HOLISTIC DESIGN STRATEGIES FOR GREEN ARCHITECTURE

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of

MASTER OF ARCHITECTURE

By

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CANDIDATES DECLARATION

I hereby certify that the dissertation entitled, '**HOLISTIC DESIGN STRATEGIES FOR GREEN ARCHITECTURE",** in partial fulfilment of the requirement for the award of the Degree of **Master of Architecture,** submitted in the Department of Architecture and Planning, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during a period from July, 2001 to February, 2002 under the guidance of **Prof. S. Y. Kulkarni.**

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

(Dawit Benti)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The Lord will perfect that which concerns me
Holy Bible, Psalm 138:8

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Dawit Benti

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HOLISTIC GREEN DESIGN STRATEGIES

CHAPTER 1

INTRODUCTION

"The environment is too important to be left to the environmentalists"
HELMUT SIHLER

We are witnessing the dawn of the season where all the actions of humankind are evaluated with reference to the impact; they have upon this planet of ours. All human activities in their various stages of development are scrutinized for their possible interference, often negative, in the affairs of the global and local environment. The way many activities, like transport, manufacturing, architecture, construction, and agriculture, are proceeding is taking its toll on the global ecosystem leading to the disruption of nature's mechanism to sustain ecological balance.

This paper is an attempt to show how the practice of architecture could take a whole new way of meaning in what is known as **green architecture** which is a holistic way of designing buildings so that all the elements and systems of the building are designed in an integrated manner to minimize their impacts upon the environment and upon the occupants of the buildings (Indoor air).

1.1. IDENTIFICATION OF THE PROBLEM.

Architecture before the advent of the industrial revolution, in its vernacular stage, was producing buildings that were part of the ecosystem. Vernacular architecture was a time tasted creation of the early humans that matured over the millennia. It was an environmentally responsive, sustainable practice that saw to it that, resources to produce buildings were extracted from sustainable means and materials were produced in labor intensive practices that didn't overburden the ecosystem's potential to supply energy. In the course of the lifetime of buildings there were no colossal demands on energy to operate and condition the buildings. Furthermore after the building has served its purpose, all the systems and members of the old building will go back to the earth, maintaining natural balance without the production of waste and the need to get rid of it.

The industrial revolution ushered in a completely new choice of materials and technologies that profoundly changed and altered the way humankind related himself with nature. Architecture, which is one of the earliest creations of human beings, took a completely different course of action due to the manifold possibilities that the new materials and technologies offered. Now that there are new materials, technologies and wealth, it seemed obsolete to design buildings which are environmentally responsive and sustainable that ensured the continuous interdependence of man, his buildings and nature. Architects began to design buildings that subdued nature instead of responding and enhancing it, and experimented in many ways than one, whatever is possible through these materials and technologies. They designed deep plan buildings that avoided the solar radiation. They made use of air-conditioning technologies that offered any kind of temperature inside the envelope of buildings irrespective of the weather of the exterior environment. A lot of scarce and purified water is used to flush the toilets. The Building materials are transported from great distances and when the lifetime of the building is over the materials are unable to go back to the earth.

Furthermore, architecture fell victim to styles and fashions and the architects yielded it to these transient phenomena at the expense of the environment. When architecture succumbed to style and technology without their careful and prudent synthesis, there arose a huge demand for energy that is harvested from unsustainable means. These made buildings to take the lion's share of the total energy production of the globe, as they consume half of the total amount of energy productions. On top of this, buildings championed as the greatest polluter of our environment, in the production of carbon dioxide, chlorofluorocarbons, waste and other harmful substances at the various stages of the life of the building materials used to construct them.

Apart from the fact that buildings consume non renewable materials and energies, and that they are the biggest polluters, their creators, the architects, lack the practical methodology of holistically designing green buildings which are responsive to the external as well as to the internal environments.

1.2. OBJECTIVES

1. To study the components of environmentally responsive green architecture and their degree of importance in the creation of the same.
2. To probe into the limitations of conventional architectural practice in producing green buildings.
3. To analyze the holistic, design process of green buildings and the role of the architect in the body of professionals that help create green architecture.
4. To synthesize a comprehensive and a holistic design methodology for the practice of green architecture which will culminate in the design of buildings that have the least impact on the environment and on the occupants of the buildings.

1.3. SCOPE

- The study is limited to the methodology of synthesizing the elements of green architecture in an integrated manner to produce green buildings. It emphasizes the process of uniting the elements into a whole, rather than the elements themselves.
- The scope of this study is limited to low rise buildings such as offices, commercial buildings, apartments, etc... The study doesn't deal with single family residences high rise buildings, and factories.
- The study is limited to tropical and subtropical climates.

1.4. METHODOLOGY

- At the outset the need for the topic of green architecture is elaborated
- Second comes the detailed collection of secondary information from journals, newsletters, books, Internet and others about the various elements of green architecture, the design process, and green buildings.
- Analysis of the design process for green architecture is done, comparing it with conventional architectural design process.

- Case studies that best exemplify the various design strategies of green architecture is presented.
- Finally based on inferences from the analysis and case studies, guidelines will be formulated that will help practicing architects to produce green buildings.

