ECOLOGICAL ECONOMICAL HOUSING

by

MARIAN AZMY NESSIM

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
ARCHITECTURE
ENVIRONMENTAL PLANNING AND DESIGN

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Under the Supervision of

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ARABIC SUMMARY
ABSTRACT

In the last three decades, the whole world has become more and more conscious about the environment and the changes occurring in climate and in the earth in general, and started to pay more attention to the impact of the technological and industrial revolution on the ecology and human health which resulted in directing all the new researches towards clean and renewable energies and recycling materials, in brief, it directed architects to start using eco friendly building materials and construction systems, natural ventilation and lighting …etc, and we started to hear terms like energy efficient, sustainable, environmental and ecological buildings, those types of buildings already exist now in Europe, U.S.A, Japan and other big industrial countries because the world started to realize the danger that is heading towards us if we don’t stop harming the earth and that the eco friendly buildings are one of those ways to preserve the earth for the next generations. And for most of us, our homes represent the biggest investment we ever make; so it probably comes as a shock when we realize that the home today can be a very uncaring place- uncaring for us, and uncaring of the environment. Our homes can damage our health, the air we breathe, and the water we drink without our even being aware of it. “Home” doesn’t stop at the front door: it affects, and is affected by, its surroundings.

So, if we take a look at Egypt, we’ll find that we’ve always built eco friendly houses till we started to import western techniques in construction and ventilation and lighting …etc, without adapting those techniques to our climate and available raw building materials and other factors and so Egypt is way beyond how the world is building its towns and houses today.

This thesis is concerned with ecological housing due to its importance and low cost housing due to its demand, it discusses the ecological principles that are applied today and on the other side presents the Egyptian experience in low cost housing and evaluates it in terms of the ecological principles stated previously.

In the end the thesis presents guide lines for architects to help them through the way starting from site selection up till construction techniques used in order to achieve the eco-eco house or the ecological economical house which will be the contribution of the architects to preserve the earth and minimize harming its resources and creating, healthy comfortable and affordable houses for the people.
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ABREVIATIONS

\[ R_{si} \] : Thermal resistance of inside surface
\[ R_{so} \] : Thermal resistance of outside surface
\[ SC \] : Shading coefficient
\[ SGR \] : Shaded glass ratio
\[ SGR \] : Solar gain ratio
\[ SHGC \] : Solar heat gain coefficient
\[ U-\text{Factor} \] : Thermal transmittance
\[ VT \] : Visible light transmitted
\[ WWR \] : Window wall ratio
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CHAPTER 1

INTRODUCTION
1.1 What is an Eco house?

Eco architecture sees buildings as part of the larger ecology of the planet and the building as part of the habitat. Eco in eco-house implies a certain ecologically conscious behavior of people in their dwellings, the near by plots, the habitations of the whole environment. To provide a sustainable equilibrium in such a system it is necessary to achieve harmony between artificial human created and natural environment. The eco-house concept promotes transition form prodigal consumption of natural resources to the use of renewable and nature rehabilitating operational methods. Ecological design is design that makes use of resources that come from earth in such a way that they can be returned back to the earth without causing harm, in a cycle that echoes the natural systems of living things. In eco design, it’s how everything works together that really matters.

1.2 Why bother making buildings connect in this way?

Because the alternative is not acceptable and modern buildings are literally destroying the planet. Buildings are the single most damaging polluters on the planet, consuming over half of all the energy used in developed countries and producing over half of all climate change gases. The shift towards green design began in the 1970s and was a pragmatic response to higher oil prices. It was then that the first of the oil shocks, in 1973, sent fossil fuel prices sky high and the "futurologists" began to look at the life history of fossil fuels on the planet and make claims about how much oil and gas were left. It is now estimated that we have left around 40 years of conventional oil reserves and 65 years of gas, at current rates of extraction. The oil crises of the 1970s resulted in the rise of the solar house movement. Homes built to use clean renewable energy from the sun. Two such houses can be seen in the case studies in Kentucky and Tokyo. These houses used passive solar and solar hot water systems with rock bed and ground storage systems to store heat between the seasons. Such innovative houses provided the foundations on which were

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4 Roaf, op cit, pp.1
developed the blueprints for the eco houses of the twenty-first century. In the 1980s came the next big shock - climate change. It was then that the rates of depletion in the ozone layer and the increase in the greenhouse gases and the global warming became apparent. The predictions made by the intergovernmental panel on climate change in 1990 have been borne out by the steadily increasing global temperatures over the 1990s, the hottest decade on record\(^5\). The main greenhouse gas is CO\(_2\) and the main source of CO\(_2\) is buildings. If we continue to produce greenhouse gases at current rates of increase, predictions by the UK Meteorological office indicate impacts will be substantial and by 2080 will include:

- A rise in global average temperatures of 3deg C.
- Substantial die back of tropical forests and grass lands.
- Substantial overall decrease in rain fall amounts in Australia, India, Southern Africa and most of South America, Europe and the Middle East.
- Sea levels will be about 40cm higher than present with an estimated increase in the annual number of people flooded.
- Health impacts will be wide spread and diverse, greater number of people will be at risk from malaria. Skin cancer rates will soar due to UV-B radiation.
- In America, in 1935 the chances of getting skin cancer were 1 in 1500, in 2000 chances are 1 in 75.

We must now reduce CO\(_2\) emissions globally and that one of the most effective sectors from which to achieve rapid reductions in emissions are buildings. Houses consume around half of all the energy used in buildings. In order to stabilize climate change will have to introduce cuts in all CO\(_2\) emissions of around 60%. This means using 60% less energy to run the home. This is actually not too difficult, as demonstrated in many eco houses. For instance, the Oxford eco house emits around 140 kg CO\(_2\) per year while other, similar sized houses in Oxford will produce around 6500 kg CO\(_2\)/ year. This is because the Oxford eco house is run largely using renewable solar energy. This demonstrates how important solar technologies are for the "Low carbon life style". Air conditioning systems represent the greatest source of climate change gases of any single technology. The world needs a new profession of ecotects, who can design passive buildings that use minimal

\(^5\) Roaf, *op cit*, pp.5
energy and what energy they do use comes from renewable sources if possible.
The sooner we start to change architecture, from an appearance driven process to a
performance-driven art, the better prepared we will be to lay the building foundations of
the post-fossil fuel age. The best place to start learning is with an eco house⁶.

1.3 Brief background of economical housing in Egypt

The state started to be involved in housing projects in 1932 when it constructed 62
housing unit in three buildings at El Kasr Einy street in Cairo as a labor housing. In 1954
started its actual involvement of the state in the housing field and gave special attention to
low income housing (الإسكان الشعبي) in order to face the increasing demand on housing units
-especially in Cairo and Alexandria), this was according to the available potentialities.
Hence, a great no. of housing projects were made all over the cities of Egypt. In this year,
the company of Urban and Common Housing development company (شركة التعمير و المصايد
الشعبيه) was formed and built few houses of small heights for low income category in
Imbaba and Zytoun. The state did not start implementing a housing strategy except in
1960 which was the first year of the first five years strategy. Eighty nine housing unit
were specified for rural housing and 60 % of them were for economical housing⁷. As soon
as the war of October 1973 ended, a new ministry evolved with the name of ministry of
development, its goal was to accelerate the development of canal cities. The change that
occurred to the society in this era had it apparent and clear impact on the housing problem
in Egypt, so we find that the renting system disappeared and the ownership system
appeared, this system spread in the late seventies and up till now. Followed this huge
increase in building costs, where it raised the cost of one meter square from 10 - 12 L.E
through out the sixties to 100 L.E in the late seventies (excluding land cost and infra
structure). This led to the exclusion of the middle and low income categories of people
from the new housing market, which directed the government to the co-operative
movement for housing construction, several corporations were formed which made the
ministry of housing form a special organization by the name of "building corporations" in
order to facilitate the job for those corporations and supervise them. In the eighties, the

⁶ Roaf, op cit, pp.7-10
⁷ رسالة ماجستير: رويجه حشا كامل،1992، "المماج الإسكان منخفض التكاليف كمدخل لحل مشكلة اسكان ذوى الدخل المحدود في مصر، تقييم المفاهيم و
التطبيق، قسم عمار، كلية الهندسة، جامعة القاهرة، ص 545.
ministry of housing redeveloped the low income housing prototypes which came out as a serious and direct trial in order to decrease the building cost, its main concept depended on creating the required residential area with the least cost possible, but the out come of this trial had negative side effects due to the concentration of its concept on the economic aspect of the structure and disregarding several criteria in the design process such as:

- The beauty touch, we can notice that the out come buildings were deserted from any beauty touch.
- The environmental and ecological aspects were totally neglected\(^8\).

In the nineties, came out a huge housing project by the name of "Mubarak housing project" for youth, in this project the first criteria was successfully implemented but the second criteria, according to the criteria explained below in this thesis, was not implemented, this is where I was interested to run my research in order to come out with a design guide that could be of an aid to the architect while designing the low income housing prototypes.

### 1.4 Benefits of the Eco-Eco House

The benefits are measurable in terms of:

1. Environmental
2. Economical
3. Social impacts

- The environmental benefits derived from reducing the buildings negative impact on the environment.
- The economical benefits come from reduced operating costs and improved occupant performance.
- The social benefits derived from the improved health and comfort of the occupants which comes from using natural light, fresh air, greater reliance on passive heating and cooling which create an environment in tune with biological rhythm houses that feel like a third skin. This benefit encourages an innate feeling of well being and comfort.
- Eco design promotes a better style of life in the fullest sense of the term\(^9\).

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\(^8\) بحث: م. منى اليسوني، (1996) "تطوير مفهوم المسكن الإقتصادي و الهدف من انشاهه"، وزارة الدولة للمجتمعات العمرانية، ص. 7-3

\(^9\)
RESEARCH PROBLEM
A great stock of low cost houses were built in the last 2-3 decades but through observation none of them adopted the principles of eco house design which resulted in a poor product that had a bad impact on its occupants' health and on the environment. Through research, it has been discovered that most of the researches handled each aspect on its own, the economical aspect separately and the ecological aspect separately, but none of them brought the two aspects together.

OBJECTIVES
Objective of this research are as follows:

- Reach a checklist which could help the designers and the decision makers throughout the different phases of the project, this checklist will include the cost factor which is evaluated through cost effectiveness modules.
- Draw a wide picture in front of architects to take into consideration while designing houses for people.
- Unite eco house design principles with low cost housing.

HYPOTHESIS
If we handled both the ecological and economical aspects and brought them together we should reach what is called the “Eco- Eco House” or the ecological economical house, which will be a healthy, comfortable, and energy efficient house that will also be environmentally friendly and an affordable house.

METHODOLOGY
The methodology of this thesis adopted the following methods to reach its objectives: Investigation – Invention – Analysis - Comparative Analysis. Where, it tried to verify the truth of the hypothesis by studying the Egyptian experience in low cost housing and deducing the different approaches that are adopted to reduce costs. Then those approaches are evaluated in terms of their impact on indoor and outdoor environment in the light of the Eco-housing design principles that are stated in the first two chapters. The thesis also tried to benefit from the international and local experiences towards the eco-house and how they participated in implementing its principles. In the end the research is concluded with a cost analysis chart and recommendations.

*Wilhide, *op cit*, pp.12
CHAPTER 1
INTRODUCTION
- What is an eco house
- Benefits of the eco house
- Research skeleton
- Research methodology

Research Objectives and Methodology

CHAPTER 2
ECO-HOUSE DESIGN PRINCIPLES FOR HEALTHY INDOOR ENVIRONMENT
- Providing healthy living conditions by controlling: Materials-inhabitants’ activities and lifestyles-outdoor pollutants
- Providing thermal comfort
- Providing energy efficiency through:
  - Shelter design
  - Building envelope
  - Housing layout

Eco-house design principles concerning indoor environment

CHAPTER 3
ECO-HOUSE DESIGN PRINCIPLES FOR OUTDOOR ENVIRONMENTAL PROTECTION
- Use of low embodied energy materials and minimal environmental effect
- Use of recyclable and renewable materials

Eco-house design principles concerning outdoor environment
CHAPTER 4
EVALUATION OF LOW COST HOUSING IN EGYPT FROM AN ECOLOGICAL PERSPECTIVE

- The Egyptian experience in low cost housing
- Impact of economical design factors on ecological efficiency
- Impact of construction factors on ecological efficiency

Eco-Eco factors for design and construction

CHAPTER 5
INTERNATIONAL AND LOCAL EXPERIENCES TOWARDS ECO HOUSING

- International Experience
- Local experience:
  - Prototypes for eco-houses
  - Egypt’s map of available raw building material and its industries
  - New types of building bricks

International and local participation in implementing the eco-eco house

CHAPTER 6
ESTABLISHMENT OF COST ANALYSIS SYSTEM FOR ECO-HOUSE DESIGN

- An integrated approach to achieve trade off between ecological and economical aspects of housing design
- Cost effectiveness modules for ecological measures
- Specific technical recommendations

Cost analysis chart and recommendations
Principles of Eco-house design

Setting Eco-house design principles concerning indoor environment

- Checking out the sites for contaminants
- Avoiding materials that cause sick building syndromes
- Controlling inhabitants’ activities and life styles

Determining the climate control strategies to obtain the thermal comfort required

- Selecting house type
- Applying orientation
- Integrating cooling systems
- Deciding dwelling form and volume
- Choosing color
- Setting ceiling height
- Utilizing roof and wall insulation
- Employing natural ventilation
- Selecting energy efficient windows
- Using shading devices
- Selecting site location
- Designing town structure
- Utilizing public spaces
- Using landscape and planting

Principles of eco-house design for indoor environment but to complete the principles of eco-house in general we need to also set the principles for eco-house design concerning the outdoor environment which leads to the next part

Setting Eco-house design principles concerning outdoor environment

- Using low embodied energy materials and minimal environmental effect
- Utilizing recyclable and renewable materials
- Integrating eco gardening and landscape through:
  Working with nature - gray water systems –

Principles of eco-house design concerning outdoor environmental protection, but since this thesis is concerned with low cost housing too therefore an evaluation of low cost housing in Egypt based on previous principles will take place in the next part
Setting economical factors for design and construction

- Reviewing the Egyptian experience in low cost housing
- Listing the economical design factors for low cost housing and evaluating them from ecological perspective
- Listing the economical construction systems for low cost housing and evaluating them from ecological perspective

Eco - eco design factors and eco - eco construction systems for low cost housing in Egypt, and in order to benefit from the accomplishments made in this topic on both International and Local sides, the coming part was created

International and local participation in implementing the eco-eco house

- Reviewing International case studies
- Reviewing Local case studies
- Stating the steps made by Egypt towards achieving an eco-eco house such as:
  - Creating Egypt’s map for raw building materials
  - Manufacturing new types of building bricks
  - Publishing Egypt’s residential energy

Case studies to learn from and local tools to use in order to help realize the goal which is the checklist represented in the last part of the thesis

Cost analysis chart and recommendations
CHAPTER 2

ECO-HOUSE DESIGN PRINCIPLES FOR HEALTHY INDOOR ENVIRONMENT
Aim of this chapter is to discuss the design tools and know-how relevant to the principles of the eco-house dealing with human health, thermal comfort and efficient use of energy. And so therefore this chapter is concerned with the following

1) Providing healthy living conditions
Healthy living environment could be achieved by providing good indoor air quality.

