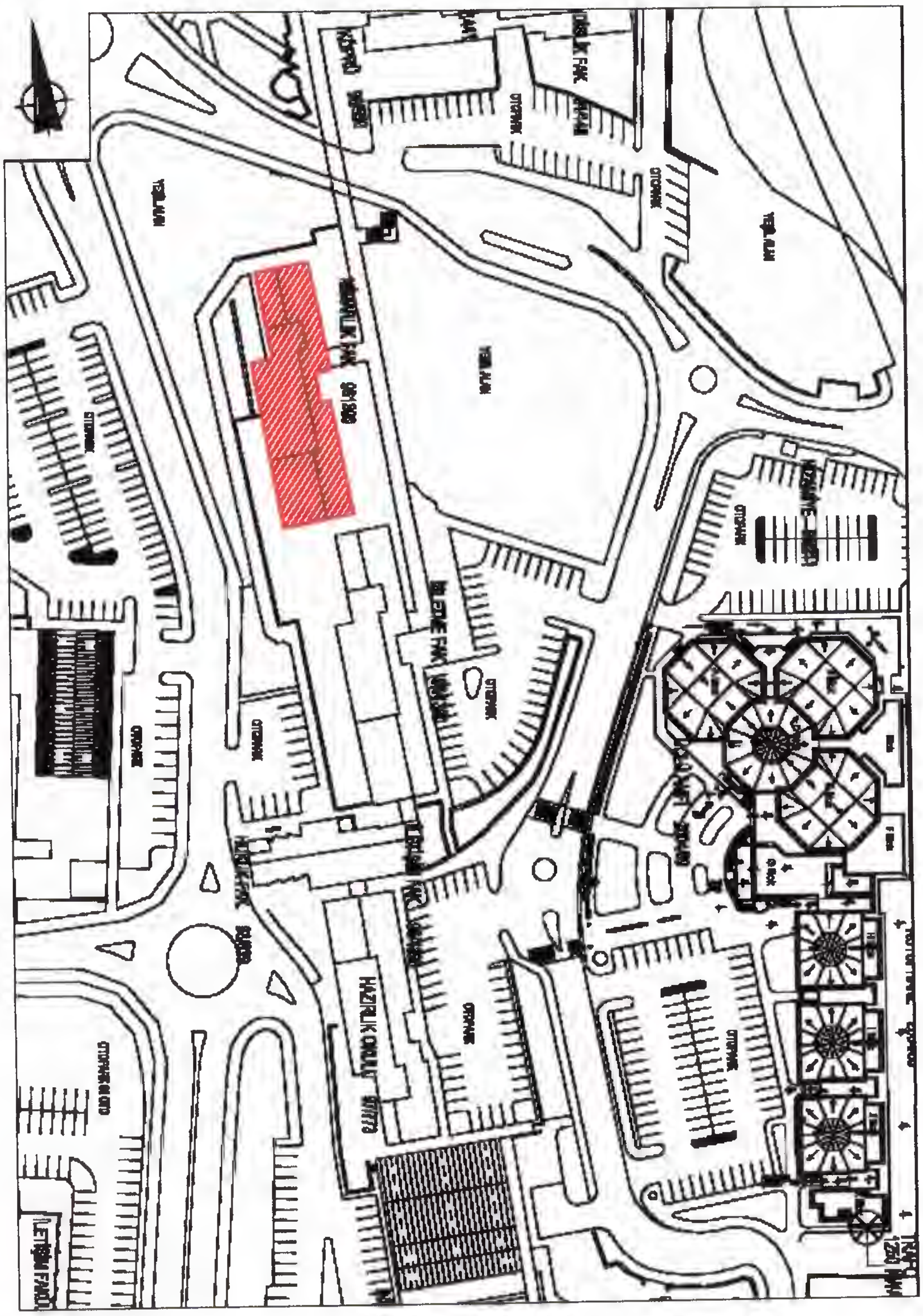


Plate 80. Site Plan of Faculty of Architecture.

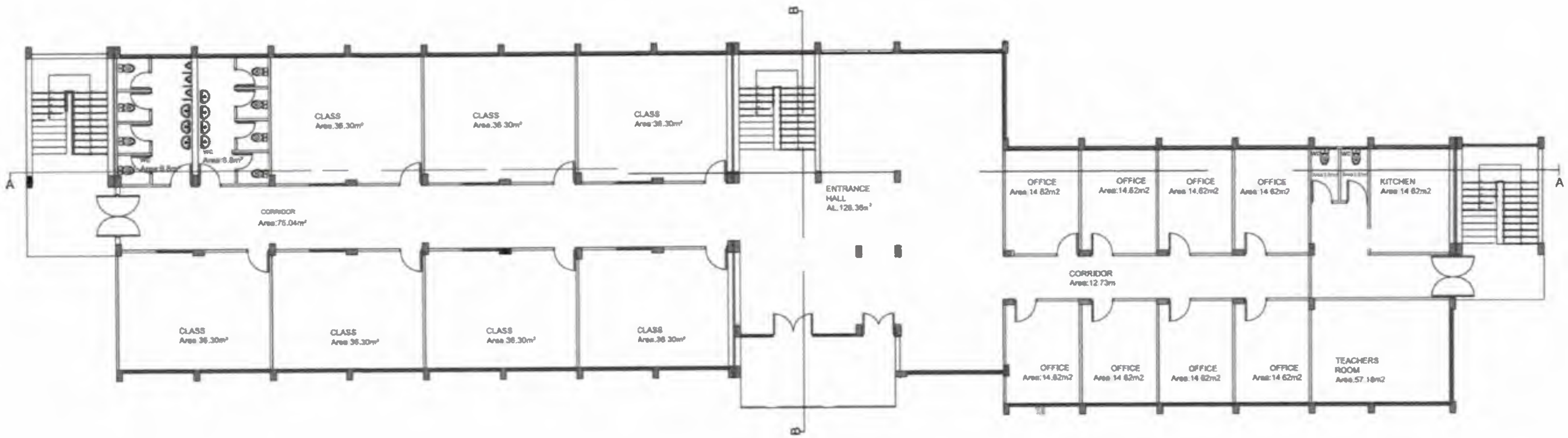


Plate 81. Ground Floor Plan.