CHAPTER 2

BACKGROUND

2.1. ARCHITECTURE AND OUR ENVIRONMENT

The green house effect, the ozone hole and global resources.

It is elusive to many, including architects, that unwise practice of architecture can affect our environment in a magnitude that we have never dreamt of. Buildings enormously contribute to the pollution of our ecosystem. In doing so they at the same time consume the majority of natural resources that the earth can provide.

Buildings directly or indirectly consume 50% of the total amount of energy that is used by human beings which is equivalent to the consumption of transportation and industries combined. In their lifetime, buildings unsustainably use 42% of the hardly earned pure water. Likewise 50% of the bulk of materials produced by human beings is spent on buildings.

Similarly 50% of world fossil fuel consumption is related to the servicing of buildings, therefore 50% of the carbon dioxide output is chiefly produced in relation with buildings. Carbon dioxide (CO_2) is the principal greenhouse gas, which contributes about 50% of the total global warming effect that is notorious for its multifaceted global environmental hazards. If CO_2 produces 50% of the global warming effect and buildings produce 50% of the CO_2 output, it then, follows that a quarter of the total greenhouse gasses is produced by buildings in the course of their lifetime.

Another burning issue, apart from the global warming is the depletion of the ozone layer (Ozone hole) that is protecting the earth from the harmful solar radiation. This depletion is chiefly attributed to the act of CFCs (Chlorofluorocarbons) on the ozone layer. Far from popular expectations, roughly 50% of CFCs produced in the world are used in buildings in air conditioning, refrigeration systems, fire extinguishing systems and, in certain insulation materials.

The greenhouse effect and the ozone hole are two of the most threatening effects of pollution, which in turn are causes for myriad global climatic aberrations.

It is therefore evident that a quarter of total greenhouse gasses, and half of ozone depleting gasses, is under the control of the designer or inhabitants of buildings, who can demand or design, environments that use less energy, and less CFCs, so that green house effect and ozone depletion can be slowed down.

GLOBAL POLLUTION	
POLLUTION	BUILDING RELATED
Air Quality (Cities)	50%
Global warming gases	40%
Drinking water pollution	40%
Landfill waste	20%
CFCs/HCFCs	50%

Table 2.1. Building related global pollution (Architectural Design, July 2001)

GLOBAL RESOURCES	
RESOURCES	BUILDING USE
Energy	50%
Water	42%
Materials (by bulk)	50%
Agricultural Land Loss	48%
Coral Reef Destruction	50%(indirect)

Table 2.2. The amount of global resources which buildings use. (Architectural Design, July 2001)

The tables show, that buildings are consuming huge amounts of resources and energy, in an unsustainable manner that some balance should be devised, which will check that, they will continue to be designed and built in the best possible manner with the least amount of pollution and judicious use of extremely limited amount of energy and natural resources

2.2. HOLISTIC GREEN ARCHITECTURE

Green buildings are buildings in which all of the materials and systems are designed with an emphasis on their integration into a whole for the purpose of minimizing their impact on the globe and on the occupants (Indoor air quality).

Green architecture is therefore an architectural practice carried out with great concern for the betterment of the global environment and the interior environment of buildings. The holistic approach takes a "cradle-to-grave" implementation process for a building project, calculating cost and effect from the day a project is conceived until the day the facility is no longer used, that is, "life-cycle" costs. Holistic approach tries to bring a solution from the synergy of the elements rather than aggregation or the sum total of the piecemeal contribution of the elements.

Holistic design.

Holistic design in our context is practiced with the following three prominent features.

- Cradle to grave (life cycle approach)

In the cradle to grave approach all the decisions at the design stage are evaluated on the effect that they have or in the cost (environmental or monetary) that they incur during the whole lifetime of the building. That is, in choosing the site, in constructing the building in the time of occupancy, and finally in the demolition of the same.

- Design in a collaborative team

No single expert is there to analyze and design all the systems of green buildings, since the elements of green architecture cross professional boundaries.

- Solution from the interaction of green elements (synergy of elements)

A decision made regarding an element or a group of closely related element should be studied for its possible effects, positive or negative, on all the elements of the components and/or the whole building system in the whole life cycle of the building.

Therefore holistic green design is the practice of designing of buildings in a team, whose materials and systems have the least impact upon the globe and upon the occupants, taking into consideration the life cycle of the building and the synergy of the elements.