2) Thermal comfort
A positive definition of comfort is "a feeling of well-being." However, the more common experience of thermal comfort is a lack of discomfort or being unconscious of how we are losing heat to our environment.

3) Energy efficiency
The purpose of climatic design is to minimize the energy cost of maintaining thermal comfort conditions within building interiors.
Both, healthy living conditions and energy efficiency could be achieved through a set of integrated design factors and principles controlling indoor environment in relation to outdoor climate.
Those design factors could be categorized in three main categories:
- Shelter design
- Building envelope
- Housing layout

This chapter will discuss the three parts consecutively
2.1 PROVIDING HEALTHY LIVING CONDITIONS

Increasing attention to indoor air quality has contributed to the awareness of poor health associated with a poor indoor environment.

Two types of illnesses related to poor indoor air quality have been identified:
- Sick building syndrome (SBS)
- Building related illness (BRI)

**Definition of Sick building syndrome:**
It is a situation in which occupants of a building experience acute health effects that seem to be linked to time spent in a building.
Symptoms of SBS include irritation of sensory organs (eyes, nose, throat, ears, and skin)

**Definition of Building-related illness:**
A specific, recognized disease entity caused by some known agents that can be identified clinically. Symptoms of BRI include hypersensitivity pneumonitis, humidifier fever, asthma, and legionella.
The distinction between SBS and BRI is whether the causes of the sickness can be diagnosed clinically.\(^\text{10}\)

The Environmental Protection Agency (EPA) considers indoor air pollution among the top five environmental risks to public health and has estimated that it costs $2 billion in medical costs and lost productivity every year.

The sources of pollutants that impact Indoor Air Quality (IAQ) can be classified into three main categories:
- Materials
- Inhabitant’s activities and life styles
- Outdoor pollutants\(^\text{11}\)

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\(^\text{10}\) Zhang, Y.,(2005),"INDOOR AIR QUALITY ENGINEERING", pp. 5, CRC Press, USA
\(^\text{11}\) ASHRAE TRANSACTIONS,(2004-Part 2),"Indoor Air Quality of an Energy –Efficient, Healthy House with Mechanically Induced Fresh Air",P.77
But before going through the sources of pollutants, the site on which the house will be built should be checked out for contaminants such as:

- **Toxic and biological waste**
  Biological materials, dangerous chemical wastes (including military) heavy metals and other dangerous substances are found in soils buried deep into the earth. Detailed investigations of such substances are also critical for the healthy positioning of any building, no matter what its use, and for the determination of measures necessary for removal of the noxious contaminant, for protection of those undertaking the removal, and to find ways and means of disposal. Certain species of reeds have been developed as a cheap and effective method to clean industrial waste land of toxic chemicals. Instead of removing toxic earth to be buried in someone else's backyard, a strain of reeds known as phragmites are grown. These reeds absorb oxygen through their pores above ground in air and transport it to the roots zone where it enters the surrounding soil and provides hydraulic pathway. This simple system, which looks like a stretch of marshland, extracts nitrates, phosphates, phenols, hydrocarbons, mineral waste and harmful bacteria. The system is working well in a number of European countries.

- **Radiation**
  Electromagnetic field forces are powerful and can damage our health. The designers of distribution systems must begin to seek ways of reducing that damage, perhaps by putting the transmission cables within special ducts within the earth.\(^\text{12}\)
  To minimize the effects, building should be located well away from transformers, overhead electric railway lines and power transmission lines. Spur cables and electrical services in metal ducts should be screened with thick loam or clay, and routed around areas where the daily occupancy is at minimum. There should be a distance of at least 1000 mm of electrical cables from water pipes, sleeping and sedentary working positions.

• **Noise and vibration**

Street noise can reach 90 dBA, causing heart stress. As soon as the decibel volume exceeds 80 dB the blood pressure starts to rise; the stomach and the intestine operate more slowly, the pupils of the eye become larger and the skin becomes paler.

Children in particular can suffer from high blood pressure due to high noise inputs, with resultant difficulty in coping with arithmetic and solving problems.

A number of methods are used to deflect and absorb noise.

One is the way in which we construct our buildings; the other is the use of barriers.

Concrete is used as a mass material to deflect and stop noise penetration.

The use of other materials such as clay loam, impacted between lightweight walls, and turf roofs on houses, and constructing small buildings are beneficial ways of absorbing noise and at the same time protecting the inhabitants from other pollutants such as radon penetration and electromagnetic field forces.

Noise barriers, earth beams and protective belts of trees answers being proposed and erected in many cities and towns. Protective belts of trees forming thick forest areas not only provide a sustainable product, but also can be irrigated by waste water\(^{13}\).

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\(^{13}\) *Ibid*, pp.71-72
The sources of pollutants that impact Indoor Air Quality (IAQ) are:

2.1.1 MATERIALS

2.1.1.A Asbestos
Asbestos causes lung cancer and mesothelioma (rare tumors) of the lungs, chest and abdomen. Asbestos comes in three forms:
1. White: In board or sheeting products, surface treatment or as thermal and acoustic insulation.
2. Brown: In laminated boards and pipe lagging.
3. Blue: In fire insulation on steel frames or thermal insulation to heating systems.
So avoid this material completely14.

2.1.1.B Formaldehyde
Many wood based panel products are with glues that give off formaldehyde, especially when new. In addition, urea-formaldehyde foam (UFF) insulation in the wall cavities may be a source of formaldehyde vapor. This is a colorless gas with a pungent odor. Low concentrations of the gas may irritate eyes, nose and throat, possibly causing running eyes, sneezing and coughing15. It may cause nose bleeds. Suspected carcinogen. Chronic exposure to UFFI vapours causes depression and triggers chemical sensitivity16. These products are widely used in the home for flooring, shelving and kit furniture. Ways of avoiding this substance include:
1. Use blown mineral fibers or expanded polystyrene beads for cavity-fill insulation rather than UFF.
2. Make sure there is no possible leakage through cracks or holes into the house from cavities filled with UFF.
3. Repair any damp patches in walls adjacent to UFF-filled cavity or material17.

14 Roaf, op cit, pp.143
15 Ibid, pp.153
17 Roaf, op cit, pp.153
2.1.1.C Lead
Lead is a poison. Avoid it. Remove all lead pipes from the home. Most house paints & primers dating from before World War 1 are likely to contain lead. Lead paint is most dangerous when it is broken and flaking. Either paint over it with modern non-lead-based paint to seal it or strip it completely\(^\text{18}\). Lead can damage the brain and the nerve tissues\(^\text{19}\).

2.1.1.D Mineral Wool
A high degree of exposure to mineral wool can lead to irritation of the upper respiratory tract but this is not considered to be a long term health risk, although many countries have legislation that specifies maximum permitted exposure levels. In the home, rock and glass wools are used for insulating loft and wall cavities. Mineral fibers are also compressed into bats or boards, pipe insulation and roof tiles. The main thing to avoid is the inhalation of the mineral wool fibers and this can be achieved with a little common sense, not allowing cracks in the construction where the fibers can infiltrate a room, such as through down-lighters or around pipes. Care should be taken not to disturb the fibers during maintenance.

2.1.1.E Legionella
Legionella pneumophila is a bacterium found in all natural fresh water where it poses little threat to health. In buildings’ water systems it grows into high concentrations and can be dangerous when inhaled in droplets of water from sprays as found in showers, hot & cold taps and ventilation and air-conditioning systems.\(^\text{18}\)

When inhaled it gives rise to legionnaires’ disease, which is a type of pneumonia that typically causes death in one in ten of those who contract it. Legionella grows best in stagnant water at temperature between 20 – 50 °C with an optimum of 30-40 °C. Organic material in the system also enhances growth rates. Thermostats in water tanks should be set to 55 °C or be regularly flushed with water above this temperature. The bacterium will not grow significantly at temperatures below 20 °C. Lipped, fitted lids should be placed securely over water tanks. Domestic systems are less of a problem as

\(^\text{18}\) Ibid, pp.153
\(^\text{19}\) Pearson, \textit{op cit}, pp.51
they have a regular turn over of water. Spa baths and Jacuzzis should be drained and cleaned daily, with a strainer removed and cleaned at the same time.

2.1.1.F Moulds
There are two kinds of moulds:

- Moulds that cause illness
- Moulds that cure illness such as penicillin

For moulds to grow, it needs moisture, warm temperature, low air movement, and a food source\(^\text{20}\). Mould feeds on the organic materials of a building such as carpets, wood and wallpaper and eats into wallboard and brickwork.

Mould can be very toxic, leading to allergies; “sick building syndrome” and even death, can result from exposure to high concentrations of some moulds that grow on wet building materials.

But where do we find hidden mould? The answer is simple: where the water is.

So, the design advices that could be given are:

- Eliminate cold bridges in the external and internal walls so that there are no patches of cold wall on which moisture will condense and mould will develop.
- Remove moisture in the home with good zoning of wet activities and a range of good opening windows and vents and repair any cracks in the structure.
- Have moisture absorbing walls such as a plaster finish with a water-based eco-paint finish which can cope with a little internal room air moisture without causing moisture to collect\(^\text{21}\).

2.1.1.G Paints

Paints affect health in two main ways: they can be toxic and they can exacerbate humidity problems in a room. A good paint breathes and allows the wall to breathe. It is permeable to air and moisture movement and it allows moisture in the wall, plaster, render and/or joints behind it to evaporate out. The great advantage of a breathing paint is that it reduces the moisture build up in a room that can be a major source of health problems. Many

\(^{20}\) Zhang, *op cit*, pp. 29

\(^{21}\) Roaf, *op cit*, pp.153-159
modern acrylic paints trap moisture in the wall and also impede the movement of the heat between the room air and the wall. Traditional paints with a lime base allow the wall to breathe. Be careful when applying lime washes because lime is caustic substance. Some of the new water-based eco-paints also perform very well. They are made from substances such as resins, water, pigments, opacifiers, waxes and water. They should not contain solvents, white spirits, turpentine, VOCs, heavy metals such as lead, cadmium or mercury, or formaldehyde. Check the content of the paint you are offered and if they contain such substances think again. Avoid any paints with chromium in them; it can cause dermatitis, ulceration and cancer. One of the most polluting products in paints is titanium dioxide. However, it is the most common of all paint colorings and it is very difficult to find a paint without it. Also be ware of the fire risk of different paint types.

2.1.1.H Plants in buildings
Studies have found that plants can indeed not only reduce the CO2 and the relative humidity of a room but also they can lower the temperature of the room. It is rather nice to think of putting a living machine in the form of plants into buildings to clean up the internal air quality.

2.1.1.I Plaster
Gypsum plaster applied wet or dry has excellent absorption and diffusion properties for heat and moisture. It must be natural gypsum, not phosphor-gypsum, which is radioactive. When using plasterboard, check that it does not contain adverse chemicals. Sand and lime plaster may also be used, possibly with a final coat of gypsum. Do not use cheaper cement-based plaster if possible as it is a poor insulator and is less permeable to heat and moisture. Mud plaster is also excellent and can be made more waterproof by mixing well-fired wood ash into the wet mix before kneading. It should be left for soaking and kneading for several days. Over all plasters an eco-paint should be used.

2.1.1.J Polyvinyl Chloride (PVC)
This polymer is widely used in construction and is known to be a carcinogen for animals and humans. In its early use, high levels of monomers were measured when the material
was stored but more recent development of technology has reduced their emissions substantially. The main concern is for the householder exposed to high levels of newly installed PVC in an airtight home for a long period of time. A number of fairly toxic substances are also combined with the PVC in the manufacture stage. Use timber windows if possible rather than PVC ones and avoid PVC furniture.\textsuperscript{22}

PVCs can cause birth defects, cancer, chronic bronchitis, and skin disease.\textsuperscript{23}

\subsection*{2.1.1.K Radon}

Radon is a naturally occurring radioactive gas that is tasteless, odorless and colorless. The amount of radon emitted into a home depends on the rocks on which the home is built and how much soil or other material covers the radon-emitting rocks. Sedimentary rocks, except for black shales and phosphate-rich rocks, are generally low in the uranium that emits the radon, and metamorphic rocks such as gneiss schist are richer in uranium than marble, slate or quartz.\textsuperscript{24}

Radon has three main routes into the house:
1. Groundwater pumped into wells
2. Construction materials such as blocks that emit radon
3. Gas that emanates up from the soil and rocks into basements and lower floors

It is not radon itself that poses the greatest threat to people, but the so-called radon-daughters. Radon decays through a succession of decay products, producing metallic ions. These decay products then attach themselves to particles suspended in the air. When inhaled, decay products rest in the respiratory tract, and present a risk of lung cancer. Some building materials are naturally more radioactive than others and the use of some forms of gypsum is already prohibited in Great Britain.