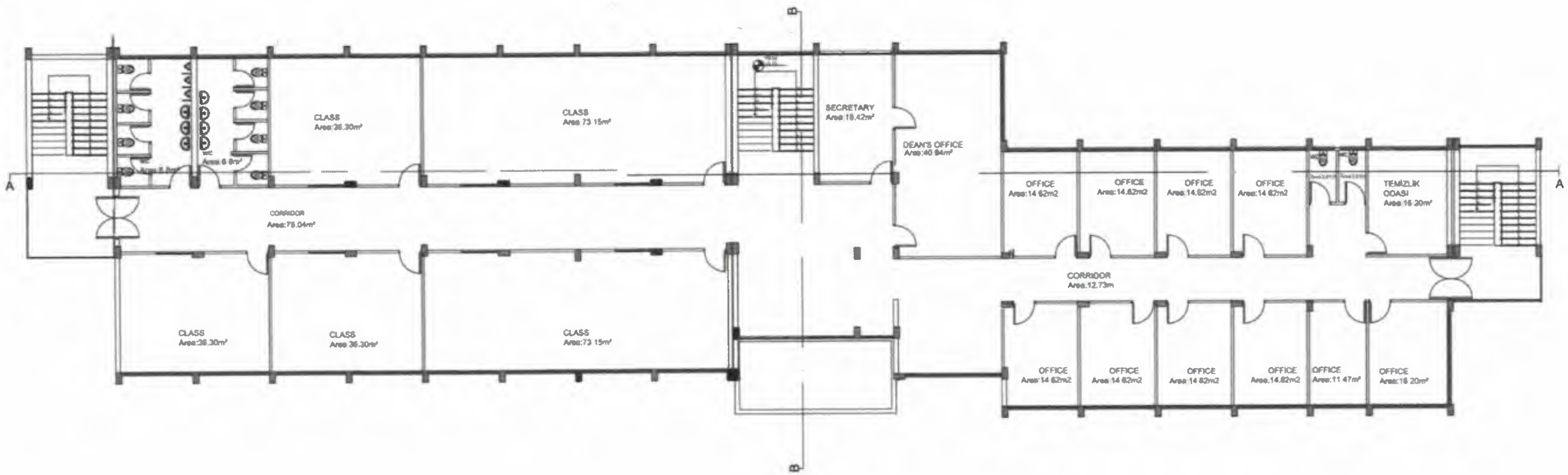


Plate 82. 1st Floor Plan.

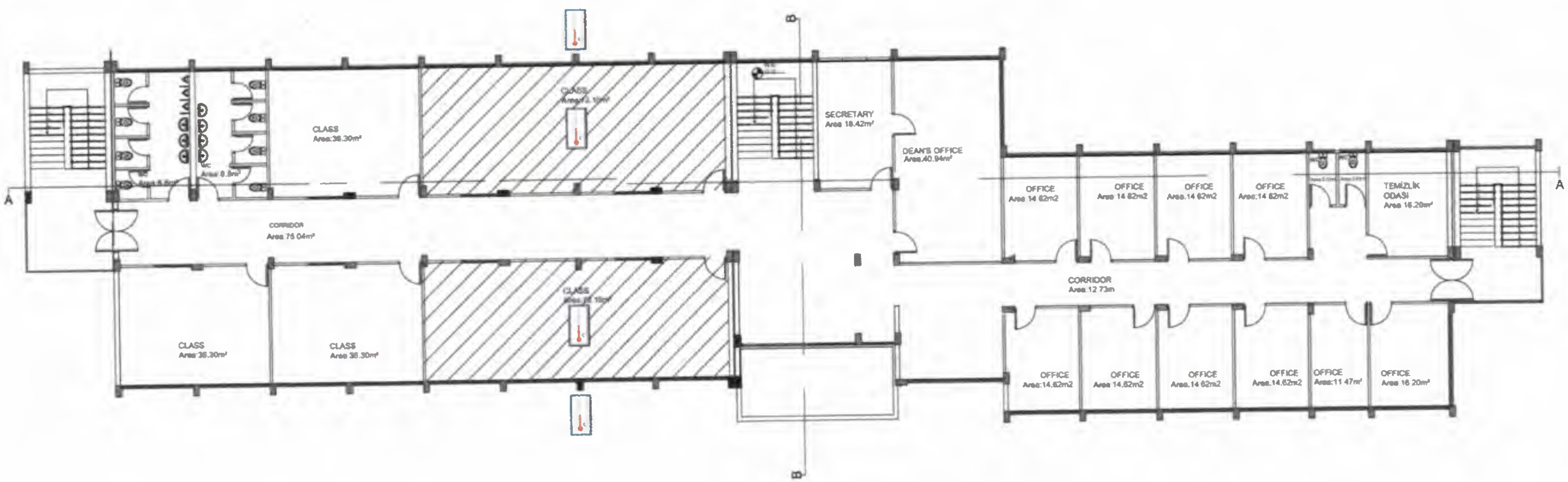


Plate 83. 2'nd Floor Plan.

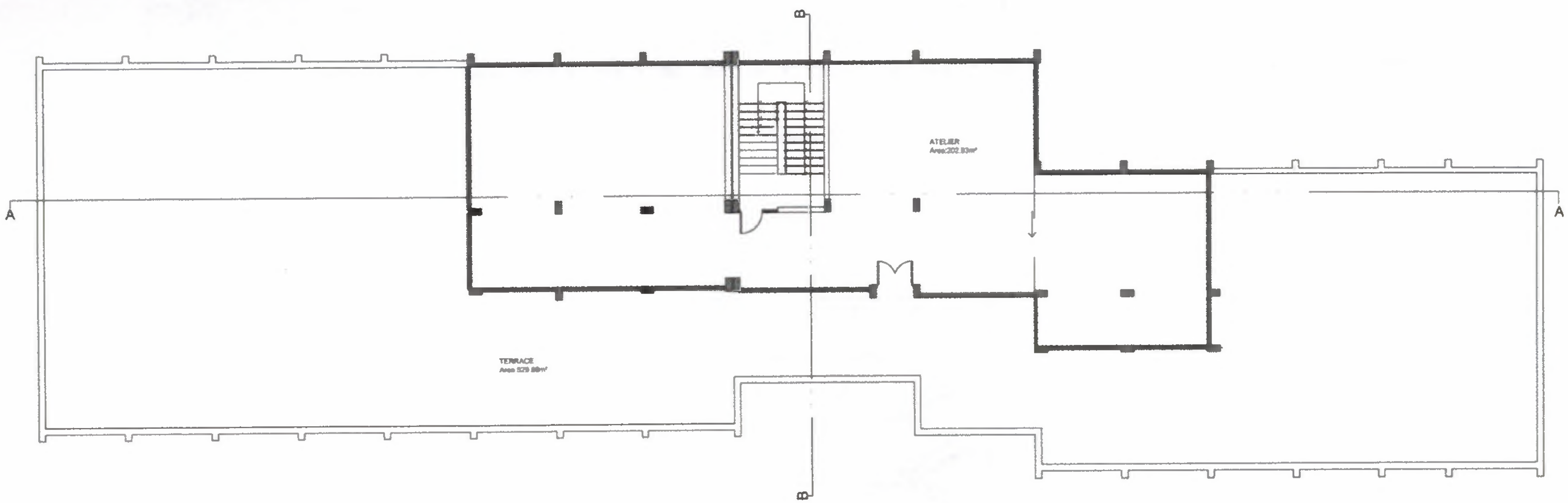


Plate 84. 3'rd Floor Plan.

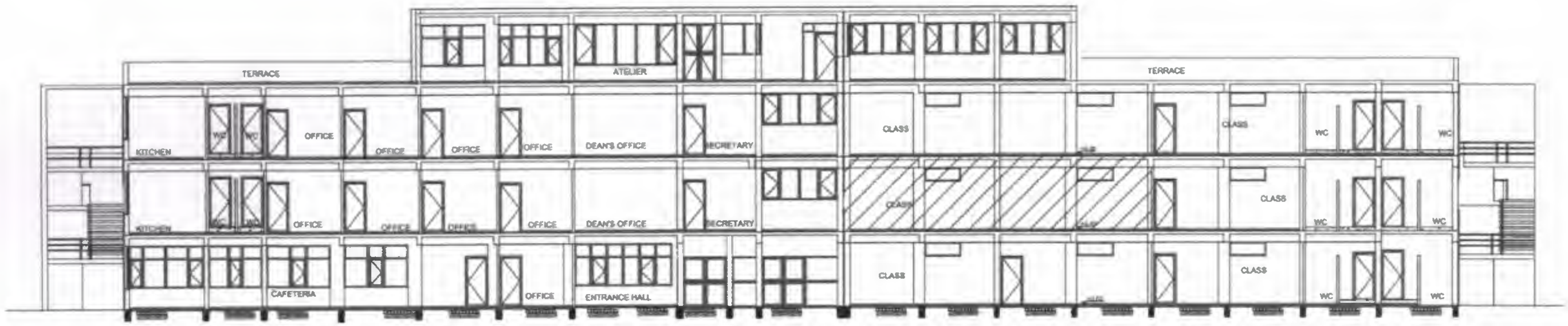


Plate 85. Section B-B.