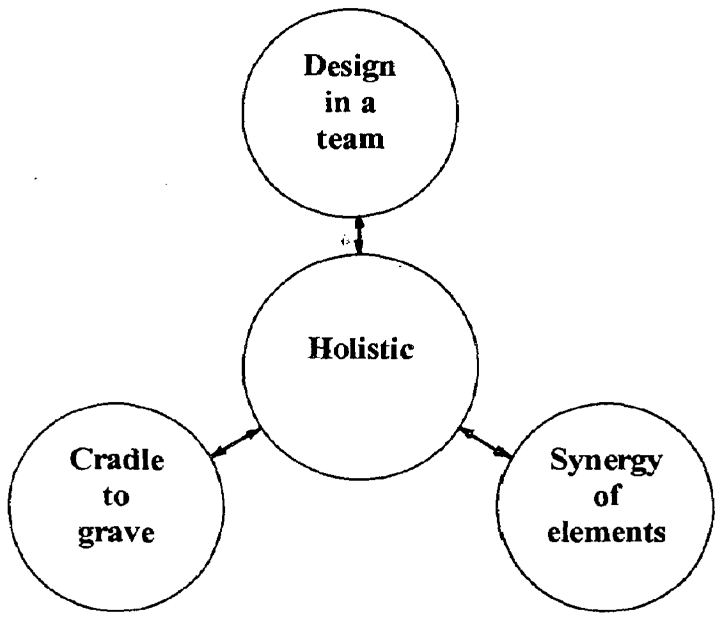


Fig 2.1 The concept of "Holistic" in the process of green architectural design

Holistic green architectural practice or green architecture has the following basic elements that are at its disposal to carry out the objective of designing with the environment.

1. Siting and land use (including transportation issues)
2. Energy efficiency
3. Material management
4. Water management
5. Waste management
6. Indoor air quality (IAQ)

We can't make a building green only by specifying few green products. An architect must pay attention to each of the six categories and capitalize on the choices that benefit a given community most. In cold regions that may mean focusing design efforts on the heating system, whereas in dry places water conservation may be the top priority and in coastal regions site preservation may be most important. Hence the practice of green architecture, is region specific.

A green design expands and complements the classical building design concerns, utility, durability and beauty. Architects should add to Vitruvius' **firmitas, utilitas** and **venustas** (strength, functionality and beauty) a further criterion for judgement of architecture, **restitutas,** restitution, in which the act of building enhances the environment in ecologically responsive manner (Architectural Review, Jan 2001).

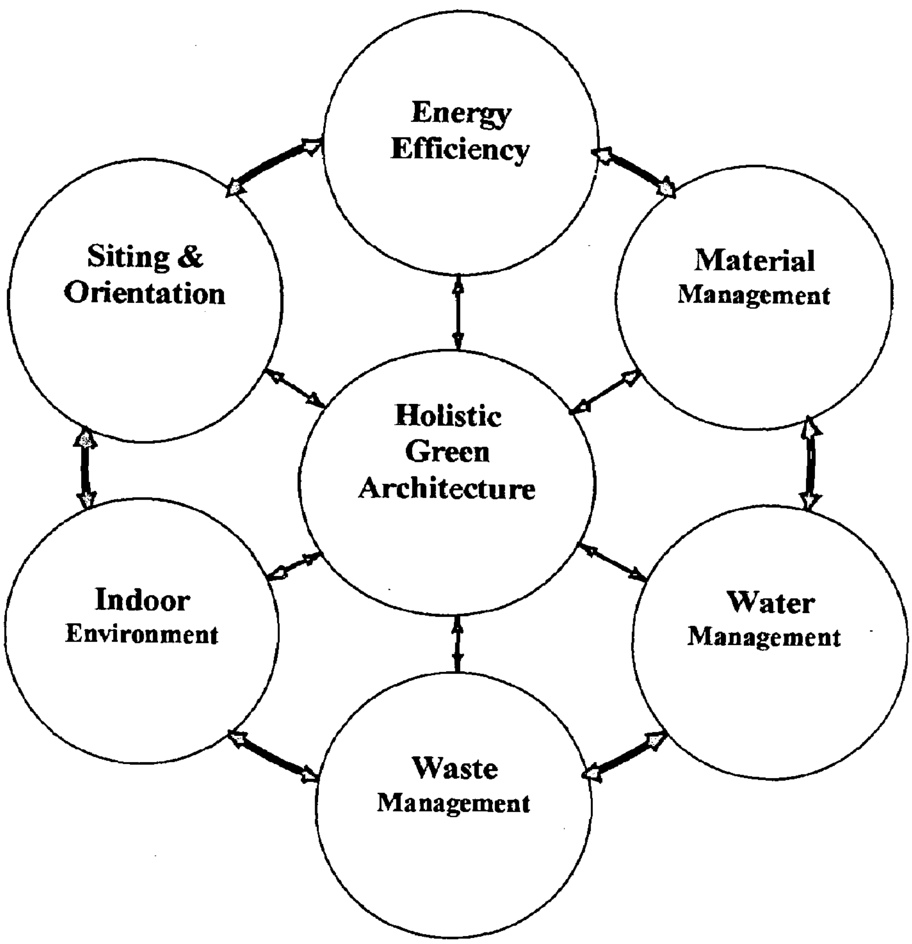


Fig 2.2. Holistic green architecture and its elements.