The major factors affecting the activity level are:
* The radioactivity of the building materials
* The proportion of the radon produced which diffuses into the room air
* The ventilation rate
* The rate at which the radon daughters are deposited

\textsuperscript{22} Ibid, pp.161-164
\textsuperscript{23} Pearson, \textit{op cit}, pp.49
\textsuperscript{24} Roaf , \textit{op cit}, pp. 164
As a means of prevention, the EPA and the Office of the Surgeon General recommend that all homes below the third floor be tested for radon. Because radon is invisible and odorless, a simple test is the only way to determine whether a home has high radon levels. In risk areas radon concentrations can be reduced by placing a perforated, impermeable membrane between the concrete lower floor slab and the ground, or a well ventilated crawl space beneath the floor. Sealing all cracks and openings into the basement will prevent the entry of radon into the house and the use of exhaust ventilation can remove any that does. Maximum permissible level (MPL) radon is 2 pci/liter or 75 Bq/m3.

Radon wells:
Radon wells are currently being used with success in Sweden, especially if installed where the building rests on a gravel outcrop. In a well 800 mm in diameter and 4 meters deep, a one-off installation reduced the radon daughter content of 15 four bed roomed houses to as little as 2-4 % of the original concentration. The total cost was the price of an expensive washing machine. The advantage of a radon well is that it takes up no space in the building; there is no irritating fan noise 25(Fig. 1).

2.1.1.L Volatile Organic compounds (VOCs) and Organic Solvents
VOCs are found in many everyday materials in the home, including carpets, under layers, adhesives, caulks, sealants, thermal insulation materials, paints, coatings, varnishes, vinyl flooring, plywood, wallpaper, bituminous emulsions and water-proof membranes. A wide range of VOCs can be emitted, including solvents or plasticizers used in the manufacturing of building products. As the weather gets hotter so the rates of emissions of VOCs increase. They can cause discomfort because of their smell and, worse, provide health hazards in the home and initiate symptoms of sick building syndrome.

25 Holdsworth, op cit, pp. 38-39
Organic solvents include white spirit, which is found in many household products such as cleaning fluids, varnishes, glues and paints. Dry cleaned clothes also contain very high levels of solvent residue, so air them outside if possible before wearing and keep those in nylon cover bag in the wardrobe. In large quantities organic solvents can cause dizziness and in smaller quantities they can exacerbate asthma problems. Avoid them by:

- Using water-based eco-paints and varnishes that do not contain ammonia
- If you are using glue, paint strippers or varnishes, open the windows wide and ventilate the rooms really well
- Keep only small quantities of them in the house
- If you have bedding dry cleaned, air it thoroughly before using.

2.1.1.M Wallpapers
If you must use them, choose wallpaper that is made of paper and not synthetic materials such as vinyl. If you paint over it make sure you choose an eco-paint that does not contain solvents, vinyl or fungicides.

2.1.1.N Wood Preservatives
Many different chemicals are used to protect wood from insect or fungal decay and many are potentially very harmful. They should be handled with care and contact with skin should be avoided. Any product for protecting buildings from woodworm should be applied only by an expert. Avoid their use in enclosed spaces and do not use rooms where a smell of the chemical product lingers. Avoid storing these chemicals in the house\textsuperscript{26}.

\textsuperscript{26} Roaf, op cit, pp.170-171
2.1.2 INHABITANT’S ACTIVITIES AND LIFESTYLES
Some of the indoor pollutants results from inhabitants activities and can be very harmful. Among these pollutants are the following:

2.1.2.A Carbon Dioxide
Carbon dioxide is not toxic except at high concentrations. It results from combustion of fuel. If CO₂ concentration increases to 1%, increase in the depth of breathing is noticed, it reaches the double at concentration of 3% of CO₂. At concentrations of 3-5 %, increased respiratory effects become uncomfortable and severe headaches may develop. A 30 minutes exposure to 5% CO₂ is reported to produce signs of intoxication and of mental depression. A CO₂ concentration of 0.5 % is normally taken as the upper limit when designing the ventilation of occupied space. The Environmental Protection Agency (EPA) recommends a maximum level of 1000ppm(1.8 gm/m3) for continuous CO₂ exposure. Opening a window or door is the most effective way of purging the room of CO₂ in a short time

2.1.2.B Carbon Monoxide
CO poisoning often results from blocked chimneys or flues, or improper venting of rooms. Symptoms of CO poisoning include, headaches, giddiness, drowsiness and nausea. To ensure that CO poisoning does not occur in your home:
- Have all your stoves, fires and appliances that burn fuel such as gas, coal, wood, etc., properly and regularly maintained.
- Avoid using flueless gas or paraffin heaters

2.1.2.C Tobacco Smoke
Major effects of passive smoking are odor and eye irritation. Suitable ventilation rate has to be applied to reduce smoking effect. Ventilation rate in Britain is 7 liter/s per smoker while in U.S.A it is 14 liter/s per smoker

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28 Roaf , op cit, pp.146
2.1.2.D Odors

Odor intensity depended strongly on the amount of space/person as well as the ventilation rate. A rule of thumb sometimes used by engineers is that body odors become objectionable when expiration raises the CO₂ level above 0.15%. For sedentary people, with a CO₂ output level of 5x10⁻³ liter/s per person, this would indicate a ventilation rate of about 3.5 liter/s per person\(^{30}\) (Fig. 2, Fig. 3).

Figure 2

The air supply necessary to maintain an acceptable dilution of body odors, after Yaglou (1936).
(Ref.: Mc INTYRE, op cit)

Figure 3

A comparison of Yaglou’s curve of acceptable body odor level and the ventilation rates recommended in the ASHRAE Guide. Each point represents the ventilation rate given for a different building type. The upper figure shows the normally recommended rates, and the lower figure the minimum rates for energy conservation-after Cain (1978)
(Ref.: Mc INTYRE, op cit)

\(^{29}\) Mc INTYRE., op cit, pp. 267
\(^{30}\) Ibid, pp.275-276
2.1.3 OUTDOOR POLLUTANTS

Dust, fumes, humidity and noise are among the main outdoor pollutants that can penetrate into indoor spaces and affect inhabitant health.

2.1.3.A Particulates
Air borne particulate matter is one of the major forms of outdoor air pollution. Dusts are small solid particles formed by the break down of material into fine particles. The most important individual disease is silicosis caused by inhalation of silicon dust and asbestosis by the inhalation of asbestos.

Some dusts and fumes when inhaled cause an acute inflammation of the lungs (pneumonitis). Some dust can cause the development of a cancer in the respiratory tract, notably the fiber of crocidolite (blue asbestos)\(^{31}\).

2.1.3.B Dust Mites
Dust mites are microscopic, spider like insects found everywhere. An adult dust mite is approximately 200 μm long and is usually invisible to the naked human eye (Fig. 4). Dust mites feed on dead skin that sloughs from our bodies. Many people develop severe allergies to dust mite droppings. Lie on a rug where they live and you may find itchy red bumps on your skin. Breathe in dust and you may have more serious symptoms, such as difficulty breathing or even a severe asthma attack. Dust mite allergy usually produces symptoms similar to pollen allergy and also can produce symptoms of asthma\(^ {32}\).

The best conditions for mite growth are temperatures of around 25 deg C with 80 % humidity. How to avoid them:

1. Lower the humidity in a room until it becomes too dry for the dust mites to survive. Put a good ventilation window above and/ or beside the cooker.
2. The first line of attack should be to remove their habitat, so out go the wall to wall carpets and curtain.
3. Beat rugs thoroughly\(^ {33}\).

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\(^{31}\) Ibid, pp.292-297

\(^{32}\) Zhang, *op cit*, pp. 29-30

\(^{33}\) Roaf, *op cit*, pp.148
2.1.3.C Humidity

**Electrostatic Effects:**
The risk of electromagnetic shocks increased sharply as the humidity fell below 40% for nearly all carpet materials. Maintaining humidity over 40% will reduce the risk of causing shocks.

**Humidity and Health:**
The reason given for the harmful effects of low RH is that it dries out the mucus in the nose. The mucus layer in the nose serves to trap foreign matter, including bacteria and viruses and prevent them from reaching the lungs. The mucus bed flows steadily to clear the contamination. However, humidification may not be the answer to everyone’s problems. Many people suffer from allergic rhinitis, where inhalation of house dust produces symptoms of sneezing and a running nose, which are similar to those of a cold.

The most important agent in producing this reaction is the faces and debris from the house dust mite. This mite inhabits mattresses, feeding on the skin scales shed by the human occupants of the bed; few mites are found in dust from other parts of the house. The concentration of mites depends strongly on the humidity, and very few are found below a vapor pressure of 11mb (45% RH at 20 deg C). Thus sufferers from allergic rhinitis are recommended to reduce the humidity in the bedroom.

**High humidity levels:**
The main reason for limiting humidity levels in buildings is to limit condensation and mould growth. It is generally held that if the relative humidity in a room exceeds 70% for long periods, say 12 hours a day or more, mould growth is possible\(^\text{34}\).

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\(^{34}\) Mc INTYRE., *op cit*, pp. 283-287
2.1.3.D Insufficient lighting

Sunlit is one of the most fundamental ingredients of life and living quality. Sufficient penetration of direct sunlight into interior spaces, constitutes one of the most critical aspects of any building particularly the residential ones. Through the penetration of infra red waves into living spaces, the effects of sunlight are set into motion. These long, heat carrying waves, have considerable possible effects on human health and contribute towards improvement in immune system capacity. The repetitive daily cycle of solar radiation and natural light have a significant influence on our comfort level, our moods and our activities. In recent years, through the development of visible light therapy as a way to treat seasonal depression, the relevance of the intensity of sunlight to hormone levels the body has been recognized. Tiredness, dry and gritty eyes and headaches can be caused by glare, flicker, lack of contrast, inadequate illumination or unsuitable spot lighting. Conventional white fluorescent lighting in particular is likely to cause eye strain and headaches (wilkins et al 1988) and should be replaced with non fluorescent lighting as much daylight as possible.

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35 HABITAT, op cit, pp.270
## Conclusion

Table (1) Comfort levels recommended by the Chartered Institution of Building Services Engineers (CIBSE 1986)\(^{36}\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommended level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (dry bulb)</td>
<td>19-23 deg C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>40-70%</td>
</tr>
<tr>
<td></td>
<td>More than 55%RH is needed in carpeted buildings with under floor heating to avoid electrostatic shocks.</td>
</tr>
<tr>
<td>Ventilation</td>
<td></td>
</tr>
<tr>
<td>Deliver of fresh air</td>
<td>8 litres /s per person (minimum)</td>
</tr>
<tr>
<td></td>
<td>16 litres /s per person where someone smoking</td>
</tr>
<tr>
<td></td>
<td>25 litres /s per person where heavy smoking</td>
</tr>
<tr>
<td>Total air supply</td>
<td>4-6 air changes per hour</td>
</tr>
<tr>
<td>Air speed</td>
<td>0.1-0.3 m/s.</td>
</tr>
<tr>
<td></td>
<td>Less than 0.1 m/sec causes stuffiness.</td>
</tr>
<tr>
<td></td>
<td>More than 0.3 m/sec causes draughts.</td>
</tr>
<tr>
<td></td>
<td>For air speeds higher than 0.1 m/sec CIBSE recommends an increase in air temperature to take account of air movement.</td>
</tr>
<tr>
<td>Sound</td>
<td>46 dBA is upper limit for general office work.</td>
</tr>
<tr>
<td>Lighting</td>
<td>500 lux for general office work.</td>
</tr>
</tbody>
</table>

And in order to achieve the above rates required for: temperature – humidity – ventilation …etc, architects should have know how of climatic design, which will eventually lead us to the thermal comfort in our homes where its definition is introduced in the coming part.

\(^{36}\) [http://www.lhc.org.uk/members/pubs/books/sbs/sbs04.htm](http://www.lhc.org.uk/members/pubs/books/sbs/sbs04.htm)
2.2 THERMAL COMFORT

Defining the thermal comfort according to ASHRAE (1989): "That condition of mind in which satisfaction is expressed with the thermal environment." Maintenance of thermal comfort is a problem of heat balance between the body and its surroundings.

The body exchanges heat with its environment through four processes:
1. Conduction (contact)
2. Conduction-convection (air movement)
3. Evaporation-convection of skin moisture
4. Radiation (solar and thermal)\(^\text{37}\).

Figure 5

There are three categories of factors that affect comfort:

- Personal
- Measurable environmental
- Psychological

Most personal factors are under our control because they depend on our metabolism and clothing. Measurable environmental factors are the familiar tools of the designer and engineer: air temperature, surface temperature, air motion and humidity.

Psychological factors are also familiar designers' tools, but they are harder to measure for comfort: color, texture, sound, light, movement and aroma. Ultimately, our buildings will be expected to demonstrate success with regard to the measurable environmental factors of comfort, so it is necessary to understand how air and surface temperature, air motion, and humidity are related to heat transfer.

<table>
<thead>
<tr>
<th>Heat transferred by</th>
<th>Is primarily dependent on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction</td>
<td>Surface temperature</td>
</tr>
<tr>
<td>Convection</td>
<td>Air temperature, then air motion, then humidity</td>
</tr>
<tr>
<td>Radiation</td>
<td>Surface temperature</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Humidity, air motion, air temperature</td>
</tr>
</tbody>
</table>

From this comparison, it is evident that humidity is of relatively low importance in cold conditions, where heat loss by conduction, convection, and radiation is dominant. But humidity is of primary importance in hot conditions, dominated by evaporative heat loss. This is further evident in comfort studies, which show that skin temperature is an important factor in cold conditions while skin wettedness (percent covered by water) is of most importance in hot conditions. Designers of building can aim for specific comfort goals, especially where the measurable environmental factors are concerned. This is where the "building bioclimatic chart" is introduced (Fig. 6). The bioclimatic chart was developed by Milne and Givoni (1979) to relate climate and design strategies. The average monthly data can be plotted here thus revealing some appropriate strategies. Although the edges of each strategy zone are shown as lines, these boundaries are much more broad and vague than such lines suggest.

Buildings usually contain sources of heat. The more heat occurs within the building, the more an artificially warmer climate is created. Thus, after plotting outdoor climate data on this chart, consider how shifting these plots would affect our choice of design strategy.