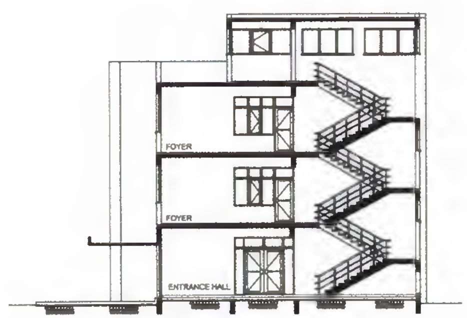


Plate 86. Section A-A.

Plate 87. North Elevation.

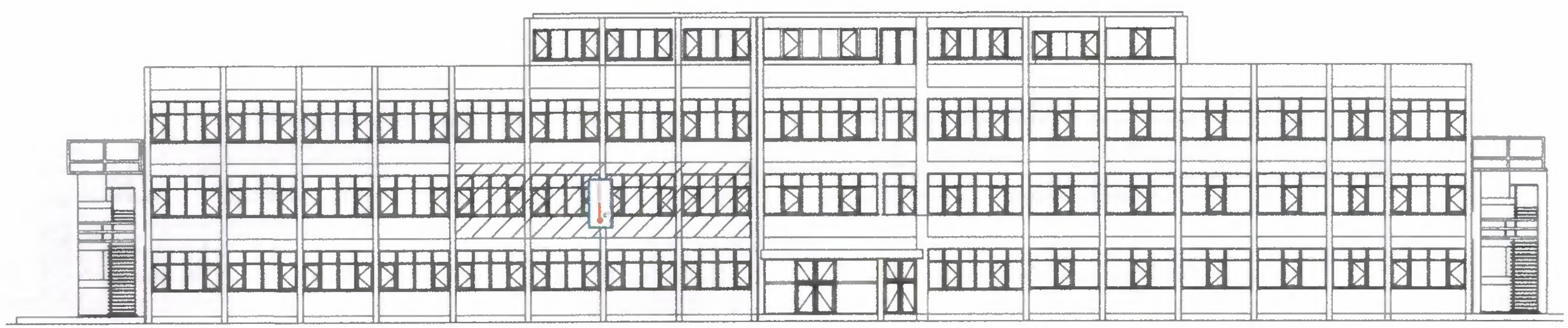


Plate 88. East Elevation.

Plate 90. South Elevation.

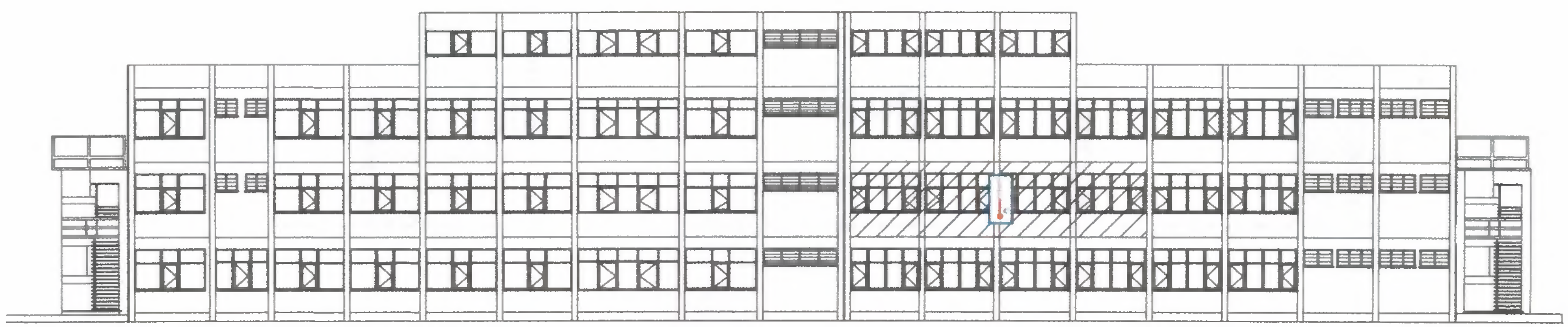
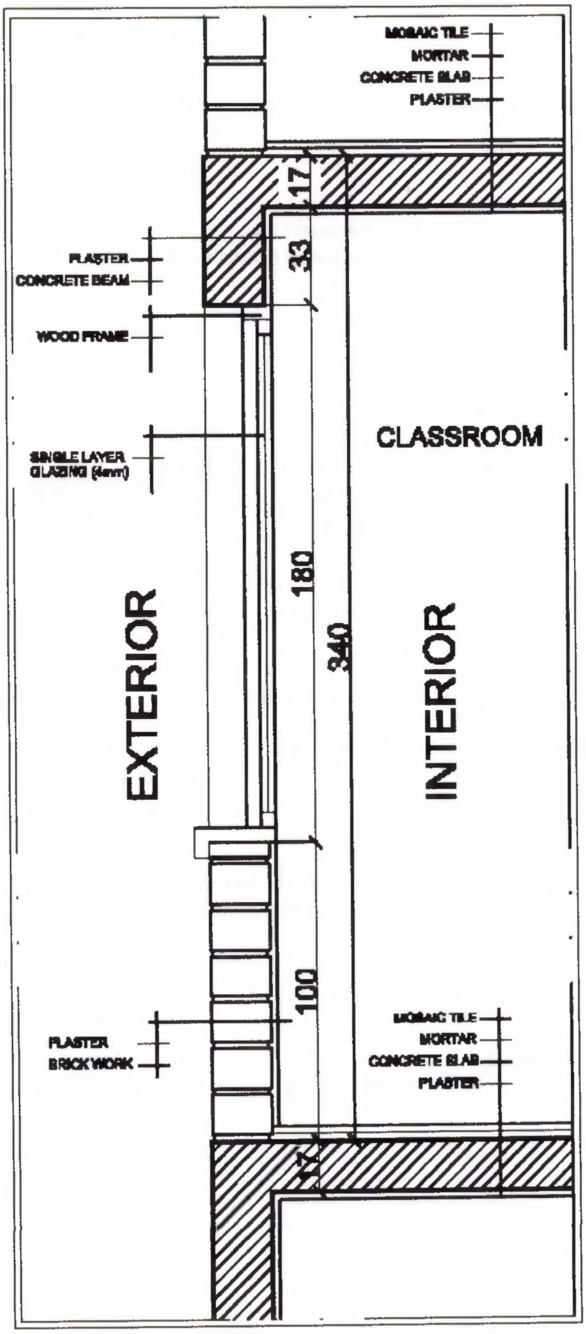


Plate 89. West Elevation.