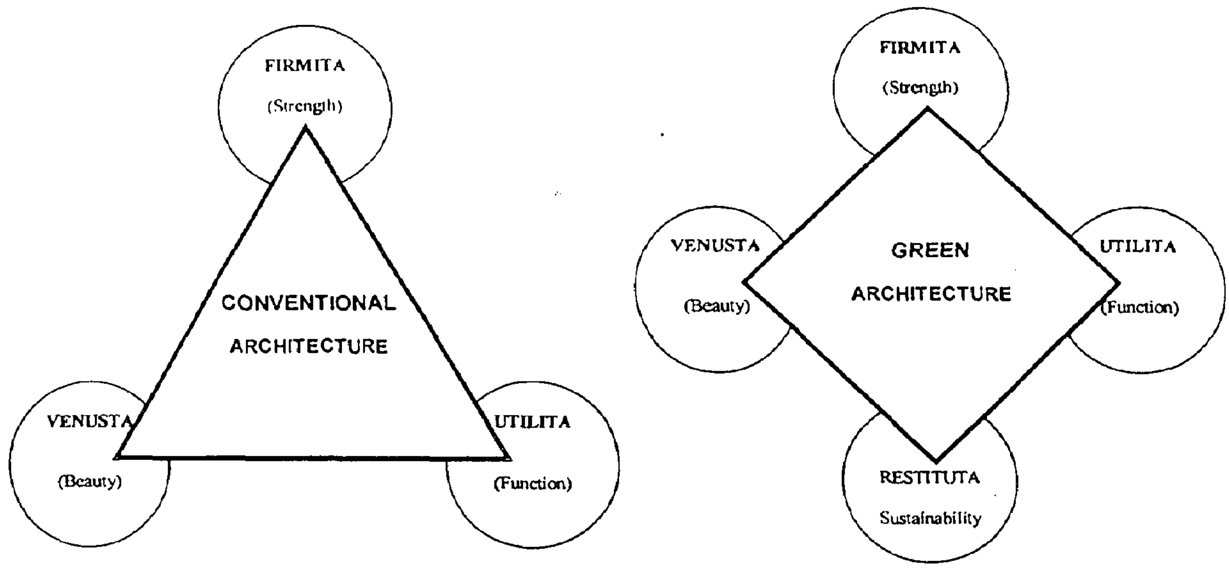


Fig 2.3. Conventional and green architecture .The place of restitution or greeness in green architecture

2.3. GREEN BUILDING RATING SYSTEMS

Building rating systems help the move towards the design and construction of green buildings as clients and developers become aware of their value and demand for greener buildings. Some countries have already produced rating systems that will evaluate the environmental performances of buildings and award them certificates.

The following sample rating system which is already in use consists of the following 6 major categories, and maximum points:

- Sustainable sites: ________________ 14
- Water efficiency: ________________ 05
- Energy and Atmosphere: __________ 17
- Materials and Resources: __________ 13
- Indoor Environmental Quality: ______ 15
- Innovation Credits:________________ 05
- Total Maximum Possible Points:______ 69

Certification Levels:

- Certified: .... 26-32 points or >37% of max
- Certified Silver Level:.. 33-38 points or >47% of max
- Certified Gold Level: .... 39-51 points or>56% of max.
- Certified Platinum Level:................................... 52-69 points or>75% of max

CHAPTER 3

DESIGN OF GREEN FEATURES

" A successful green building is one that integrates seamlessly with the natural systems in the biosphere, with minimal distinctive impact on these systems and maximum positive impact."
Ken Yeang.

It seems daunting to take the step to analyze every element of green architecture and rigorously trace the interactions with various professionals to ultimately come up with the design of buildings that have the least impact on the environment and on the occupants of the buildings. The classification of green design strategies into the six major categories, namely siting and orientation, energy efficiency, material management, water management, waste management and indoor environment is a major breakthrough in understanding the almost complex and elusive concept of green architecture.

3.1. SITING AND ORIENTATION

Very early in the design process it is necessary to consider how development of the any particular building project is going to affect the local ecosystem beginning from the outset of the construction stage, till the end of its lifetime.

The location of any building with respect to other buildings of related occupancy is also of utmost importance since, there is going to come the need for continuous movement of people using transportation that will eventually have a deleterious impact upon a given locality.

Finally, once the general location of the building is fixed, the building must be placed in such a way that it is oriented to get the most out of passive solar and passive ventilation systems using the direction of the sun and wind. All passive systems should be analyzed in relation to microclimate, topoclimate and macroclimate.

The following diagram represents all the components to be considered in the whole siting process