The more: solar gains allowed inside, electric lights, business machines, etc.
The more the plots move horizontally to the right.
The more: people, cooking, bathing, other heat-plus-moisture sources.
The more the plots move up and to the right, following the rh curves.

The design strategies shown in fig. 5 include the following:

- Active Solar Heating and Conventional Heating:
These are familiar heating methods that can concentrate heat (from burning fuel, a heat storage tank, electric resistance coils, etc.) on demand.
They are frequently used as backup heat to passive solar systems, as well as stand alone systems.
- **Passive Solar Heating:**
The collection and storage heat is integrated within the surfaces of the building. Large (optimum) areas of south-facing glass admit winter sun, which strikes surfaces of high thermal mass (brick, quarry tile, concrete, water containers, etc.). In colder climates, thermal shades or shutters protect the windows against night time heat loss.

- **Humidification:**
In this infrequently occurring zone, moisture should be added to indoor to avoid respiratory problems and to reduce static electricity. For the following cooling strategies, the exclusion of direct sun, by shading devices, is assumed.

- **High-Mass Cooling:**
This is an especially useful strategy in warm, dry climates, where the extremes of hot days are tempered by the still-cool thermal mass of the building. Cool nights slowly drain away the heat that such mass accumulates during the day. The thermal mass can be on floors, walls or roofs; the roof has the advantage of radiating to the cold night sky, but should, like all other thermal mass in these conditions, be protected from the sun by day. As in all these cooling strategies, daylighting is usually designed to occur without direct sun, since solar space heating is unneeded in these conditions.

- **High-Mass Cooling with Night Ventilation:**
This hot dry climate design strategy must use the air at comfortable night time temperatures to flush away the heat stored in daytime. The fewer the comfortable night hours, the more thermally massive surfaces must be provided to store the day's heat. Also, ventilation must occur more quickly and thoroughly, perhaps with fans. The building switches from a closed condition by day (to exclude sun and hot air) to an open one at night (to allow ventilation to cool the mass). Note: Night time outdoor temperatures should be cooler than the comfort zone, if this strategy is to be effective.
Natural Ventilation Cooling

This is the most obvious strategy suggested by the comfort charts presented earlier, where higher air temperatures were offset by increased air motion. It is most appropriate in more humid, hot climates where temperatures are only slightly lower by night than by day. Buildings should be very open to breezes while simultaneously closed to direct sun. They should be thermally light weight as well, since night air is not cool enough to remove stored daytime heat.

Evaporative Cooling

This design strategy relies on the principle that when moisture is added to air, the air increases in relative humidity while decreasing in dry-bulb air temperature. (On the bioclimatic chart, this pattern exactly follows the wet bulb line, upward to the left). In conditions that are more uncomfortably dry then uncomfortably hot, higher humidity is gladly exchanged for lower air temperature. However, large quantities of both water and outdoor air are needed; fan-driven evaporative coolers are the most common way to provide this kind of cooling.

Conventional Dehumidification and Air Conditioning:

These are familiar air conditioning methods, which rely on machinery and can cool on demand. Buildings utilizing such equipment should be very closed to both wind and direct sun. Thus, conventional air conditioners can be used as backup to passive systems, which imply closed buildings, such as high mass with night ventilation. Where evaporative coolers are used, conventional air conditioners can also be used to back up their cooling.

Ways of implementing the above mentioned cooling strategies will be discussed thoroughly in the coming part in order to achieve thermally comfort house and at the same time energy efficient.

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39 *Ibid*, pp. 44-46
2.3 ENERGY EFFICIENCY

Energy efficiency as well as healthy living conditions could only be achieved through the application of climatic design which is concerned with three main parts:
Shelter Design – Building Envelope – Housing Layout
So here are some guiding tools for these three main points:

2.3.1 SHELTER DESIGN

2.3.1.A HOUSE TYPES

• **Compact "patio" house type**
Is preferred: adjoining houses, row houses, and group arrangements (all continuous on E-W axis), which tend to create a volume effect, are advantageous\(^40\).

• **Courtyard conventional house type.**
The courtyard acts as a light well as well as an airshaft bringing both daylight and ventilation to the rooms around it.
Talib(1984) has described how the courtyard functions in 3 phases (Fig. 7):
• During the first phase, the cool night air descends into the courtyard and fills the surrounding rooms. Walls, roof, columns, floors, ceilings, even furniture are cooled at night and remains so until late afternoon. In addition, the courtyard loses heat rapidly by radiation to the clear night sky.
• During the second phase, at midday, the sun strikes the courtyard floor directly. Some of the cool air begins to rise and also leaks out of the surrounding rooms. This induces convection currents which may afford further comfort. The courtyard now begins to act as a chimney during this time when the outside temperatures are highest.
• During the third phase, the courtyard floor and the inside of the house get warmer

\(^{40}\) Olgay, V. (1963), "Design with climate, bioclimatic approach to architectural regionalism", pp. 167, Princeton University, New Gersey
and further convection currents are set up by late afternoon. Most of the cool air trapped within the rooms spills out by sunset. During the late afternoon the street, courtyard, and the building are further protected by shadows of adjacent structures. As the sunsets, the air temperature falls rapidly as the courtyard begins to radiate rapidly to the clear night sky. Cool air begins to descend into the courtyard, completing the cycle. The roof can be designed to enhance this courtyard cooling cycle. If the roof surrounding the courtyard is sloped towards the courtyard, as the roof cools by radiation at night, the layer of air above the roof is also cooled and drains into the courtyard displacing the warmer air (Fig. 8). In practice, this configuration is common in order to drain rain water into the court, collecting valuable moisture for evaporation. In addition to the radiative, convective and evaporative cooling processes that make the courtyard an effective design strategy in hot-arid climates, the additional aesthetic and psychological effect of this contained “oasis” should not be underestimated.\(^{41}\)

The advantages of earth-sheltered construction include reduced heating and cooling loads (due to reduced conductive and infiltrative transfer, and the potential for seasonal storage), the possibility of increasing the area of vegetation on the site (in the case of earth-covered roof), fire-resistive construction, greater acoustical privacy, reduced exterior surface area for maintaining, and reduced exterior visibility. Disadvantages include increased structural costs, expensive roof waterproofing systems that are inaccessible for repair, expensive moisture- and vermin-resistant rigid foam Insulation, humidity control necessary to prevent condensation in cool, humid climates, and the necessity for installing thermal breaks to prevent conductive heat losses through structural walls and roof.

To properly establish air circulation within the house, air may enter through a series of vertical tunnels in the walls of the structure which begin at the roof and lead down to the subterranean dwelling space, some of which are:

- **Wind roof catchers** with vertical surface openings of two, three, or four facets to catch air from or expel air to all possible directions. The ratio of the dimensions of the chimney opening should not exceed 2 to 1. In addition, the chimney should be straight, extending a minimum of 1 meter above the roof line, it should have no air leakage which would reduce air draft, and, of course, it should be built of non-corrosive materials. (Fig. 9, Fig 10)

- **Freely rotating**, curved and semi-circled lightweight catcher could be used, where; the catcher will rotate itself and force the wind to move forward into the shaft and to the house. The shaft with the air catcher should be high, a few meters above the roofs (Fig. 11).
Figure 9
An air circulation system which will reverse its flow as prevailing winds shift. (Ref.: Golany, G. S., (1983), "EARTH-SHELTERED HABITAT", VNR, N. Y.)

Figure 10
Four faceted roof and vertical-surface air catch for possible diurnal changes of wind direction (Ref.: ibid)

Figure 11
Rotating semicircular air catch which moves as the air moves (Ref.: ibid)
Such vertical tunnels will support movement downward through the chimney, but such movement can be insufficient and may bring warm air into the house. An additional system is necessary if we need a cooling air movement within the house. Any one of the following systems might be used to provide such results:

- **Wall Humidification:**
  In this system, moisture is dispersed throughout the structure's soil-surrounded walls. The water would move by capillary action from outer to inner walls and then humidify the hot air which is entering the interior space of the structure. Watering in this system must be carefully regulated and supplied only when necessary. The watered soil close to the structure's walls should also be covered paved or shaded to minimize evaporation. Water can be supplied externally from a water pipe extending around all the walls of the structure. (Fig. 12-A)

- **Drip Humidification:**
  In this system, regulated water drips from pipes built into the blocks, passes into the outer walls of the air tunnels of the blocks and moves by capillary action to the air passing through the tunnels. In this case (to distinguish it from wall humidification), the pipe is part of the prefabricated blocks (Fig. 12-B).

- **Drip Humidification through Tunnels:**
  A prefabricated terra-cotta tunnel is built into the wall. This air tunnel, if constructed of relatively thin materials, will be most effective in accelerating the evaporative cooling of the hot air passing through the tunnel. (Fig. 12-C)

- **Mist Humidification:**
  In this system the hot outside air is mixed with water mist when entering the air tunnel or opening. The air temperature will fall as a result of evaporative cooling before the humidified air enters the room (Fig.12-D). The density and temperature differentiation will force the air to move downward. This system seems to be the most effective and is easy to install.
The ventilation and evaporative-cooling concept introduced above is a passive system employing wind force and air density differences. It works simply through the appropriate orientation of tunnels and the strategic location of interior vents. There is no need for fans or blowers since the incoming air, now cooler due to humidity-induced density, will move down toward the floor and then, as it warms, will rise within the subterranean space as it is replaced by further incoming air. The location of the inlet and the outlet openings is therefore crucial. Small outlet openings at high levels will be necessary to support this ventilation and cooling method. Heating could also be a problem in the subterranean house. Passive heating could be by trapping the solar heat and storing it within insulated rock storage or water barrels or directly blowing the air into the house.\footnote{Golany, G. S., (1983),"EARTH-SHELTERED HABITAT", pp.88-98, VNR, N. Y.}

A. Water dripping pipes built circumferentially wall to provide controlled water flow

B. Pipes built into standard into the cement block to drip water and use the block holes for ventilation
C. Wall humidification by air passing through water surface or by dripping pipes on ceramic air tunnels ventilation.

D. Provision of mist through pipes with special valve into the block holes.

Figure 12
Cooling by evaporation humidification. Four possible passive methods for air cooling by humidification. Humidified air becomes cooler and therefore heavier and is forced to move downward into the air tunnel and to the house. (Ref.: *ibid*)

A. Closed patio

B. Open patio

Figure 13
Use of the cooling systems of combined passive ventilation with evaporative cooling in an aboveground house is possible, although it will be less effective because of the probable heat gain throughout the house walls. (Ref.: *ibid*)

A. Closed patio

B. Open patio

Figure 14
Combined application of the three innovation systems—subterranean placement, passive ventilation and evaporative cooling—in a semi-subterranean house with closed or open patio. (Ref.: *ibid*)
Table (2) Comparative checklist of norms and standards of conventional and subterranean houses

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CONVENTIONAL</th>
<th>SUBTERRANEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building material</td>
<td>Varied</td>
<td>Must be strong</td>
</tr>
<tr>
<td>Design overall</td>
<td>Varied</td>
<td>High standard required</td>
</tr>
<tr>
<td>Noise protection</td>
<td>Varied but mostly plenty</td>
<td>Absent</td>
</tr>
<tr>
<td>Pollution</td>
<td>Varied</td>
<td>Absent</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire</td>
<td>Varied</td>
<td>Highly protected</td>
</tr>
<tr>
<td>Earthquake</td>
<td>Varied but mostly risky</td>
<td>Secure</td>
</tr>
<tr>
<td>Storms</td>
<td>Varied but mostly risky</td>
<td>Secure</td>
</tr>
<tr>
<td>Light and air</td>
<td>Varied but mostly plenty</td>
<td>Can be limited and require special design considerations</td>
</tr>
<tr>
<td>Sunshine</td>
<td>Varied but mostly plenty</td>
<td>Can be limited and require special design considerations</td>
</tr>
<tr>
<td>Outdoor space</td>
<td>Limited</td>
<td>Ample</td>
</tr>
<tr>
<td>Privacy</td>
<td>Limited mostly</td>
<td>Good</td>
</tr>
</tbody>
</table>

Conclusion, given the special structural, waterproofing, and insulation requirements for earth-covered roofs, it is unlikely that the added construction cost can be justified solely on the basis of energy savings (in comparison with, for example, well-insulated, conventional frame roof construction above bermed wall construction).

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43 Ibid, pp.101
2.3.1.B ORIENTATION

1. Exposures 25 deg E of S secure balanced orientation, but all exposures are good from S to 35 deg E of S.
2. For bilateral buildings with cross ventilation, 12 deg S of W axis is preferred.
3. East and West walls should decrease and North and South walls should increase.

2.3.1.C INTEGRATED COOLING SYSTEMS

- **Solar chimney**

  It is a chimney covered on the outside with black metal which absorbs solar heat. As the temperature increases in the chimney, convection draws the interior air up and out of the chimney. In many cases, a west-facing chimney may help counteract the excessive heat problems presented by afternoon summer sun (Fig. 15).

  ![Solar chimney diagram](image)

  **Figure 15**

  Decorative roof ventilation structure
  1. Incoming solar radiation
  2. Glass traps heat into
  3. Cavity
  4. Black metal (or high density black material for thermal mass storage overnight)
  5. Radiant heat
  6. Stimulated air up-draught ventilates room
  7. In cold, draught conditions, insulated hatch is lowered (with rod or line and pulleys)


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44 Olgay, *op cit*, pp.167
• **Skytherm system**

Roof-pond system provides both passive summer cooling (radiative) as well as winter passive solar heating (Hay and Yellott, 1970). It consists of un-insulated, metal-pan structural roof. The roof supports a plastic "bag" filled with water (similar to a simple water bed) 6 to 8 in. deep. The upper layer of the bag was transparent while the bottom layer was black to increase absorption. Finally, the roof is equipped with horizontally sliding insulating panels which slide into place to cover the roof and off to one side (over an unconditioned area, such as a garage or porch). In operation, during a summer day, the water absorbs heat through the metal roof; ceiling from the room below and is protected from solar heat gain by the Insulating panels. At night, the panels are removed, allowing the water bags to radiate heat to the night sky. During a winter day, the water bags are uncovered and absorb solar heat; this heat is conducted through the metal ceiling/roof and radiated to the room below. At night, the bags are covered by the insulating panels to reduce heat loss. Operation is enhanced by the use of a second covering plastic layer slightly Inflated to provide an insulating air space. During the summer, the top surface may be flooded or sprayed to promote evaporative cooling. In addition, ceiling fans can be used to increase the convective transfer between the room air and the metal ceiling (Fig. 16).