WALL SECTION of the SELECTED CLASSROOMS :



II. Simultaneous Heat Measurement Graphics

II-I. Simultaneous Indoor and Outdoor Heat and Humidity Measurement Graphics at Winter

INDOOR MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

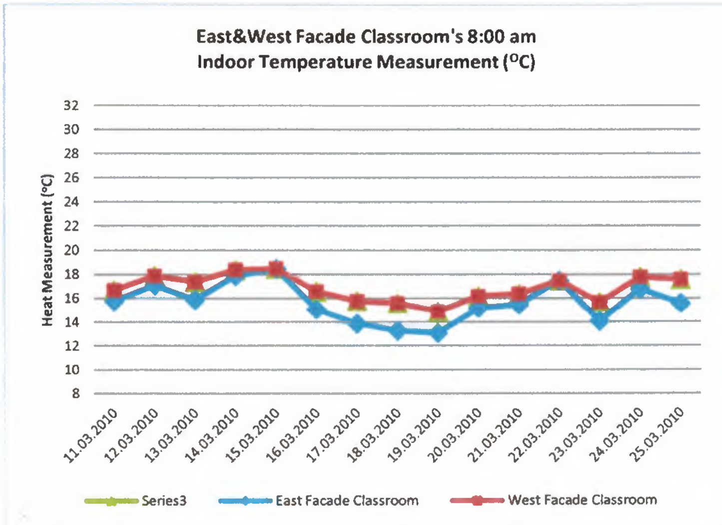


Plate 91. East and West Facade Classroom's 8:00 am Indoor Temperature Measurement (^{O}C)

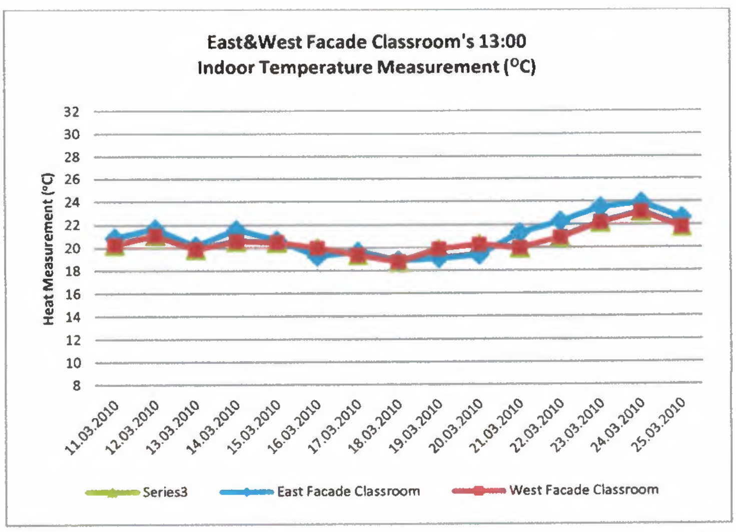


Plate 92. East and West Facade Classroom's 13:00 Indoor Temperature Measurement (^{O}C)

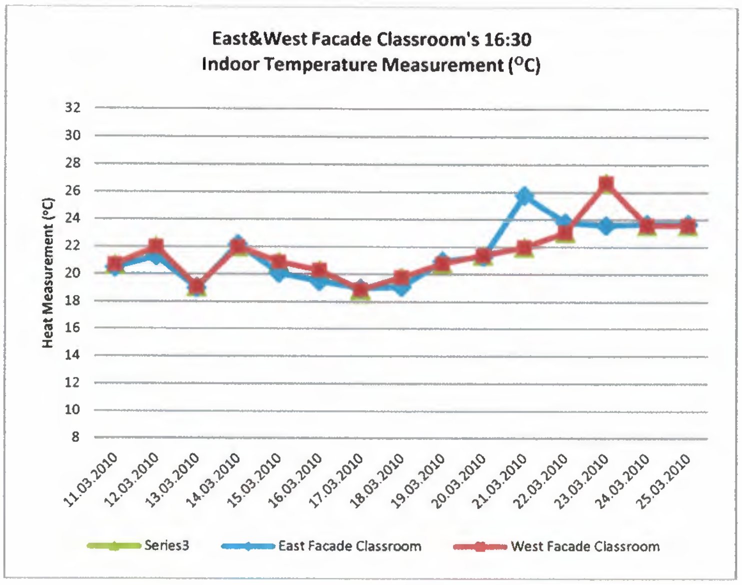


Plate 93. East and West Facade Classroom's 16:30 Indoor Temperature Measurement (^{O}C)

OUTDOOR MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

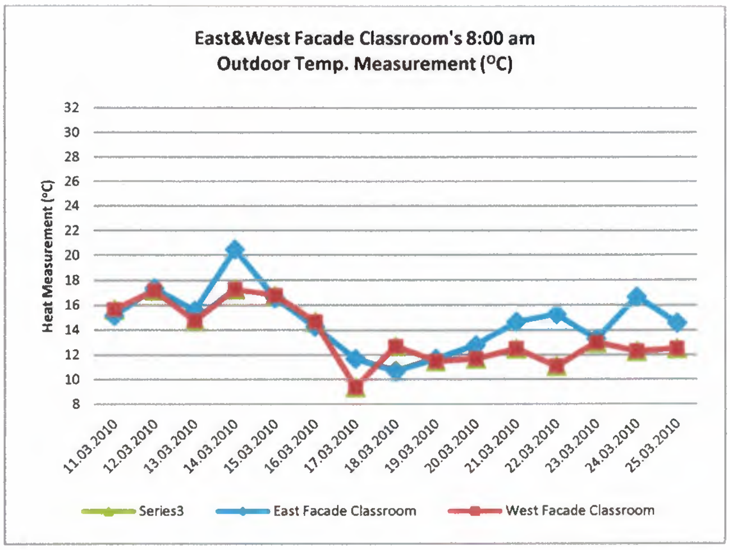


Plate 94. East and West Facade Classroom's 8:00 am Outdoor Temp. Measurement (^{O}C)

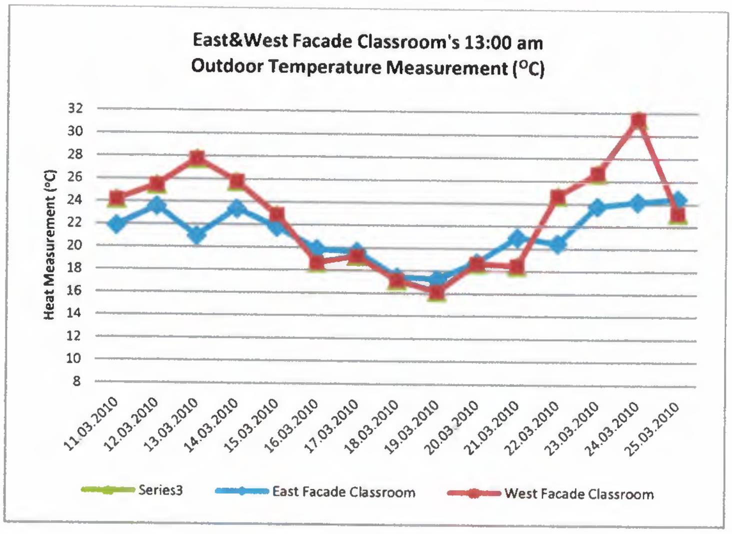


Plate 95. East and West Facade Classroom's 13:00 Outdoor Temperature Measurement (^{O}C)