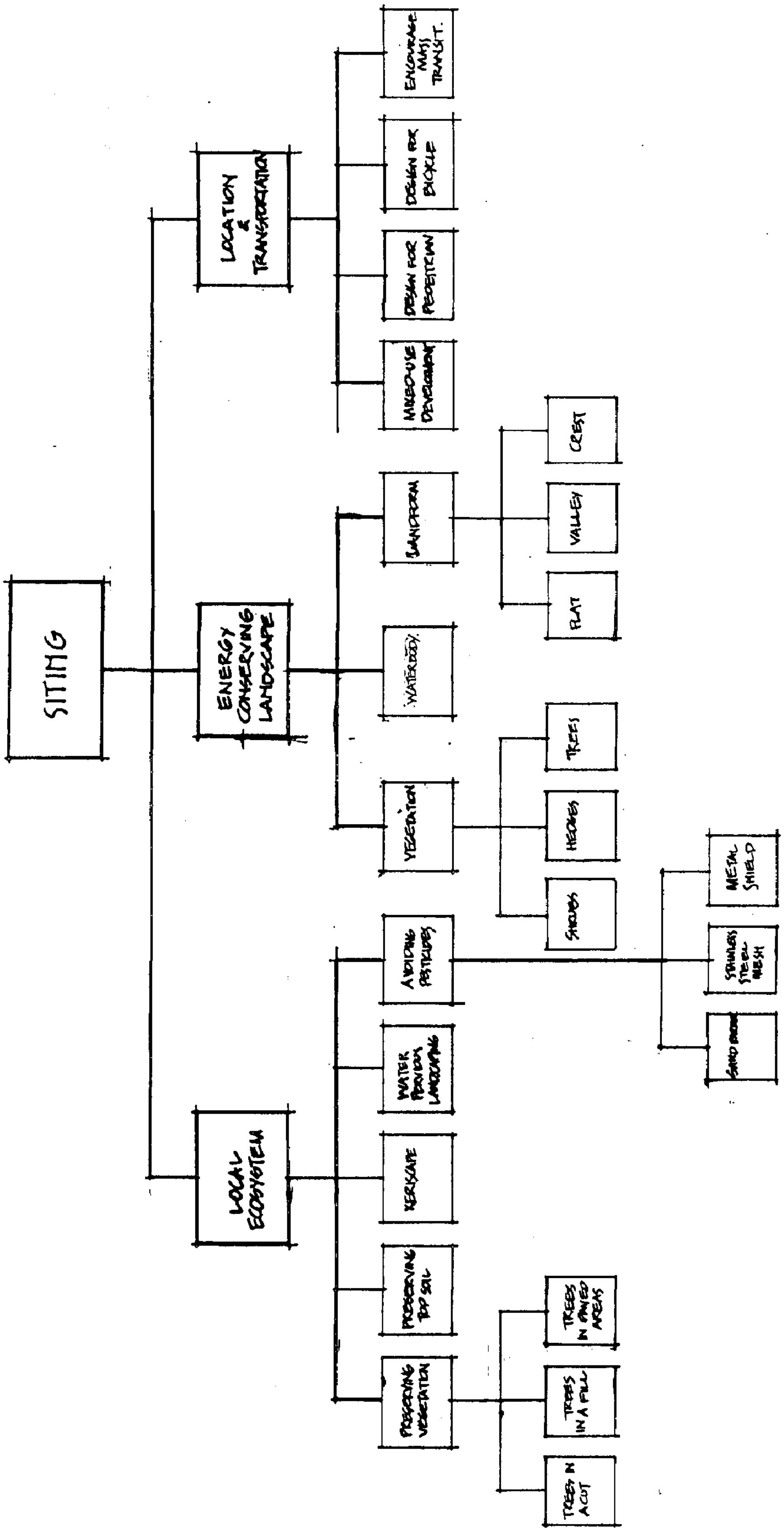


Fig 3.1. Diagram showing all the considerations in siting design

3.1.1. Local ecosystem

The site of the construction project must be protected and enhanced and the local ecosystems and biodiversity must be preserved. Moreover the existing natural or man made systems must be considered as integral elements of climatic design to be used in the design of green buildings.

3.1.1.1. Preserving existing vegetation.

Trees should be protected from damage during construction with clearly visible fencing located below the outermost branches. Much of the damage that occurs to trees during the construction process is due to soil compaction from heavy equipment and materials being driven, stored or dumped under trees. Roots which extend out far beyond the trunk are damaged when soil becomes compacted. This will kill the tree.

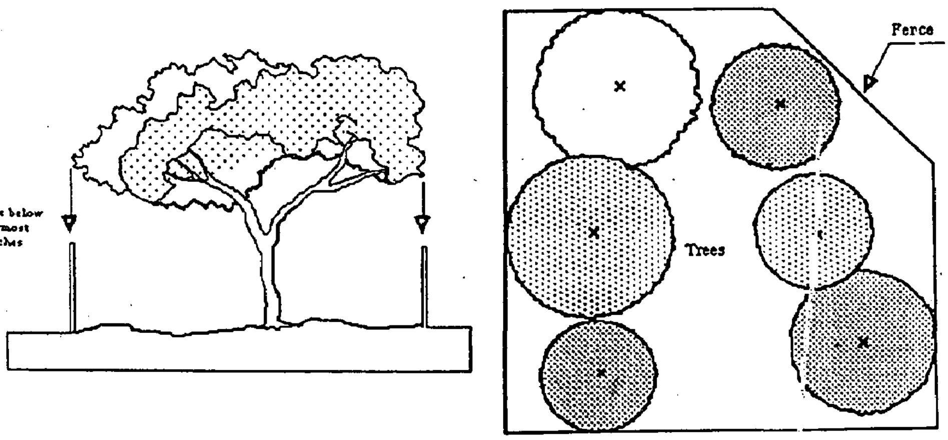


Fig 3.2. Tree protecting fence. (www.greenbuilder.com)

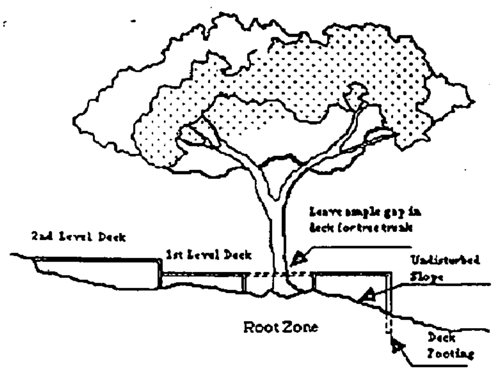


Fig 3.3. Terraced deck on slope with tree. (www.greenbuilder.com)

a) Existing trees in area of cut

Lowering the soil cover around a tree involves the actual removal of fibrous roots upon which the tree relies for food, and if the quantity removed is substantial, the tree may not survive. If roots are removed, a corresponding amount of leaf surface must also be removed to maintain the balance of water absorbed and water evaporated. The trees could be protected by retaining wall or by root pruning to induce fibrous system at a lower level. In the latter case the tree is trenched circumferentially to a depth of four feet at the drip-line. At the bottom of the trench, a layer of manure should be installed.