![Skytherm diagrams](image)

**Figure 16**

Skytherm diagrams:
(a) Summer operation showing insulation in place over water mass during the daytime and retracted at night
(b) Winter operation showing insulation retracted during the daytime and in place at night.
(Ref.: Moore, *op cit*)
• **Cool pool**
The cool pool is an innovative passive roof-cooling system (Crowther and Melzer, 1979; Crowther, 1979). It consists of an open roof pond shaded from summer sun by sloping louvers which still allow exposure of the pond to the north sky. In addition to evaporation, the pool is cooled by radiation to the sky. The cooled water is piped to a large water storage tube inside the building below so that thermo circulation occurs any time the roof pool is cooler than the storage tube. The cooling performance of this system is impressive. Cool pool tubes could be designed to function as a water wall for winter passive heating by locating them behind south glazing and blocking circulation to the roof pond\(^{46}\) (Fig.17).

• **Indirect evaporative coolers**
Indirect evaporative coolers separate the evaporatively cooled air from the conditioned room air. This technique allows reducing the dry-bulb temperature without adding humidity to the room air, and is particularly well-suited where humidity is too high for direct evaporative cooling but where the dew-point temperature is sufficiently low to achieve comfort using only the sensible component of the evaporative process. This is usually done by a conductive divider which serves as a heat exchanger. Because a motor is usually employed, it is typically a hybrid process rather than a purely passive one. One method is an open-loop process which sprays exhaust air from the room, cooling it by

\(^{46}\) Moore, *op cit*, pp. 197-199
evaporation; this cooled exhaust air is used to indirectly cool incoming hot, dry air from the outside.

The alternative indirect process is closed-loop, spraying the outside air to cool it by evaporation; before being exhausted back to the exterior, this cool moist air in turn cools recirculating room air by means of a heat exchanger (Fig. 18).

Akridge (1982) has suggested the following design guidelines for earth tubes:

- Small-diameter tubes are more effective per unit surface area than are larger tubes.
- Air reaches the adjacent ground temperature relatively quickly, so long tubes are unnecessary.
- A large-diameter tube of a given length will transfer more energy than a small-diameter tube of the same length; therefore multiple small tubes should be used.
- Tubes should be placed as deeply as possible so that the surrounding soil temperature is the lowest and relatively constant.
- Exit temperature is highly dependent on inlet temperature; thus, using outside air drawn through open-loop earth-cooling tubes results in higher exit temperatures, higher soil temperatures, and a higher relative humidity (than a comparable closed-loop configuration which recycles interior air).
- Ground thermal resistance is so high that tube thermal resistance is immaterial (i.e., plastic or concrete tubes perform as well as copper tubes).
- While higher airflow rates result in greater cooling, this results from more air being cooled than from more efficient conductive heat transfer between the tube and air.

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47 *Ibid*, pp. 204
• **Night ventilation cooling**

This is the process by which heat is removed from the structure of a building by passing cooler night air over the surfaces of the building, thus lowering the temperatures of the walls, floors and ceilings of rooms. For a successful night-time ventilation system it is important that the air inlets and outlets can be left securely open at night.

A good rule of thumb is that for sufficient thermal storage to be built into a house, the walls of each room should be at least 100mm thick (that is 150-200mm if rooms are back to back) and made of high density building material. The problem is that as the air beneath the ceiling gathers heat during the day it also heats the ceiling above that then becomes warm and begins to radianty heat the people in the room below. Cool night air flowing along the floor of this space may not affect the hot pool of air on the ceiling. Do note that, in this situation, adding insulation to the ceiling would only exacerbate the problem here (Fig. 19). This case demonstrates the need to look at the thermal design of a building and its ventilation holistically. To solve this problem single-sided ventilation can be replaced with cross ventilation by making a door between the two rooms.

To remove the hot pool beneath the ceiling, either the door should nearly reach to the ceiling or there should be a higher level window out of which this heat can flow during the day. In so doing it draws the air from the night cooled floor up over the room occupants, so increasing their comfort. An alternative, not so good, solution is to use angled louvers on the windows that will direct the wind up to the ceiling so disturbing and dissipating the heat pond beneath it.

However, the night cooling will not work if the window is improperly shaded and during the day the floor is continually heated, forming a radiant and convective heat source that will make the room occupants even more uncomfortable 49.

Cooling a building by the nighttime ventilation of the thermal mass depends upon a two-fold process. First, during the day, when the out-side temperature is too warm for ventilation, any generated heat is stored in the building's mass.

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49 Roaf, *op cit*, pp. 128-130
Second, at night, when the outside temperature is lower, outdoor air is allowed to ventilate through the building to remove its heat. The mass is thus cooled so that it can absorb excess heat again the next day. In order for this to work, there must be enough mass in the building to absorb the generated heat, and the mass must be distributed over enough surface area so that it will absorb the heat quickly and keep the interior air temperature comfortably low. The openings must be large to allow enough cool outside air to flow past the mass to remove the heat accumulated during the day and carry it outside the building.

2.3.1.D COLOR

White paint has high reflection ratio on sun exposed surfaces. Dark absorptive colors are adaptable where reflections toward interior are expected (such as under eaves). Deep-set surfaces can be dark colored for winter radiation absorption. Bright color contrasts are in agreement with the general character of the region\textsuperscript{50}.

\textsuperscript{50} Olgay, \textit{op cit}, pp. 167
2.3.1.E FORM, VOLUME

• Proportion and depth

The ratio of volume to surface area is an important indicator of the speed at which the building will heat up by day and cool down at night. If the temperature range is high and it is desirable that the building heats up slowly, a high volume to surface ratio is preferable. Where air movement is seldom necessary, and where high volume to surface ratios are required, dwellings with 'double banked' rooms can be used, to achieve buildings with greater depth 51 (Fig. 20).

Figure 20
Effect of building depth on internal conditions
(1) Single-banked rooms (buildings which are one room deep in section) should be used when low heat capacity and cross ventilation are required
(2) Double-banked rooms can be used to give a high heat capacity building in climates where air movement is not so important for comfort
(3) A compromise for composite climates: the upper floor can be used in the humid season or at the time of day when air movement is needed; the lower floor, with its higher heat capacity, can be used in the hot dry season. (Ref.: Evanes, M. (1980), "Housing Climate and Comfort", The architectural press, London)

• Ceiling height

High ceilings cost money, both in terms of construction costs, and indirectly in terms of reduced intensity, construction speed, and maintenance costs. The supposed benefits of high ceilings in hot climates have therefore been studied in a number of countries. The conclusion that can be drawn from the studies is that the rooms with high ceiling are not significantly more comfortable than rooms with ceiling heights of 2.7m or even 2.5m (Fig. 21).

The optimum shape was defined as the one which has minimum heat gain in summer and the minimum heat loss in winter and so for hot arid regions the optimum ratio for the shape of the house is 1:1.3. (Fig. 22)

When sun and prevailing wind both come from the west it is difficult to prevent the sun from entering without excluding the wind. It is therefore clear that west-facing windows should be avoided. Wind from the west may still be deflected through windows facing north and south, by staggering the building form and using suitably placed external walls to create high and low pressure zones to induce cross ventilation (Fig. 23). When openings cannot be oriented to the prevailing breeze, landscaping can be used to alter the positive and negative pressure zones around the building and induce wind flow through windows parallel to the prevailing wind directions (Fig. 24).

**Dwelling forms**

The optimum shape was defined as the one which has minimum heat gain in summer and the minimum heat loss in winter and so for hot arid regions the optimum ratio for the shape of the house is 1:1.3. (Fig. 22)

When sun and prevailing wind both come from the west it is difficult to prevent the sun from entering without excluding the wind. It is therefore clear that west-facing windows should be avoided. Wind from the west may still be deflected through windows facing north and south, by staggering the building form and using suitably placed external walls to create high and low pressure zones to induce cross ventilation (Fig. 23). When openings cannot be oriented to the prevailing breeze, landscaping can be used to alter the positive and negative pressure zones around the building and induce wind flow through windows parallel to the prevailing wind directions (Fig. 24).

Figure 21

The effect of increased ceiling height

1. Lowered ceilings will increase radiation from the ceiling to the body, but the difference is not noticeable
2. The change in temperature gradient will usually be less than 0.5 deg C at body level, which is not noticeable
3. Increased ceiling heights will not give 'sensible' air movement due to stack effect under normal conditions (Ref.: *Ibid*)
Figure 23
The optimum form in hot arid regions.
(Ref.: Olgay, op cit)

Figure 22
Alternative solutions to the problem created when sun and wind both come from the west.
(1) With wind and sun from the west, rooms with two external walls facing north and south will have little air movement but protection from solar radiation.
(2) Rooms facing east and west will have breeze and solar radiation, a less desirable combination
(3) The careful placing of external walls can be used to create high and low pressure zones to achieve cross ventilation 'turning' the air movement through 90 deg
(4) The staggering of rooms can be used to achieve the same result, obtaining the benefit of cross ventilation and protection from solar radiation at the same time. (Ref.: Evanes, op cit)
Where winds blow obliquely to the north or south wall, the average wind speed within the room may actually be greater than when the winds blow directly onto the face of the building. When the angle between the face of the wall and the wind is less than 45 deg, average wind speeds within the room will begin to fall quite sharply. So long as this angle is above 30 deg, the use of projecting fins will assist in deflecting air achieving a better distribution of air movement in the room.

Since air movement is vital for comfort, buildings must be well spaced to allow wind to return to ground level when it has been deflected upwards by buildings to windward. For most proportions of building, a space between buildings of five times the height of the windward building will allow the wind to return to ground level and to blow against the face of the leeward building52 (Fig. 25).

---

52 *Ibid*, pp. 61-63
Figure 25

The shaded area indicates the approximate shape of the area in which air movement will be poor, and the dotted line shows the limit within which other buildings requiring cross-ventilation are not recommended.
(Ref.: Evanes, *op cit*)

Figure 26

A comparison between the advantages of low-rise and high rise building forms in hot dry climate
1. In hot dry climates, isolated slab blocks result in large sunlit spaces which are difficult to maintain or landscape, and a small proportion of external shaded space.
2. Closely clustered low courtyard buildings leave less external space at ground level, but it is sheltered from the wind, and a high proportion is shaded. With low buildings the roof space is also more easily used by occupants.
(Ref.: *Ibid*)
In hot dry climates, the form of dwellings should provide protection from solar radiation and shelter from hot dusty winds. These requirements can be satisfied by building forms that are compact and low rise, using small courtyards to provide light and air (Fig. 26). These small courtyards will also provide outdoor spaces sheltered from the sun and wind. With inward-looking dwelling forms and windowless boundary walls, the building form can be continuous, with one building sheltering the next. This pattern of dwelling is typical of traditional areas in the hot dry tropics. Massive buildings with a high volume-to-surface ratio are advantageous since this will reduce the high range of external air temperature. Isolated high rise apartment blocks are totally unsuited to this climate as they are highly exposed to solar radiation and hot dusty winds and do not provide sheltered outdoor spaces for the occupants. The ground between blocks will lack privacy and climatic control. Medium rise apartment blocks are suitable to provide a dense and continuous urban form. They should avoid west facing windows and minimise the area of wall exposed to the west, as this wall will receive the maximum solar radiation during the hottest period of the year\textsuperscript{53}.

Table (3) Summary of requirements for building form in relation to climate\textsuperscript{54}

<table>
<thead>
<tr>
<th>Climate</th>
<th>Element and requirement</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot dry</td>
<td>Minimise west walls</td>
<td>to reduce heat gain</td>
</tr>
<tr>
<td></td>
<td>Minimise surface area</td>
<td>to reduce heat gain and loss</td>
</tr>
<tr>
<td></td>
<td>Maximise building depth</td>
<td>to increase thermal capacity</td>
</tr>
<tr>
<td></td>
<td>Minimise window wall</td>
<td>to control ventilation heat gain, and light</td>
</tr>
</tbody>
</table>

\textsuperscript{53} Ibid, pp.71
\textsuperscript{54} Ibid, pp.74
2.3.2 BUILDING ENVELOPE

2.3.2.A ROOFS AND WALLS

Roofs and walls with high thermal capacity and adequate resistance will reduce this external diurnal range so that the temperature variation at the internal surface is only about 15 to 20% of the external air or sol-air temperature range. The time lag should be at least eight hours and time lags of up to 14 hours are still advantageous. A time lag of eight hours can be achieved more economically if a roof construction has an insulating layer on the outside of a heavy layer (a concrete slab). When insulation cannot be afforded, a cheaper but less effective alternative is to shade the roof with reed matting or timber boards, suspended above the roof so that an air cavity is formed.

A maximum 'U' value of 0.9 Watts/m² deg C is recommended for roofs of night-use rooms in hot dry conditions when the diurnal temperature range is 10 to 12 deg C. A lower 'U' value may be required if the absorptivity of the external surface is greater than 0.4. A distinction can be made between walls which are orientated in different directions. North-facing walls receive very little direct solar radiation in the northern hemisphere, and can be completely shaded without difficulty. Insulation against heat is not so critical on these walls as on those which face in other directions. South-facing walls will receive a greater intensity of solar radiation in the winter months than in the summer. It is also possible to shade a south-facing wall so that it receives little radiation in summer, but absorbs radiation in winter. The east and west walls will receive high levels of solar radiation and cannot be shaded easily. A relatively low 'U' value is important to reduce heat gains. The maximum sol-air temperature on the east wall will occur at about 9.00 or 10.00 hours in the morning. A longer time lag is therefore needed if the maximum heat gain is to be delayed until after sunset. Alternatively more insulation is needed to reduce the rate of heat flow. It will almost invariably be cheaper to use a light surface colour (reducing μ) rather than adding insulation (to reduce U or μ)\(^55\).