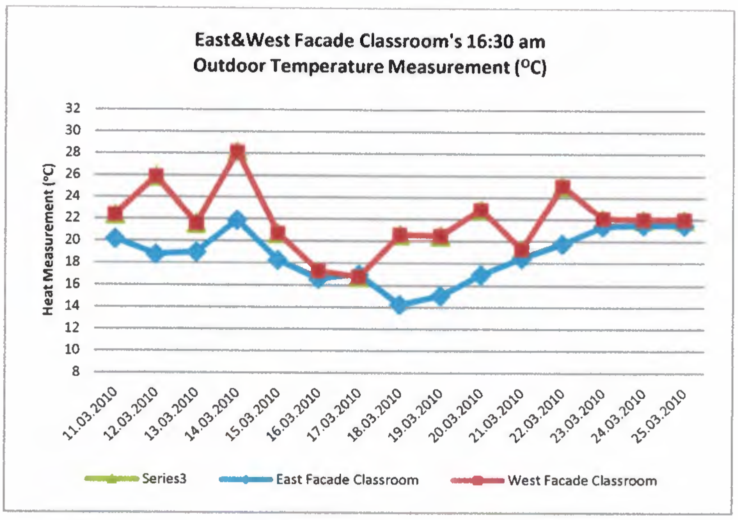


Plate 96. East and West Facade Classroom's 16:30 Outdoor Temperature Measurement (^{O}C)

INDOOR HUMIDITY MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

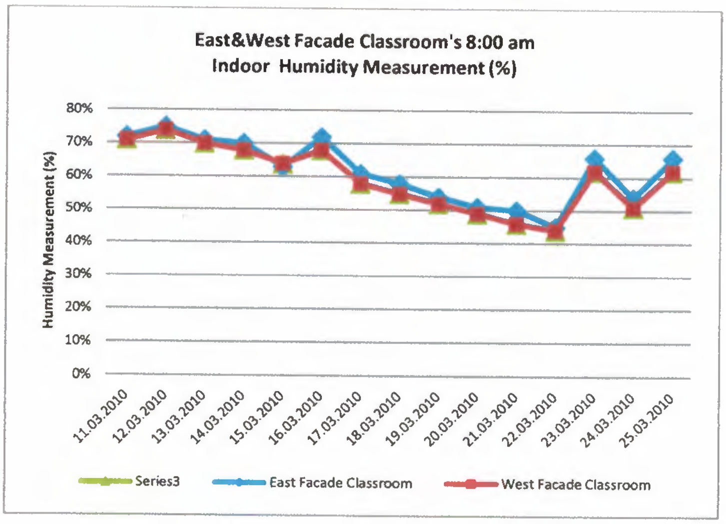


Plate 97. East and West Facade Classroom's 8:00 am Indoor Humidity Measurement (%)

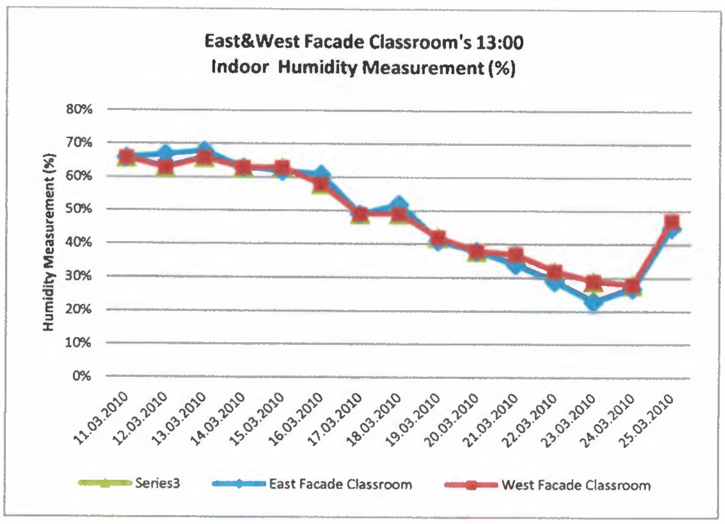


Plate 98. East and West Facade Classroom's 13:00 Indoor Humidity Measurement (%)

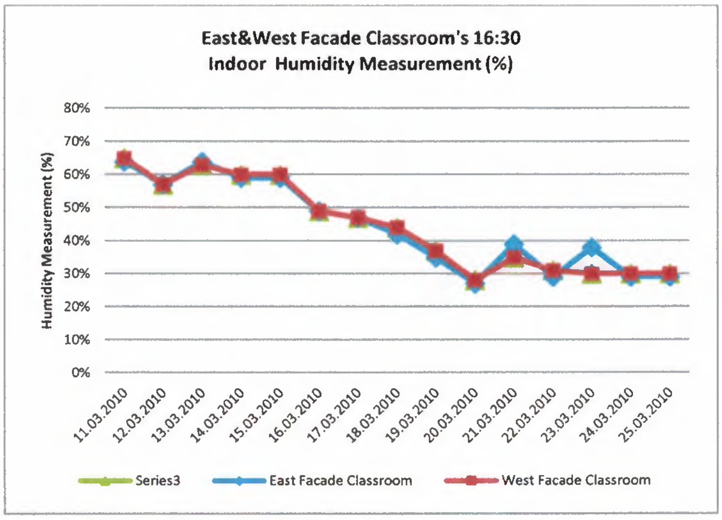


Plate 99. East and West Facade Classroom's 16:30 Indoor Humidity Measurement (%)

AVERAGE GRAPHICS – EAST and WEST FAÇADE:

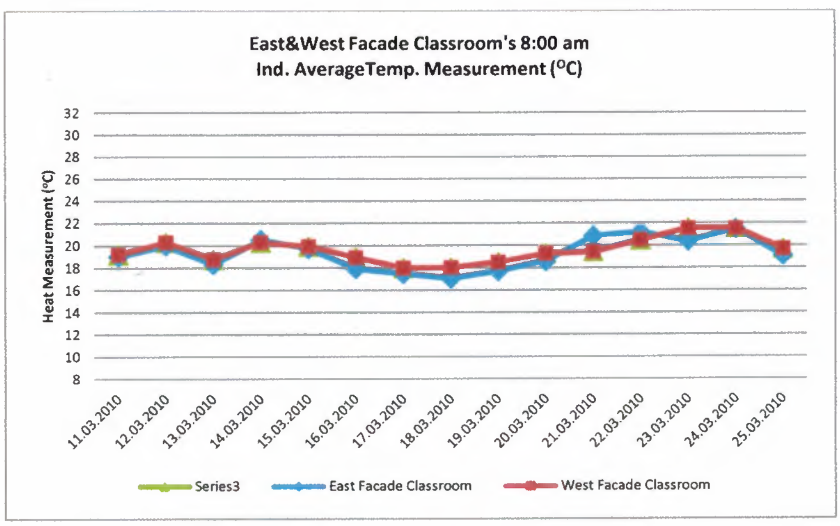


Plate 100. East and West Facade Classroom's 8:00 am Ind. AverageTemp. Measurement (^{O}C)