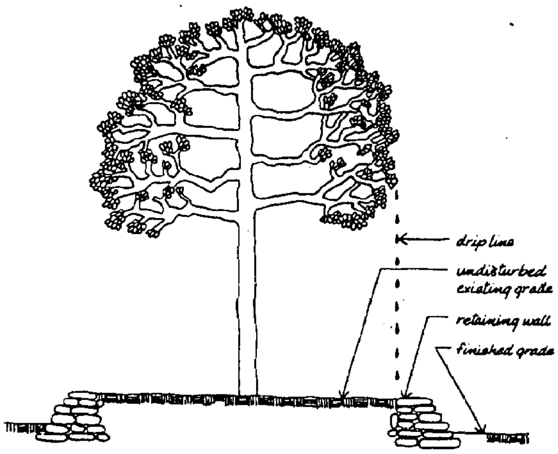


Fig 3.4. Existing tree in cut protected by a retaining wall (Zion, 1968)

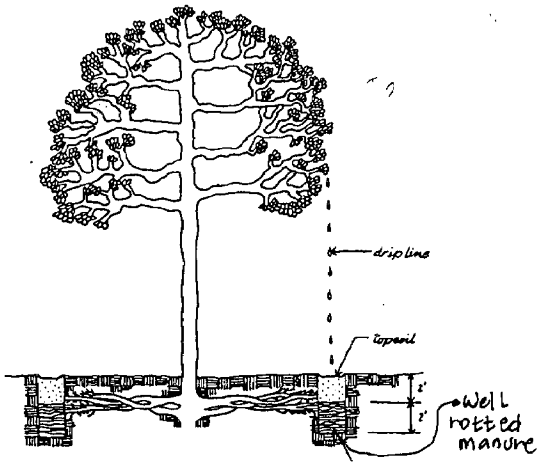


Fig.3.5. Root pruning to induce fibrous root system at the lower level (Zion, 1968)

b) Existing trees in area of fill

It is possible to raise the soil level around a tree, by using rough coarse rock fill to allow supply of oxygen to the roots. The top six or eight inches of fill may consist of topsoil so that grass can be grown. A galvanized metal guard is placed around the base of the tree to protect the bark from contact with moist soil which will induce rotting.

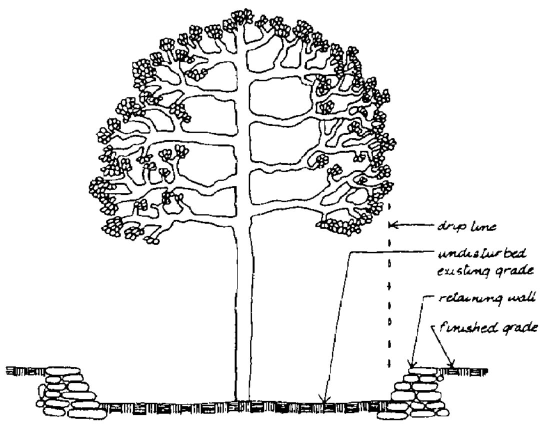


Fig3.6 An existing tree in fill protected by a well.

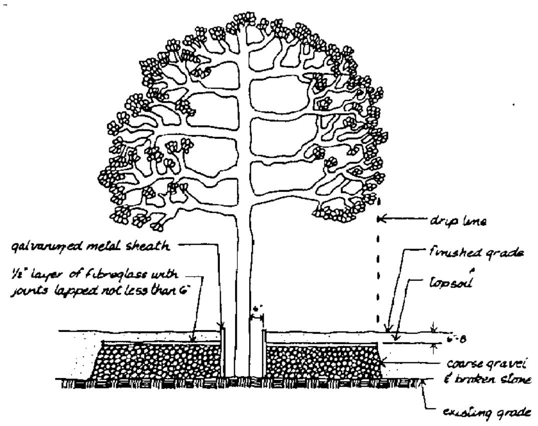


Fig3.7. An existing tree in fill by coarse gravel.(Zion 1968)

c) Existing trees in areas of pavement

The tree in pavement is deprived of much of its supply of surface water and oxygen. The preservation of such trees involves a severe pruning to reduce evaporation. To guide water and oxygen to the root system, four lateral, perforated pipes should be installed at right angles to each other and extended to the drip line. At the base of the trunk these pipes should be brought to the surface by means of an elbow.