\(^{55}\textit{Ibid}, pp. 88-90\)
Table (4) Recommended thermal properties for walls and roofs

<table>
<thead>
<tr>
<th>Element and condition</th>
<th>U value</th>
<th>α</th>
<th>Time lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy roofs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rooms for night use: diurnal range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 deg C</td>
<td>0.90</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>0.85</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.80</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>17.5</td>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.70</td>
<td>0.4</td>
</tr>
<tr>
<td>East wall</td>
<td>1.2(0.9)</td>
<td></td>
<td>10-16</td>
</tr>
<tr>
<td>West wall</td>
<td>1.2(0.9)</td>
<td></td>
<td>6-14</td>
</tr>
<tr>
<td>North and south wall</td>
<td>1.2(0.9)</td>
<td></td>
<td>8-14</td>
</tr>
<tr>
<td>Walls shaded from direct solar radiation</td>
<td>2.0(1.6)</td>
<td></td>
<td>8-14</td>
</tr>
</tbody>
</table>

In order to achieve the time lag required using insulating materials as mentioned before, the designer should be acquainted to the specs of the different types of the insulating materials for roofs and walls.

**ROOF INSULATION**

- Thermal Insulation Materials

Thermal insulation materials can be classified as follows:
1. Loose fill insulating materials
2. Semi-rigid insulating materials
3. Rigid insulating materials
4. Foamed insulating materials
5. Reflective insulating materials

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56 Ibid., pp. 98
Table (5) in the appendix shows the thermal specs for thermal insulation materials\textsuperscript{57}

But not all those thermal insulating material are eco friendly and so therefore a rating has been developed to classify the thermal insulating materials in terms of ecological impact. In the coming table, an evaluation has been applied over the insulation from the ecological point of view. A score of six or more indicates an appropriate material from the view point building biology and ecology philosophy\textsuperscript{58}.

Table (6) is intended as a guide, from which the architect, engineer or builder will be able to give one further advice.

Table (6): Comparison of insulation materials:

\begin{itemize}
  \item +2 = Very advantageous to use
  \item +1 = Advantageous
  \item 0 = Neutral
  \item -1 = Disadvantageous
  \item -2 = Very advantageous
\end{itemize}

\textsuperscript{57} مرك‌‌ز بحوث الإسكان والبناء، (2001) مواصلات بنود أعمال العزل الحراري، مركز بحوث الإسكان والبناء، القاهرة، 18-21-4.1

\textsuperscript{58} Sydney, \textit{op cit}, pp..173
Table (6) An evaluation of thermal insulation materials from ecological and cost impact perspectives

<table>
<thead>
<tr>
<th>Insulating Material</th>
<th>Insulation Value</th>
<th>Toxicity</th>
<th>Waste Disposal</th>
<th>Diffusivity</th>
<th>Hygroscopicity</th>
<th>Draught-proofing</th>
<th>Fire-resistance</th>
<th>Cost</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NATURAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straw and clay mix</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>+9</td>
</tr>
<tr>
<td>Woodwool</td>
<td>+1</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>0</td>
<td>-1</td>
<td>+2</td>
<td>+8</td>
</tr>
<tr>
<td>Sawdust or shavings with bark</td>
<td>+1</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>0</td>
<td>-1</td>
<td>+2</td>
<td>+8</td>
</tr>
<tr>
<td>Strawboard</td>
<td>+1</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>+6</td>
</tr>
<tr>
<td>Cellulose (recycled paper)</td>
<td>+2</td>
<td>-1</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>0</td>
<td>-1</td>
<td>+2</td>
<td>+6</td>
</tr>
<tr>
<td>Cork (Baked)</td>
<td>+2</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+2</td>
<td>+1</td>
<td>-1</td>
<td>-2</td>
<td>+5</td>
</tr>
<tr>
<td>Coconut fibre</td>
<td>+2</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+1</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>+5</td>
</tr>
<tr>
<td>Foam glass</td>
<td>+2</td>
<td>0</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>+2</td>
<td>-1</td>
<td>+5</td>
</tr>
<tr>
<td>Foamed lime or cellulose</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>+1</td>
<td>+2</td>
<td>+2</td>
<td>-1</td>
<td>+5</td>
</tr>
<tr>
<td>Clay bead (&quot;Liapor&quot;)</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>+2</td>
<td>+1</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>+4</td>
</tr>
<tr>
<td>Vermiculite or Perlite</td>
<td>+1</td>
<td>-1</td>
<td>0</td>
<td>+2</td>
<td>0</td>
<td>+1</td>
<td>+2</td>
<td>-2</td>
<td>+2</td>
</tr>
<tr>
<td><strong>SYNTHETIC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral wool (glass, rock fibre)</td>
<td>+2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>+1</td>
<td>0</td>
<td>+1</td>
<td>-6</td>
</tr>
<tr>
<td>Polystyrol</td>
<td>+2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>-2</td>
<td>+2</td>
<td>-8</td>
</tr>
<tr>
<td>Urea formaldehyde</td>
<td>+2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>-2</td>
<td>+1</td>
<td>-9</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>+2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>-2</td>
<td>-1</td>
<td>-11</td>
</tr>
</tbody>
</table>

57
Concrete roofs made of fixed forms that are thermally insulated
Concrete roofs could be made using fixed thermally insulated forms that consists of rigid boards resistant to water absorption and of rough corrugated texture to guarantee complete bondage with concrete roof and appliance of plaster works; it has pressure resistance complying with design requirements. In this system, the thermal insulation is made during the execution of the reinforced concrete forms. This system is a modern construction technique, it is highly economic since it protects the boards of the wooden forms from being destroyed and makes it capable of usage for several times besides saving the time and labor and wood quantities used\textsuperscript{59}.

In general, required thermal resistance could be calculated using the coming equations for walls and roofs respectively according to Givoni:

\[
\begin{align*}
R &= 0.05(T_{\text{max}} - 25) + 0.002 (a \times I_{\text{max}}) & \text{Walls} \\
R &= 0.05(T_{\text{max}} - 25) + 0.003 (a \times I_{\text{max}}) & \text{Roof}
\end{align*}
\]

Where:
- \(R\): required thermal resistance
- \(T\): maximum temperatures in the area
- \(a\): surface color
- \(I\): quantity of solar energy and differs according to direction

Climatic design criteria for roofs
- During the day, the surface is heated and the heated air rises by natural convection. At night, the cooled air remains on the surface due to its increased density. A simple way of utilizing the cooled air is to let it sink into a small enclosed courtyard. This acts as a basin, trapping the cooled air and allowing it to flow into the rooms around the courtyard, while heated air from the rooms of the courtyard can rise unhindered. Courtyards should then be surrounded by open railings with low kerbs to encourage air to flow into them\textsuperscript{60} (Fig. 27).
- Horizontal and perpendicular roofs receive less sunlight than inclined roofs (Fig. 28).

\textsuperscript{59} مرتكز بحث الإسكان و البناء، مرجع سابق، ص 91
\textsuperscript{60} Evanes, \textit{op cit}, pp. 105-106
Figure 27
Iraq house in summer day and summer night. (Ref.: Brown, *op cit*)

Figure 28
WALL INSULATION

There are three different ways in which a wall can be insulated:

- **Resistive insulation:**
  This is what most of us think of as insulation. These are the “bulk” insulation products which include mineral wools, strawboard, wool-wool slabs, glass fibre products, kapok, wool, and cellulose fibre. They also include expanded and extruded polystyrene, polyurethane, urea formaldehyde, vermiculite and perlite. That type of insulation is based on preventing convection, which in turn, depends on the conductivity and viscosity of the liquid or gas in the gap or contained in the material, the temperature difference, and to some extent the thickness of the gap.

- **Reflective insulation:**
  This requires a highly reflective material, such as aluminium foil, to face into a cavity. Foil has an extremely low emissivity and thus radiant heat transfer between the walls of the cavity is much reduced. Performance is compromised if the face of the foil is touching the opposite wall as conduction of heat is then allowed. The amount of heat a material can radiate depends on its surface emissivity, i.e. how easily it allows heat to move through its surface, and the temperature difference between its surface and which it is radiating to. Its thickness is irrelevant.

- **Capacitive insulation:**
  This is often described as “thermal mass” and is found in buildings as heavy walls. Heat is conducted through the solid material of the wall and the rate of the heat flow depends on conductivity of the material the wall is made of, its thickness and the difference in temperature between the air on the two different sides of the wall. While resistive and reflective insulation work instantaneously, using high capacity insulation affects the timing of the heat flows. The difference is best illustrated by the comparison of 61:

---

61 Roaf, *op cit*, pp. 75-76
1. 10 mm polystyrene slab (U = 2.17 W m²K)
2. 400 mm of dense concrete slab (also U = 2.17 W m²K)

- Criteria affecting the efficiency of wall insulation material:

  o Construction materials

- Construction bricks:
Usage of building materials available in the hot dry region alone is not enough and does not fulfill the thermal needs of the building, and therefore thermal insulation materials should be used with those building materials in order to increase its thermal resistivity and decrease its thermal capacity. Thermal insulation layer must be placed in the outer surface of the wall in order to create a layer capable of storing heat during day and expelling it during night.
Usage of several consecutive air voids in walls give positive results in decreasing the U-value, it also decreases the thermal capacity of the structure and therefore the building structure becomes convenient during night. Reflective thermal insulation materials could be placed on the outer layer.

  o Plaster mortar:
Walls could be finished with light weight interior and exterior plaster of low thermal conductivity, such as:
Foamed cement plaster - Expanded perlite plaster - Foamed polystyrene plaster - Vermiculite plaster - Enhydrite gypsum plaster.

  o Wall cladding:
Wall cladding material was developed to achieve dual benefit, decorative and insulating at the same time.
Wall cladding thermal insulating materials are:
1. Tiles with complex section from epoxy and polystyrene, it consists of two layers of artificial marble glued together.
2. Tiles with complex section from marble and polystyrene, similar to previous type except in the front layer which consists of natural marble with 1-1.5cm thickness
3. Tiles with complex section from artificial stones and polystyrene, it consists of polymer or gypsum mortar treated with base coat that has the texture and shape of natural stone with a back layer of foam which has low moisture absorptivity.
4. Reflective aluminium sheets ,prevents the spread of heat due to radiation, and it is usually placed over the exterior surfaces or between the space of the doubled wall.

- **Paint Coating:**

Paints could be used as an aid to thermal insulation as follows:
1. By adding crushed Vermiculite to some paints in order to produce special paints that are inflammable and fire resistant.
2. By choosing light painting colors of low absorptivity to sun rays.
3. Steel surfaces should be painted with reflective aluminium epoxy paints.
4. External cement surfaces should be painted with reflective silver acrylic paints.\(^{64}\)

Table (7) in the appendix shows thermal specs for construction and finishing materials.\(^{65}\)

- **Location of the thermal insulation material**

There are three ways for placing the thermal insulation material in walls:
- From outside
- In the middle
- From inside

Advantages of each are as follows:
- **Insulation material from the outside**
  Insulation materials of high mechanical properties are used because they are exposed to external shocks or weather conditions, and so therefore the best types of insulation materials used are:
  - Tiles with complex section from marble and polystyrene
  - Tiles with complex section from epoxy and polystyrene
  - Tiles with complex section from artificial stones and polystyrene
  - Cellular concrete

- **Insulation material in the middle**
  The insulation material is placed in the space between the doubled walls, and so therefore any type of insulation material can be used since it is protected from both sides from the weather conditions and any internal use.

- **Insulation material form the inside**
  Insulation material used should be isolative to water vapor or protected with a layer that prevents vapor, also has to be fire resistant and its surface strong enough to resist shocks or friction due to interior use, and so therefore the best of these Insulation materials are:
  - Tiles with complex section from epoxy and polystyrene
  - Rigid board, and could be protected by cladding it with wooden sheets or building another interior wall or by placing cement plaster on steel mesh
  And as it is known in the science of heat transfer that the insulation material should be placed in the direction of heat source, so in cold countries it is placed from inside and in hot countries it is placed from the outside.

In general:
- For roofs:
  1. Heat storage insulation is best, which uses the flywheel effect of outgoing radiation for daily heat balance. However a shaded, ventilated roof is also applicable, primarily over night-use rooms.
2. Water spray or pool on roof is effective. High solar reflectivity is a basic requirement; emissivity is essential for long-wave radiation.

3. Maximum U value of 0.9 watts/m² deg C is recommended for roofs.
   • For walls:
     1. Walls of daytime living areas should be of heat-storing materials; walls of night-use rooms of materials with light heat capacity.
     2. E and W walls should preferably be shaded.
     3. High reflective qualities are desirable for both thermal and solar radiation.\textsuperscript{67}

\textbf{\textsection DYNAMIC INSULATION}

In a conventional construction, the ventilation air enters the building through a combination of desired pathways, via opened apertures, such as windows and vents, and “undesired” pathways, via cracks around external openings, joints between building materials, etc. By contrast, in constructions with dynamic insulation components (e.g. wall, ceiling), the ventilation air is drawn into the building through the dynamic component. Structures with dynamic insulation incorporate porous insulating material in the envelope and air passes through the porous material. According to the direction of the air flow in relation to the heat flow through the component, two types of dynamic insulation are distinguished:
   • Contra-flux
   • Pro-flux (or parallel flux)

In contra-flux dynamic insulation the air moves through the insulation in the opposite direction than the heat flow. Thus, the ventilation air through the porous material reduces the heat losses by conduction to the exterior of the building envelope. The reduction of the conduction heat losses is also accompanied by pre-heating of the ventilation air before entering the building. The heat loss to the outside can be practically reduced to zero by quite small air flows. In the pro-flux dynamic insulation, the air flows

\textsuperscript{67} Olgay, \textit{op cit}., pp. 168
in the same direction as the heat flow. Another distinction for the breathing envelope types is made in the literature between the dynamic insulation and the diffusive insulation, in the last case, the only driving forces being concentration gradients.