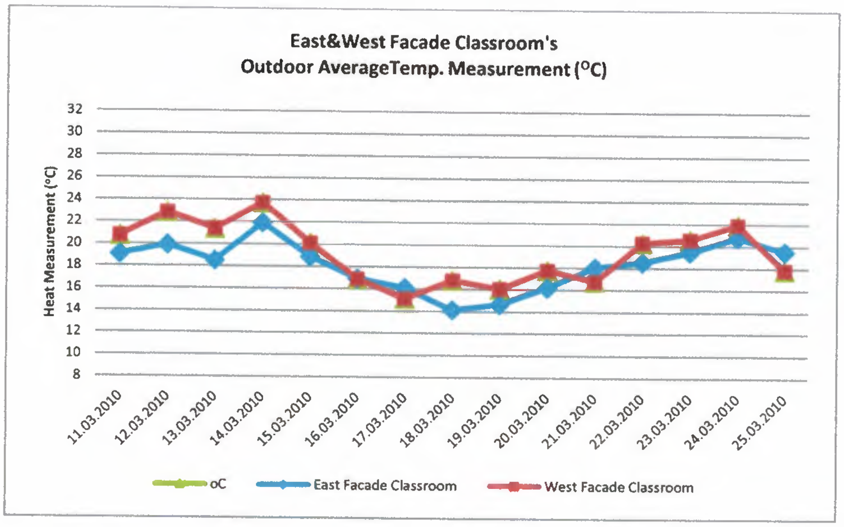


Plate 101. East and West Facade Classroom's Outdoor AverageTemp. Measurement (^{O}C)

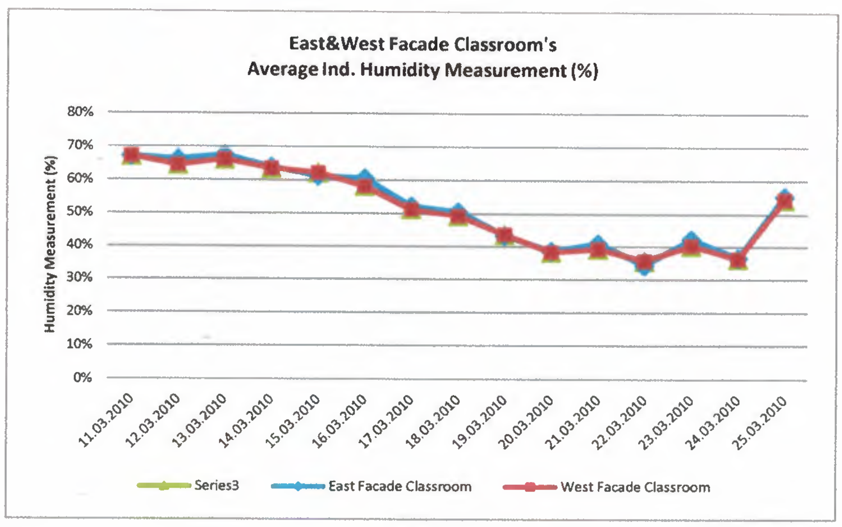


Plate 102. East and West Facade Classroom's Average Ind. Humidity Measurement (%)

II-II. Simultaneous Indoor and Outdoor Heat and Humidity Measurement Graphics at Summer

INDOOR MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

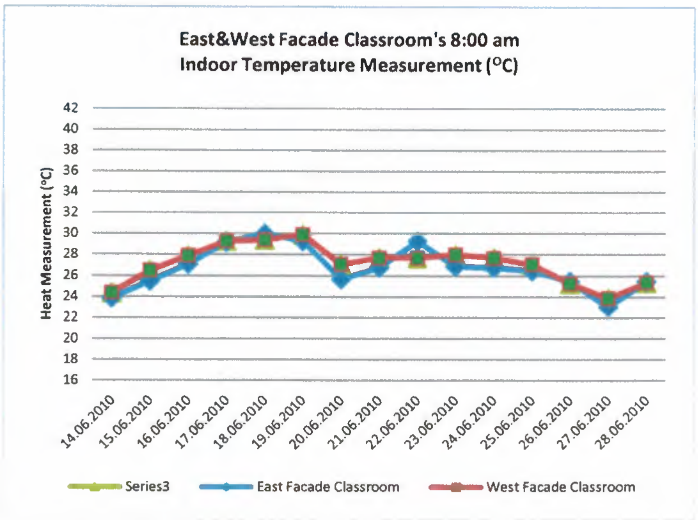


Plate 103. East and West Facade Classroom's 8:00 am Indoor Temperature Measurement (^{O}C)

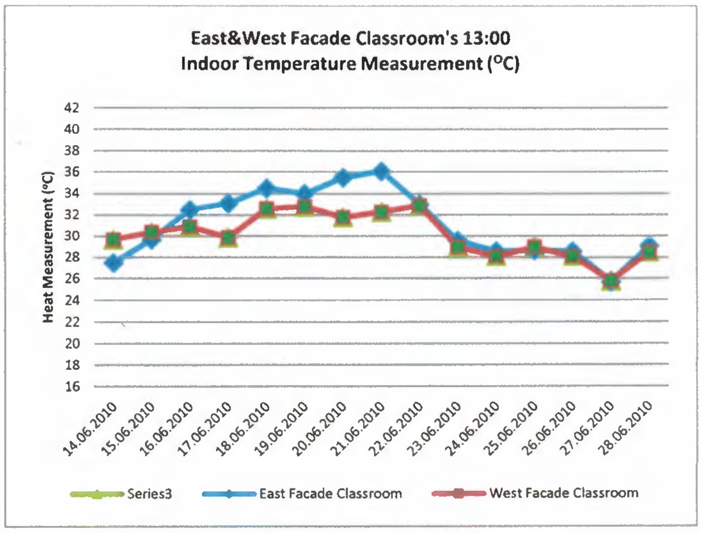


Plate 104. East and West Facade Classroom's 13:00 Indoor Temperature Measurement (^{O}C)

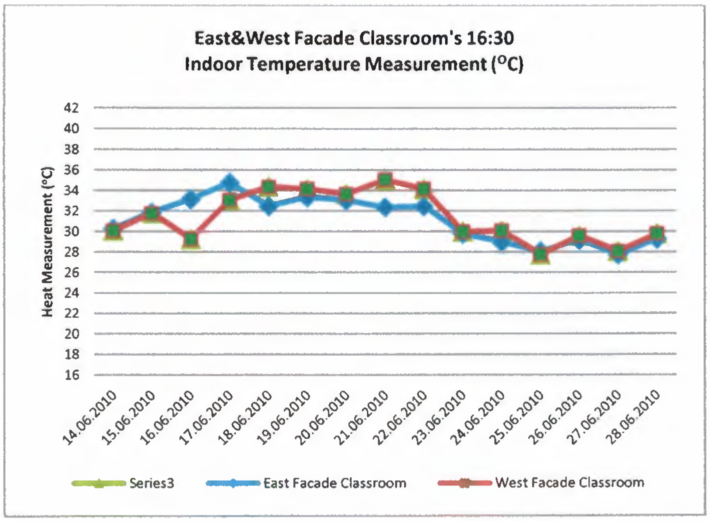


Plate 105. East and West Facade Classroom's 16:30 Indoor Temperature Measurement (^{O}C)