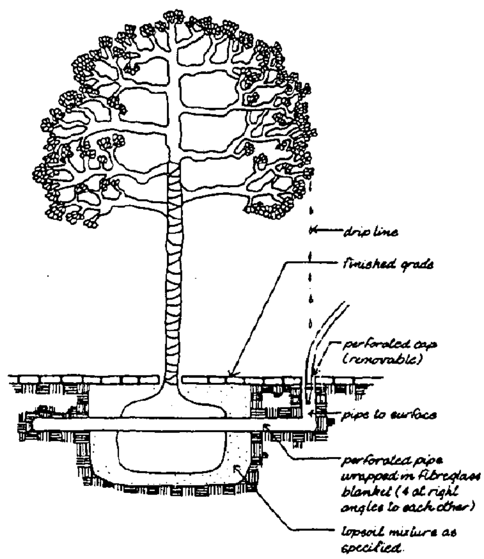


Fig. 3.8. The protection of a tree in pavement. (Zion, 1968)

3.1.1.2. Preserving and protecting top soil on construction sites.

Topsoil is a virtually irreplaceable natural resource. During any construction, topsoil should be stockpiled in an area and protected by barriers. This protects the soil's structure texture, porosity and chemical balance from the compaction that would occur if building operations were carried out on top of it or if it was mixed with subsoil, lime and cement. Areas should be set aside for the topsoil stockpile. The topsoil should be stockpiled at a depth no greater than 1 metre, and keep it well weeded and aerated until it can be reused.

3.1.1.3. Selection of xeriscape plants (that require a minimal amount of watering).

Xeriscape is a quality, low-maintenance landscaping that conserves water and protects the environment by using mulch, soil analysis, and appropriate plant selection. Especially in drought-ridden areas xeriscape plants won't need supplemental watering after an establishment period. Annual and exotic plantings can be located in small, easily accessible areas to make maintenance easier.

3.1.1.4. Landscaping with water pervious flooring.

Urban runoff from paved surfaces carries with it pollutants such as fuel, oil, paint, heavy metals, pesticides, human and animal wastes, and trash. By reducing the surface of car parking areas, increasing the permeability of surfaces not used for car movement, and integrating natural landscaping into car parking area, urban runoff can be naturally treated, groundwater supplies replenished and pollution eventually entering rivers and large water bodies could be reduced.

The impervious area of the total surface area could be calculated in a simple imperviousness ratio as Total impervious area/ Total project size. Impervious areas include rooftops, impervious driveways, sidewalks, etc. Permeable pavements are excluded from the impervious calculation. A percentage greater than 20% needs no additional measures.

3.1.1.5. Construction detailing that avoids pesticide treatments

When wood is used as a building material, termite prevention in the form of treated wood or naturally resistant wood is required. But such treatments as chromated copper arsenate (CCA), chlordane, heptachlor, aldrin, dieldrin, organochlorides, organophosphates have proved to be detrimental both to the environment and to the health of human beings. They can offgas and leach out into the soil and water table. They can be absorbed through the skin, lungs and through ingestion. Organochlorines accumulate in the fat cells of humans and produce cancer in animals. Organochlorines last some 5-8 years in the ground and act as slow poison. Dieldrin and aldrin remain active in the soil for 20-30 years, heptachlor causes long-term genetic damage.

Non-toxic termite control is the use of termite prevention and control without chemicals using, physical controls installed during construction such as sand barriers or metal termite shields. If termite infestation does occur, least toxic methods of treatment are used. Physical barriers place impediments in the path of termites, which force them to come out into visible locations as they try to enter the building's structure. Integral to the success of a physical barrier system is clear visibility, access and regular inspection.

a) Prevention.

Avoiding moisture in buildings is the best precaution in protecting against subterranean termites. Moist soil is necessary for termites and any dampness through direct contact with wood or capillary action through concrete slab or masonry foundation to the wood framing above will attract termites. 6 mm polyethylene can be used to cover the area under the structure in above-ground foundations. Foundation wall vents should be placed to ventilate buildings with crawl spaces. Soil should be 15-20 cm below any wood member. All exterior grades should slope away from the structure to provide drainage.
With regards to exterior landscaping a small dry space should be retained between plant leaves and walls to prevent moisture and mold build up. Automatic irrigation heads should be properly aligned or shielded to prevent direct spray onto the building. All wood-to-soil and wood-to-concrete contacts should be eliminated for fence and deck posts, rail supports, and trellises etc. Exterior windows and sidings must be moisture sealed.
Finally backfill under a foundation should never contain wood scraps.

b) Physical barriers

i. Sand barrier.

Sand barrier of the appropriate size is a physical barrier, since they can not tunnel through it. However it should not be so small that the termites can easily remove it. Sand is applied in crawl spaces under pier and beam foundations, under slab foundations and between the foundation and concrete porches, terraces, patios and steps, fence posts, underground electrical cables, and against retaining walls. Sand sizes should not be larger or smaller than that able to sift through a 16-mesh screen. Sand trenches of 10 cm deep and 15 cm wide could be made around outer perimeters of foundations capped by some kind of masonry can well protect against termite attack. Appendix 1 gives the list of tested aggregates and termite species.

Fig. 3.9 Sand barrier. (www.termitebites.com)

ii. Woven stainless steel mesh.