The principle of contra-flux dynamic insulation demands that as much incoming ventilation air as possible enters through the porous insulated panels. Thus, the insulation material must permit the passage of air at an appropriate rate.

The pressure difference needed to maintain the required flow through the insulation material can be eliminated by uncontrolled infiltration. Thus, uncontrolled ventilation, by doors and windows opening and by infiltration e.g. air passage through gaps between insulation panels or between panels and other building components such as windows doors, must be minimized in dynamic insulation structures. The required pressure difference can be achieved either in a passive way (e.g. utilizing the stack effect in climates with very low external air temperature during winter) or mechanically (e.g. by fans operating in bathrooms and kitchens in domestic structures. This puts the whole building under negative pressure, so that air passes only through the walls in an inward direction (i.e. regardless of ambient wind direction). A dynamic insulation envelope also acts as an air filter, as due to the thickness used in the envelope, it effectively traps particles in the size of 0.5- 5.0 \mu m, which are dangerous for lung damage. Dynamic insulation can provide energy efficient ventilation but its operation may be associated with possible hazards like the deposit of chemical contaminants and mould growth.

In order to assess the overall performance of the dynamic insulation, a dynamic U-value for a multi layer envelope can be calculated, based on an ID steady state heat transfer analysis, given by the expression:

\[
U_d = \frac{\rho a c_a}{R} \left( e^{\frac{\rho a c_a R}{\rho a c_a}} - 1 \right)
\]

Where:

\( v \) : air flow through the wall

\( \rho a , c a \) : density and specific heat of the air

\( R \) : thermal resistance of the wall.
From the equation it is derived that the higher the thermal resistance of the wall, the better dynamic U-value and performance of the dynamic wall, for a certain wall thickness, and the dynamic U-value decreases with the increase of the air flow through it.

A very significant parameter for the performance of the dynamic insulation is the high airtightness of the whole building structure\(^\text{68}\) (Fig. 29, Fig. 30).

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\(^\text{68}\) Energy and Buildings 36, (2004), "Experimental work on a linked, dynamic and ventilated, wall component", pp.443-445, ELSEVIER,
2.3.2.B OPENINGS AND WINDOWS

Windows are one of the main sources for ventilation and heat gain or loss in a dwelling, and so therefore we will present how it affects both ventilation and heat gain or loss and how they should be carefully designed.
There are two ways by which ventilation could be achieved:

- Stack effect
- Wind pressure

And there are several ways to minimize heat gain or loss and this is through different window types, but we will start with the ventilation first.

Ventilation through windows by stack effect

When there is a difference in air temperature between the inside air and outside air, the pressure difference caused by the differential expansion of the air can be used to achieve ventilation by stack effect\(^{69}\) (Fig. 31).

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\(^{69}\) Evanes, *op cit*, pp. 125
To determine the area of inlet needed, which must be equaled by the outlet area and the cross-section of the stack, enter the graph on the vertical axis with wind speed for cross-ventilation or stack or room height for stack ventilation. Move horizontally until the appropriate curve is intersected; then drop down to determine the area of the inlet as a percentage of the mass area. The graph assumes that the wind blows from between perpendicular and diagonal to the openings for cross-ventilation and that the difference between the outside temperature and inside temperature is 3 deg F for stack ventilation\(^7\) (Fig. 32).

\[\text{Figure 32} \]
\[\text{Graph to determine area of inlet needed. (Ref.: Brown, op cit)}\]

Air movement within dwellings due to wind pressure

There are several factors that affect the air movement within dwellings due to wind pressure.

- **External conditions**
  Stack effect will provide adequate pressure to achieve ventilation for odour removal and structural cooling, but cannot provide air movement for sufficient speed to achieve effective cooling of the body. To achieve air movement within the dwelling, wide spacing is required. The spaces between buildings will condition the air before it enters through the window. It is normally possible to grow grass and trees which will shade the ground, cool the air and filter the dust.

- **Window openings**
  - **Vertical position**
    The main factor in achieving the desired flow of air within the room is the positioning and treatment of the window on the windward face of the building. The position of the outlet has little effect on the pattern. The position and treatment of the window opening in section is therefore, considered first (Fig. 33).

**Figure 33**

Air flow related to the position of the inlet in the wall
(1) High inlet and outlet do not produce good air movement at body level
(2) Low inlet and outlet produce a good pattern of air movement when it is required for cooling
(3) Low inlet and high outlet also produce a low level wind pattern
(4) The air flow at ceiling height produced by a high inlet is hardly affected by an outlet at low level. (Ref.: Evanes, *op cit*)
**Projections**

Airflow will also be affected by overhangs and sun shading devices. Overhanging roofs and projecting roof slabs, as well as providing shade, will reduce the proportion of air flowing around the edge of the building, slightly increasing the airflow through the opening and within the building (Fig. 34).

**Figure 34**

The effect of an external sunshade. All the sunshades shown are equally effective at shading 45 deg angle sun.
(1) Projection shading devices produce an upward air flow in the room
(2) A slot between wall and shade results in a more direct flow of air
(3) Moving the position of the shade has the same effect, but a larger shade is required
(4) Louvers in the windows give a more direct flow but the sun may hest the louver and the louver may heat the air as it enters the room. (Ref.: Ibid)

**Horizontal position**

Windows placed in the center of walls on plan will have symmetrical internal airflows when the wind is blowing perpendicular to the face of the building. Windows near the corners of buildings will cause asymmetrical patterns of air movement.

But while a horizontal external wind flow can be assumed in section the wind will not always blow onto the face of the building at 90 deg in plan. As the direction of the wind moves from a direction perpendicular to the face of the building to other angles of incidence, the internal airflow pattern will be affected and the wind pressure on the window reduced ⁷¹ (Fig. 35).

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⁷¹ Evanes, *op cit*, pp.128-131
Figure 35

Effect of size of inlet and outlet on internal wind speed and distribution

1. A small inlet and a large outlet will result in a high maximum speed but poor distribution, with large areas of the room experiencing low wind speeds.
2. A large inlet and a small outlet will result in a lower maximum speed but a better distribution of air movement over the room, with only a small area having low speeds.
3. Graph assumes rooms which are close to square on plan and wind blowing directly onto the face of the building. Internal wind speed does not increase significantly when window size is increased beyond about 40% of the wall area.

(Ref.: Ibid)
Table (8) Summary of ventilation functions and requirements

<table>
<thead>
<tr>
<th>Function</th>
<th>Required</th>
<th>Conditions</th>
<th>Suitable building</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Minimum ventilation for odour removal etc.</td>
<td>In all occupied buildings</td>
<td>All conditions of external temperature</td>
<td>All buildings</td>
</tr>
<tr>
<td>2. Ventilation for structural cooling</td>
<td>Mainly in hot dry conditions</td>
<td>Outside air cooler than inside air by more than 2 deg C</td>
<td>High internal heat capacity building</td>
</tr>
<tr>
<td>3. Air movement for cooling the body</td>
<td>Mainly in warm humid conditions</td>
<td>Outside air the same or cooler than inside air</td>
<td>Single banked building</td>
</tr>
</tbody>
</table>

**Methods**

| 1. Stack effect | Adequate for ventilation under most conditions | Adequate for cooling | Not adequate |
| Openings | No special requirements | High outlet and low inlet, each 5 % of floor area | |
| 2. Wind pressure | Adequate for ventilation | Adequate but may not be available at night | Good if available |
| Openings | No special requirements | High outlet and low inlet, each 5 % of floor area | Large inlet and outlet on opposite sides of building each 20 % of wall area minimum |
| 3. Mechanical | Not usually necessary, but extract fans may be used in kitchens, internal WCs also | Not necessary, as stack effect will work automatically if outside air is cooler | May be desirable, fans are needed to move the air in the room not to provide |

72 Ibid, pp. 131
require extract fans than inside air air change
Typical requirement

| 1 air change per hour | 10 air change per hour | 1-1.5 m/sec air speed (equivalent to 100 air change per hour or more) |

**Window Type**

When we come to selecting window type, the designer will face a variety to choose from and so therefore it is important to know the specs of the most dominant types in the market.

- **Single-Glazed with Clear Glass**
  Single-glazed with clear glass allows the highest transfer of energy while permitting the highest daylight transmission (Fig. 36).
  
  (U-Factor=1.04, SHGC=0.86, VT=0.90)

- **Single-Glazed with Bronze or Gray Tinted glass**
  The primary purpose of bronze or gray tinted glass is to reduce solar heat gain. But, it also reduces visible light as compared to Single-Glazed Clear Glass. Tinted glass is useful in controlling glare but solar heat gain and visible light transmission may be reduced (Fig. 37).
  
  (U-Factor=1.04, SHGC=0.73, VT=0.68)

- **Double-Glazed with Clear Glass**
  The inner and outer layers of glass are both clear

![Figure 36](http://www.efficientwindows.org/gtypes.cfm)

Single glazed with clear glass (Ref.: http://www.efficientwindows.org/gtypes.cfm)

![Figure 37](http://www.efficientwindows.org/gtypes.cfm)

Single glazed with tinted glass (Ref.: Ibid)
and separated by an air gap. Double glazing, compared to single glazing, cuts heat loss in half due to the insulating air space between the glass layers. In addition to reducing the heat flow, a double-glazed unit with clear glass will allow the transmission of high visible light and high solar heat gain.
(U-Factor=0.50, SHGC=0.76, VT=0.81)

- **Double-Glazed with Bronze or Gray Tinted Glass**
The outer layer of glass is bronze or gray and the inner layer is clear. These two layers are separated by an air gap. The tint has no effect on the U-factor but reduces solar gain which may be a benefit in the summer and a liability in the winter.
(U-Factor=0.50, SHGC=0.63, VT=0.61)

- **Double-Glazed with High-Performance Tinted Glass**
This tinted glass reduces solar heat gain to below that of bronze or gray tint but has a visible transmittance closer to clear glass. The tint has no effect on the U-factor but reduces solar gain, which may be a benefit in the summer and a liability in the winter.
(U-Factor=0.50, SHGC=0.51, VT=0.69)

- **Double-Glazed with High-Solar-Gain Low-E Glass, Argon/Krypton Gas**
These Low-E glass products are often referred to as pyrolitic or hard coat Low-E glass, due to the glass coating process. The properties presented here are typical of a Low-E glass product designed to reduce heat loss but admit solar gain. High solar gain Low-E glass products are best suited for buildings located in heating-dominated climates. While the high solar gain glazing performs better in winter, the low solar gain performs better in summer. Low solar gain Low-E glazings are ideal for buildings located in cooling-dominated climates.
(U-Factor=0.29, SHGC=0.71, VT=0.75)

- **Double-Glazed with Moderate-Solar-Gain Low-E Glass, Argon/Krypton Gas**
These Low-E glass products are often referred to as sputtered (or soft-coat products) due to the glass coating process. (Note: Low solar gain Low-E products are also sputtered...
coatings.) Such coatings reduce heat loss and let in a reasonable amount of solar gain and are suitable for climates with both heating and cooling concerns.

(U-Factor=0.27, SHGC=0.58, VT=0.78)

- **Double-Glazed with Low-Solar-Gain Low-E* Glass, Argon/Krypton Gas**
  This type of Low-E product, sometimes called spectrally selective Low-E glass, reduces heat loss in winter but also reduces heat gain in summer. Compared to most tinted and reflective glazings, this Low-E glass provides a higher level of visible light transmission for a given amount of solar heat reduction. While the high solar gain glazing performs better in winter, the low solar gain performs better in summer.
  (U-Factor=0.15, SHGC=0.51, VT=0.65)

- **Triple-Glazed** with Moderate-Solar-Gain Low-E Glass, Argon/Krypton Gas
  In this case there are three glazing layers and two Low-E coatings, 1/2" argon gas or 1/4" krypton gas fill between glazings, and low-conductance edge spacers. The middle glazing layer can be glass or plastic film. With this window, both Low-E coatings are spectrally selective in order to minimize solar heat gain. This window is best suited for climates with both significant heating and cooling loads.
  (U-Factor=0.25, SHGC=0.39, VT=0.71)

- **Triple-Glazed** with Low-Solar-Gain Low-E* Glass, Argon/Krypton Gas
  In this case there are three glazing layers and two Low-E coatings, 1/2" argon gas or 1/4" krypton gas fill between glazings, and low-conductance edge spacers. The middle glazing layer can be glass or plastic film. Some windows use four glazing layers (two glass layers and two suspended plastic films). Both Low-E coatings in this product have high visible light transmittance. The use of three layers, however, reduces the beneficial solar heat gain. This product is suited for buildings located in very cold climates, although Double-Glazed with High Solar Gain Low-E should be considered if passive solar heat gain is desired73. (U-Factor=0.14, SHGC=0.33, VT=0.56)

73 [http://www.efficientwindows.org/gtypes.cfm](http://www.efficientwindows.org/gtypes.cfm)
Conclusion:
1. Relatively small openings reduce intense radiation.
2. Windows should be shielded from direct radiation, and set high to protect from ground radiation.
3. Openings should be tight-closing as protection against high diurnal heat. External shades are preferred.
4. Openings should be located on S, N, and, to a lesser degree, on E sides\textsuperscript{74}.
5. West facing windows should be avoided
6. Ventilation for structural cooling using stack effect requires high outlet and low inlet, each 5% of floor area.
7. Air movement for cooling the body using wind pressure requires large inlet and a small outlet on opposite sides for better distribution of air movement over the room.

\subsection*{2.3.2.C SHADING DEVICES}

Shading devices can be tabulated according to their masks in three main categories:

- Horizontal overhangs
- Vertical louvers
- Eggcrate types

Horizontal shading devices protect southern orientations efficiently, while the other types work well toward east and west. Exterior devices may conduct heat into a structure on windless, hot days, especially if they are made of dull-finished materials.