OUTDOOR MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

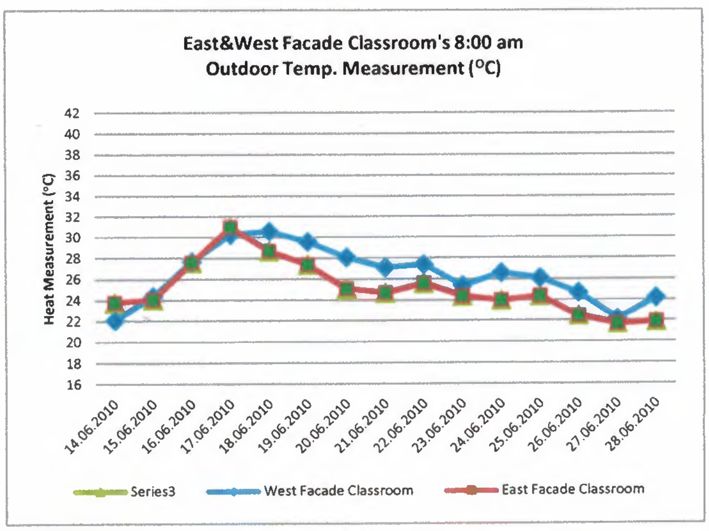


Plate 106. East and West Facade Classroom's 8:00 am Outdoor Temp. Measurement (^{O}C)

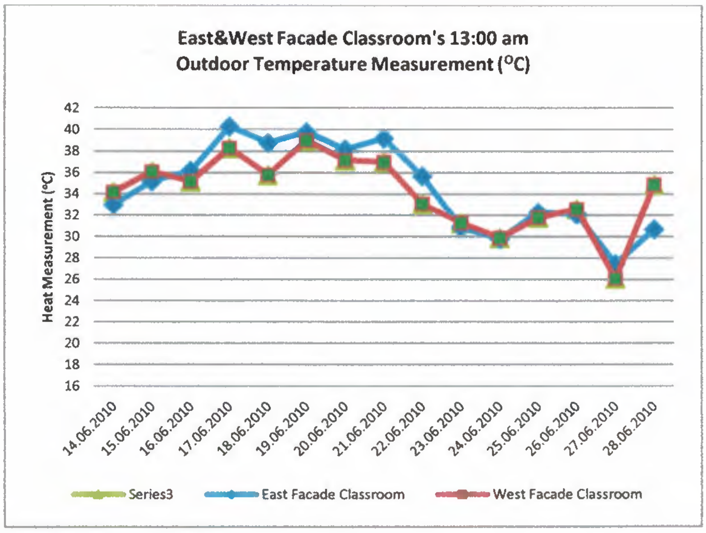


Plate 107. East and West Facade Classroom's 13:00 Outdoor Temperature Measurement (^{O}C)

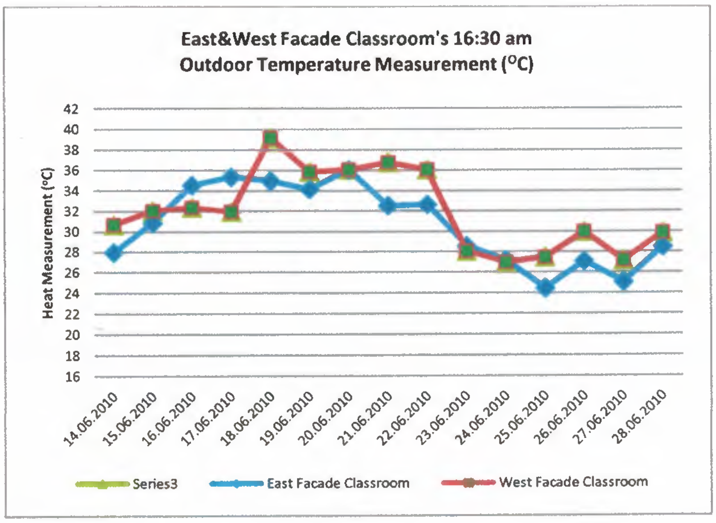


Plate 108. East and West Facade Classroom's 16:30 Outdoor Temperature Measurement (^{O}C)

INDOOR HUMIDITY MEASUREMENT GRAPHICS – EAST and WEST FAÇADE:

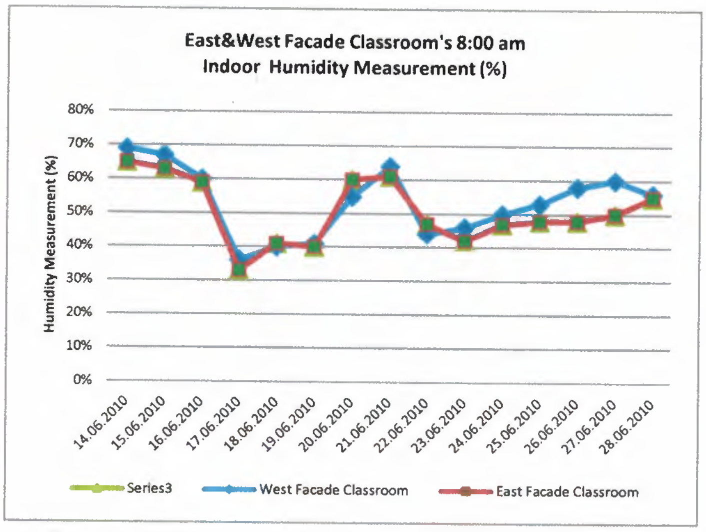


Plate 109. East and West Facade Classroom's 8:00 am Indoor Humidity Measurement (%)

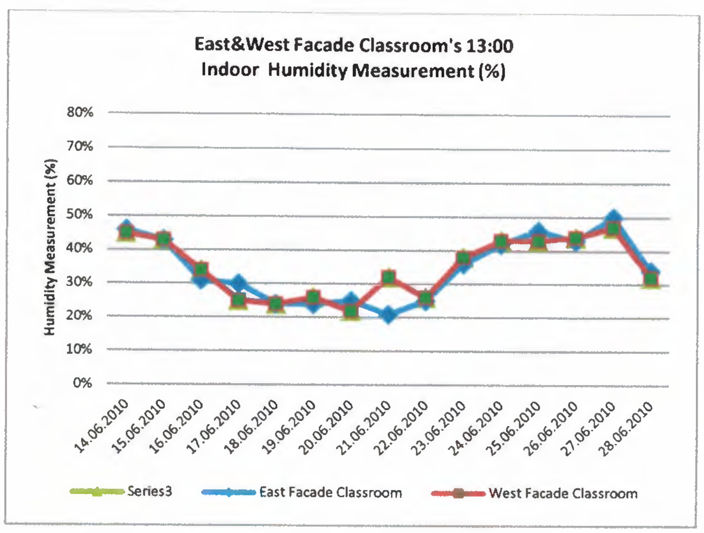


Plate 110. East and West Facade Classroom's 13:00 Indoor Humidity Measurement (%)

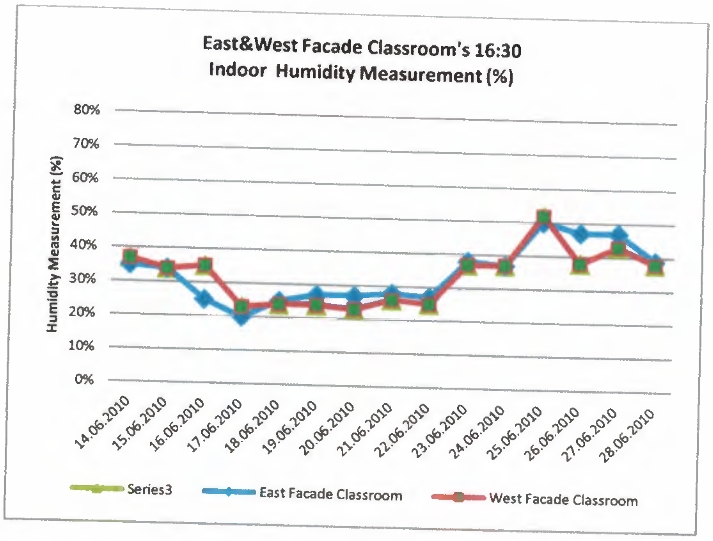


Plate 111. East and West Facade Classroom's 16:30 Indoor Humidity Measurement (%)

AVERAGE GRAPHICS – EAST and WEST FAÇADE:

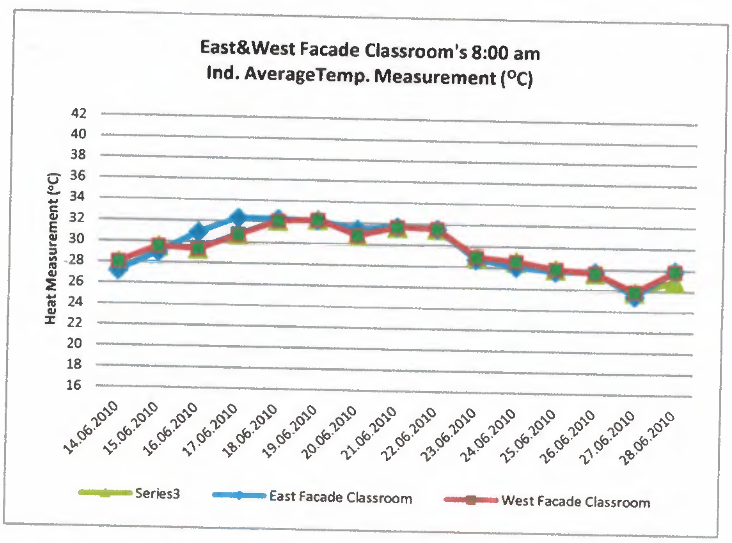


Plate 112. East and West Facade Classroom's 8:00 am Ind. AverageTemp. Measurement (^{O}C)

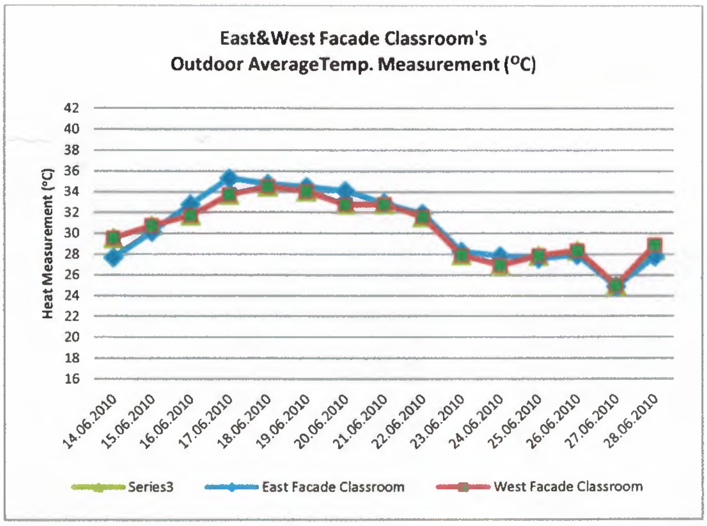


Plate 113. East and West Facade Classroom's Outdoor AverageTemp. Measurement (^{O}C)

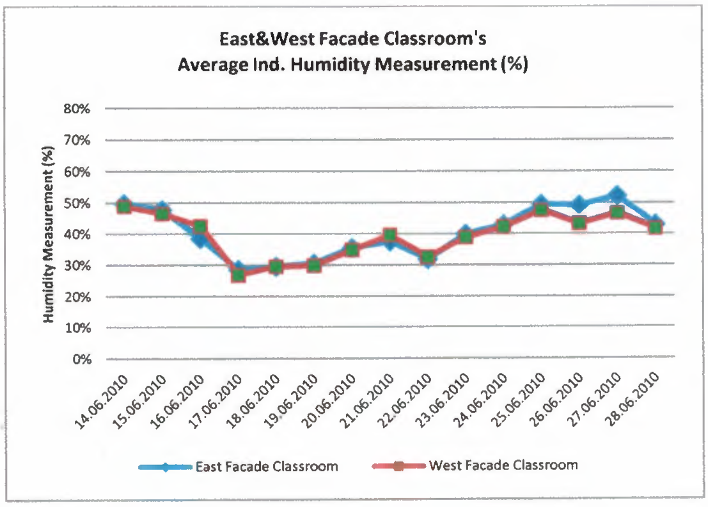


Plate 114. East and West Facade Classroom's Average Ind. Humidity Measurement (%)

III. Technical Specifications Of Hama Electronic Weather Station

Plate 115. Hama Electronic Weather Station

- Two-part set, consisting of a base station and a wireless outdoor sensor (range: max. 30 m; 433 MHz), for digital meteorological observation and to display the time, weekday and date
- LCD display with illumination
- Max. three wireless outdoor sensors can be connected
- For wall mounting or free-standing
- Low battery indicator
- Batteries (2x AA Mignon; 2x AAA Micro) not included in the delivery package

- Thermometer:
- Measuring range, inside: 0°C to +50°C
- Measuring range, outside: -50°C to +70°C
- The temperature can be displayed in °C or Fahrenheit
- Max./min. data memory for indoor and outdoor temperature
- Temperature alarm (max./min.)

- Barometer:
- Weather forecast with symbols (sunny, slightly cloudy, cloudy, rainy)

- Hygrometer:
- Air humidity, inside: 20% to 99%

- Clock/calendar function:

- Time (12h or 24h format can be selected)
- Date and weekday display (8 different languages)

- Additional functions:
- Moon phase display

Technical Details:

- Additional Function:	Moon-phase display
- Colour:	Yellow
- Colour Display:	No
- DCF Radio Clock:	No
- Hygrometer:	Yes
- Measurement Range (inside):	0°C up to +50°C (32°F up to 122°F)
- Measurement Range (outside):	-50°C up to +70°C
- Outside Sensor:	Yes
- Weather Forecast:	Yes
- Number of Batteries Outside Sensor:	2
- Number of Batteries Station:	2
- Type of Battery Outside Sensor:	Micro AAA
- Type of Battery Station:	Micro AAA

Technical details:

Outside Sensor:	Yes
Colour Display:	No
Colour:	Yellow
DCF Radio Clock:	No
Weather Forecast:	Yes
Additional Function:	Moon-phase display
Measurement Range (outside):	-50°C up to +70°C
Measurement Range (inside):	0°C up to +50°C (32°F up to 122°F)
Hygrometer:	Yes
Number of Batteries Station:	2
Type of Battery Outside Sensor:	Micro AAA
Type of Battery Station:	Micro AAA
Number of Batteries Outside Sensor:	2