\textsuperscript{74} Olgay, \textit{op cit}, pp.168
This can be avoided, if the devices are insulated from the building. The simplest solution to this is to connect the device to the building only at necessary points, leaving an open airspace in between. This open slot also serves as an escape hatch for banked-up warm air\textsuperscript{75}. The size and spacing of some simple shading elements may be estimated from the graph\textsuperscript{76} (Fig. 38).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure38.png}
\caption{South Facing Window, Horizontal Louver at Infinite Length, 20°-40° N. Latitude}
\end{figure}

Graph to estimate the size and spacing of the shading element (Ref.: Brown, \textit{op cit})

\textsuperscript{75} \textit{Ibid}, pp.74
\textsuperscript{76} Brown, \textit{op cit} ,pp.146
2.3.3 HOUSING LAYOUT

2.3.3.A SITE SELECTION

In hot dry climates, wind is a liability not an asset. Hot dry winds will increase discomfort and carry dust and sand and so therefore:

1. Protected sites where wind speeds are lower are therefore to be preferred
2. Sites in the proximity of large advancing crescent-shaped dunes (barchans) should be avoided\(^{77}\) (Fig. 39).
3. Maximise shade and minimize wind.
4. In case there is a slope, the site should be chosen at the bottom of the slope for exposure to cold air flow at night and on east orientations for decreased solar exposure in the afternoons\(^{78}\) (Fig. 40).

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\(^{77}\) Evanes, *op cit*, pp.55-56

\(^{78}\) Brown, *op cit*, pp.74
2.3.3.B SUBDIVISION LAYOUT

Subdivision layouts can plan roads to run east/west, allowing builders to orient towards the road and gain optimum solar exposure. Building lots easily can be arranged on east/west roads to eliminate shade cast from one lot to the next. If roads must run predominantly north/south, siting for proper solar orientation is more difficult. Two simple ways to optimize building orientation in these situations are to combine lots and to use “flag lots.” These involve redesigning the shape of the lot to simplify access to the road. Both options must be considered in relation to local zoning restrictions and market response79 (Fig. 41).

Figure 41
Subdivision layout for solar access. (Ref.: Schwolsky, op cit)

2.3.3.C PASSIVE CONDITIONING OF OUTDOOR AIR

- **Wind breaks:**
  These can be used not only to lessen the impact of strong hot or cold wind but also, if shrubs and trees are used, the air will pick up moisture from the leaves and so increase its humidity, so cooling the air.

- **Dust:**
  Use air that has passed over natural planted ground cover to reduce dust levels. Ensure that land on the windward side of the site or settlement is planted or maintained so that the earth's crust is not broken because, if it is, this produces erodible dust particles that will be carried on the wind to the house. Avoid exposed land and replant natural vegetation if possible, even on unused plots in the centre of towns. Adopt compact plans for groups of houses in hot dry areas to avoid the formation of dust. In addition, a small plot size will increase the likelihood of more of the site being landscaped, so reducing dust. Compact plans also provide more shade.

- **Natural air conditioning:**
  Use air that has traveled over water or vegetation, for cooling. Also because the surface of water is flat, wind speeds can be very high over water because of the surface resistance. Trees around the house can lower the air temperature by several degrees.

- **Sound barriers:**
  If the site is noisy build a substantial garden wall to keep the noise out. Sound is very persistent and will slip through any holes in a barrier so make sure the barrier is continuous.

- **Cool pond:**
  Sunken gardens are a classic example of a coolth pond into which the cooler air descends. Garden walls can act as pond walls. Cool, moist, well shaded gardens within such walls around a house (not too large that the intrusive wind above will stir up the cool air) can lower the air temperatures by 2-5 deg C in hot dry climates.

- **Sun traps:**
  If higher air temperatures inside the house are required, expose the ground surface in a sheltered sun spot facing towards the south or west, and shelter from the incident wind.
The actual ground temperature can be significantly increased by doing so and will warm the air above it. Using deciduous planting over such a space means that in winter one could have a sun trap and in summer a coolth trap in the same space.

- **Basement coolers:**
  Use the prevailing wind and the coolness of a basement to lower the temperature of the air around the house before it is taken in to ventilate the building (Fig. 42).

- **Wind catchers:**
  Wind catchers or ducts through which air travels before reaching the house can reduce or increase the temperature of the air entering the building, as air issuing from ducts in the wall can be cooler or warmer than the incoming air.

- **Pavements:**
  Use pavements around the house to condition the air. Hard, light surfaces with a high reflectivity directly adjacent to the building will not only reflect light indoors but will also heat the air directly above this hot pavement convectively before it moves into the house. If the object is to reduce the temperature then ensure that the ground surfaces adjacent to the house are shaded and absorptive, or planted. Shading, such as awning, verandas or deciduous planting, around the building can be designed to allow sunshine in winter and to keep it out in summer.

- **Breeze walls:**
  Use "breeze walls" around the garden of the building or on roof parapets. Well placed holes can be placed in the walls to allow the pleasant wind in, while obstructing the view. Walls facing unpleasant winds should have no holes through them.

- **Heat – scape:**
  Heat-scape the external envelope of the building.
  People often think that heat only travels into the building via the windows but it can also enter the building through the walls by conduction through the wall. Shade walls to keep them cool in summer if necessary. A wall in the sun will, in still conditions, heat the air adjacent to it, which then rises and can be caught and funneled into the window above the hot wall. If there is a sun shade above the window, this will trap the rising warmer air in which the pressure will build and so force it in through the window. Vent solar shades to remove this heat if it is unwanted.
This may be an excellent thing in winter where the heat will add to the internal comfort of the occupants. Windows can be designed to take advantage of this winter heat if required. A good way of keeping walls cooler is to place planting against the wall that will dissipate the heat before it reaches the wall. If deciduous species are used then the wall can be warming in winter and cooling in summer.\textsuperscript{80}

\section*{Shading effects of trees and vegetation}
Deciduous trees are valuable when placed close to buildings, since one aim of solar control is not to interfere with the winter sunshine. To achieve efficient shading, trees have to be placed strategically. As the sun passes in the morning and late afternoon at a low latitude, trees give their best performance in the east-south and on west – south – west sides. At mid-day the sun’s path is high and the rays can be intercepted easily with an overhang; at this time of day the trees on the south side perform poorly, casting their shadows near themselves\textsuperscript{81} (Fig. 43,44,45).

\textsuperscript{80} Roaf, \textit{op cit.}, pp. 122-124
\textsuperscript{81} Olgay, \textit{op cit.}, pp. 76
Figure 43
Trees used to guide cool air flows into dwellings. (Ref.: Ali, T. C. and Brown Jane, (1977), "Landscape Design for the Middle East", RIBA, London)

Figure 44
Vegetation used to shield roofs and walls. (Ref.: Ibid)

Figure 45
Orientation of building and vegetation in hot arid climate

Orient building to receive breezes but provide shading from morning and afternoon sun

High crown trees to provide shade and allow breezes to penetrate through building
Conclusion
This chapter is concerned with human health and comfort which are the responsibility of the architect starting from selecting the site and materials used at home to the design of the house itself.

PART A: PROVIDING HEALTHY LIVING CONDITIONS

- Check the site for contamination, if contaminated then it could be treated with neutralizing chemicals and removed or replaced with clean top soil or by sealing the base of site.
- Avoid using asbestos in all its forms: white, brown, or blue.
- Urea formaldehyde foam could cause irritation and in order to avoid it:
  1. Use blown mineral fibres or expanded polystyrene beads for cavity-fill insulation rather than UFF.
  2. Make sure there is no possible leakage through cracks or holes into the house from cavities filled with UFF.
  3. Repair any damp patches in walls adjacent to UFF-filled cavity or material.
- Avoid using lead and remove all lead pipes from home.
- In order to avoid the growth of legionella, thermostats in water tanks should be set to 55 deg C and lipped fitted lids should be placed securely over water tanks.
- Do not allow cracks in construction where mineral fibres can infiltrate a room.
- In order to avoid the growth of mould:
  1. Eliminate cold bridges in the external and internal walls.
  2. Remove moisture in the home with good zoning of wet activities and a range of good opening windows and vents and repair any cracks in the structure.
  3. Have moisture absorbing walls such as a plaster finish with a water-based ecopaint finish.
- Paints containing: solvents, white spirits, turpentine, VOCs, heavy metals such as cadmium, lead, mercury or formaldehyde are not preferred. Avoid all paints with chromium.
• Put a plant at home to clean up the internal air quality.
• Use gypsum plaster but natural gypsum and not phosphogypsum.
  Use sand and lime plaster. Mud plaster is also excellent and could be mixed with well-
  fired wood ash. Do not use cement based plaster.
• Use timber windows rather than PVC ones and avoid PVC furniture.
• In risk areas, radon concentrations could be reduced by placing an perforated,
  impermeable membrane between the concrete lower slab and the ground, or a well
  ventilated crawl space beneath the floor.
  Also all cracks and openings in basements should be sealed.
• Avoid organic solvents by:
  1. Using water-based eco-paints and varnishes that do not contain ammonia
  2. If you are using glue, paint strippers or varnishes, open the windows wide and
     ventilate the rooms really well.
  3. Keep only small quantities of them in the house
  4. If you have bedding dry cleaned, air it thoroughly before using.
• Use wall paper that is made of paper and not synthetic materials such as vinyl.
  If you paint over it chose eco paints that do not contain solvents, vinyls or fungicides.
• Avoid using wood preservatives in enclosed spaces and avoid storing them in the
  house.
• In order to avoid dust mites:
  1. Lower the humidity in a room until it becomes too dry for the dust mites to survive.
     Put a good ventilation window above and/ or beside the cooker.
  2. The first line of attack should be to remove their habitat, so out go the wall to wall
     carpets and curtain.
• Fluorescent lighting should be replaced with non fluorescent lighting as much
daylight as possible.
PART B: ENERGY EFFICIENCY

1. HOUSING LAYOUT

Site selection
1. Protected sites where wind speeds are lower are therefore to be preferred
2. Sites in the proximity of large advancing crescent-shaped dunes (barchans) should be avoided.
3. In case there is a slope, the site should be chosen at the bottom of the slope for exposure to cold air flow at night and on east orientations for decreased solar exposure in the afternoons.

Subdivision Layout
1. Roads should run east-west
2. If roads must run predominantly north/south, either combine lots or use “flag lots.”

Passive conditioning of outdoor air
1. Use shrubs and trees to lessen the impact of strong hot wind and to cool the air.
2. To reduce dust:
   - Ensure planting the land on the windward of the site.
   - Avoid exposed land
   - Adopt compact plans for group of houses to avoid formation of dust.
3. Use air that has traveled over water or vegetation
4. If site is noisy build a substantial garden wall
5. Ensure that ground surfaces adjacent to the house are shaded and absorptive or planted.
6. Well placed holes in “breeze walls” around the garden can allow pleasant wind in and walls facing unpleasant wind should have no holes.
7. Use deciduous trees on east-south and on west-south west sides.
2. SHELTER DESIGN

House types

1. Adjoining houses, row houses and group arrangements (all continuous on East-West axis) are advantageous.
2. The radiative, connective and evaporative cooling process of the courtyard houses makes it an effective design strategy in hot arid climates.
3. Earth sheltered house types are:
   - Lower in energy consumption
   - Highly protected from fire risks
   - Secured from earthquakes and storms
   - Protected from noise and pollution
But needs special structural, waterproofing and insulation requirements which will add more construction cost that may not be accepted.

- When considering orientation, East and West walls should decrease and North and South walls should increase.
- Integrated cooling systems

The following methods are recommended:

1. Wind catchers
2. Solar chimney
3. Skytherm
4. Cool pool
5. Indirect evaporative coolers
6. Night ventilation cooling

- Colors:
  1. Use white paints on sun exposed surfaces.
  2. Use dark absorptive colors where reflections toward interior are expected.
  3. Use dark colors for deep surfaces for winter radiation absorption.
- Form and Volume
1. High volume to surface ratio and dwelling with double banked rooms are preferable.

2. High ceilings are not significantly more comfortable than rooms with ceiling heights of 2.7m or even 2.5m.

3. More compact form with courtyard is required to minimize heat gain.

4. Closer spacing between dwellings should be adopted.

5. Medium rise apartment blocks are suitable meanwhile high rise isolated apartment blocks are totally unsuitable.

3. BUILDING ELEMENTS

1. Roofs and Walls

   Roof insulation
   1. A maximum “U” value of 0.9 watt/m² deg C is recommended for roofs.
   2. A cheaper but less effective way of shading the roof is with reed matting or timber boards suspended above the roof leaving an air cavity.
   3. A relatively lower “U” value is recommended for East and West walls.
   4. Insulation material in Egyptian code are not necessarily ecologically friendly so it is recommended to study its ecological impact first.
   5. Roofs that are horizontal receive less sunlight per sq. ft.

Wall insulation
   1. Use construction bricks with insulation materials to increase its thermal resistivity and decrease its thermal capacity especially in East-West walls.
   2. Thermal insulation layer in walls should be placed in the direction of heat source.
   3. Use several consecutive air voids in walls to decrease "U" value.
   4. Reflective thermal insulation could be used and placed on outer layer of the wall.
   5. Light weight interior and exterior plaster of low thermal conductivity could be used for wall finishing.
   6. Decorative and insulative wall cladding materials could be used.
7. Special paints could be used as an aid to wall thermal insulation.

2. Openings and Windows
   1. Use low inlets and high outlets to produce a good pattern of air movement, each outlet is of 5% of floor area, this is in case of structural cooling using stack effect.
   2. In case of using wind pressure for cooling, a large inlet and a small outlet is recommended because it results in a lower maximum speed but a better distribution of air over the room.
   3. When using sun shades, a slot between wall and shade is required for more direct air flow.
   4. For hot dry conditions, ventilation for structural cooling is recommended and this requires high internal heat capacity building.
   5. 10 air change /hr is recommended.
   6. Double glazed windows with low-solar gain is recommended.

3. Shading Devices
   1. Connect shading devices to the building only at necessary points, leaving an open air space in between.
   2. Horizontal shading devices are recommended for southern orientation while vertical and eggcrate types work well towards East and West orientation.

By following the above mentioned guidelines we will achieve a healthy, comfortable and energy efficient house and by following them also we will succeed in minimizing the running cost of the house, but we need not to neglect the outdoor environment which our buildings hold a great responsibility towards harming and polluting it, and so therefore the next chapter will be concerned with outdoor environmental protection.