Stainless steel mesh control will control even the smallest species of termite. It doesn't corrode and can be applied to all types of buildings with concrete floors, The mesh is installed after the plumbing and footings are finished. A collar of mesh is stretched and fastened around any component that passes through the concrete slab. The mesh also provides extra security for the damp proof or waterproof membrane, which is subsequently laid on top of the mesh.

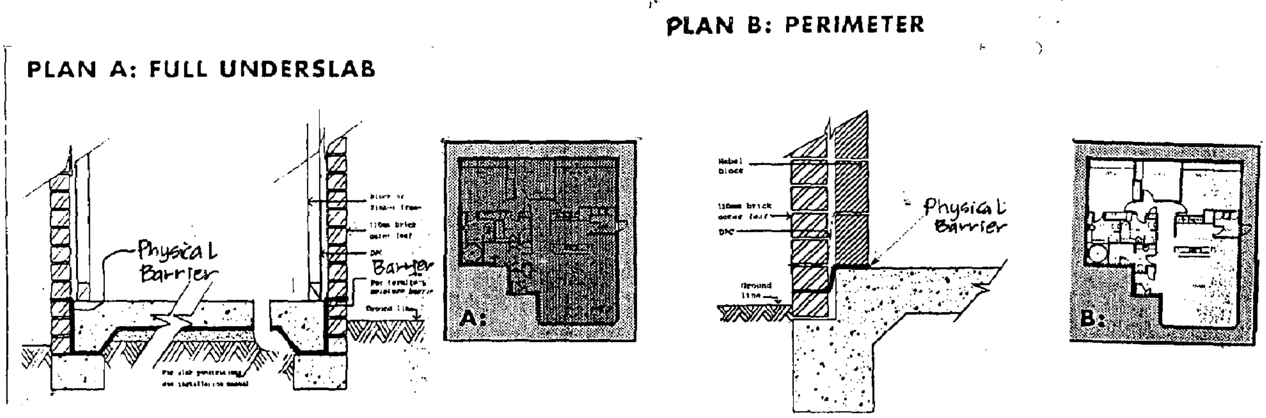


Fig. 3.10 Example of a physical barrier. (www.termitebites.com)

iii. Metal shields.

These are barriers, which prevent termites to build invisible tunnels. They force them to build tunnels on the outside of the shields, which are easily seen. Metal sheets are used in conjunction with concrete or solid masonry walls, and are fabricated of sheet metal, which is attached over the foundation walls. The edges are then bent at a 45^0 angle. They must be very tightly constructed, and all joints must be completely sealed.

3.1.2. Landscaping for energy conservation.

Climate responsive landscaping contributes to significant reduction in energy consumption by buildings as it helps to regulate the amount of wind, solar energy, and temperature that is readily available to the building environment. The landscape offers one of the most inexpensive and flexible forms of investing in energy efficiency since it doesn't require large initial investment. Here vegetation, the landform and other structures are going to be discussed.

3.1.2.1. Vegetation (Trees and Shrubs)

Vegetation as part of the landscape controls the microclimate by controlling the quality and quantity of the sun, the wind, temperature, precipitation and humidity. Architects therefore can manipulate vegetation for an energy conscious design that makes use of the energy that is readily available.

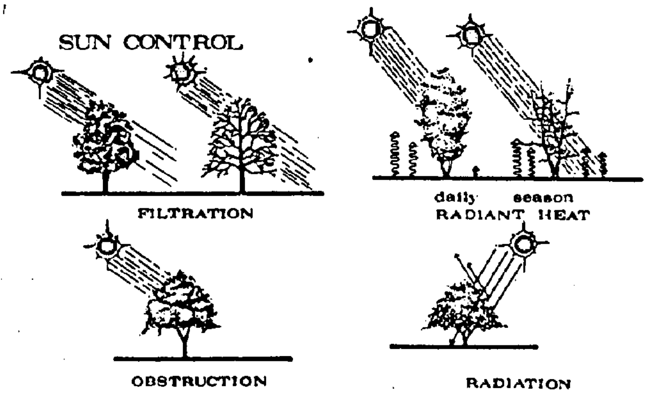


Fig 3.11 Vegetation controls the suns effect by filtration of the solar radiation and by control of the ground surface And hence the amount of reflected radiation (Robinette, 1983)

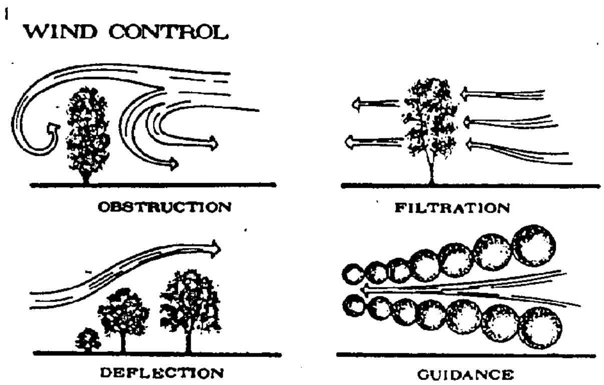


Fig 3.12 Vegetation controls wind through direct obstruction, filtration, guidance and, reflection (Robinette, 1983)

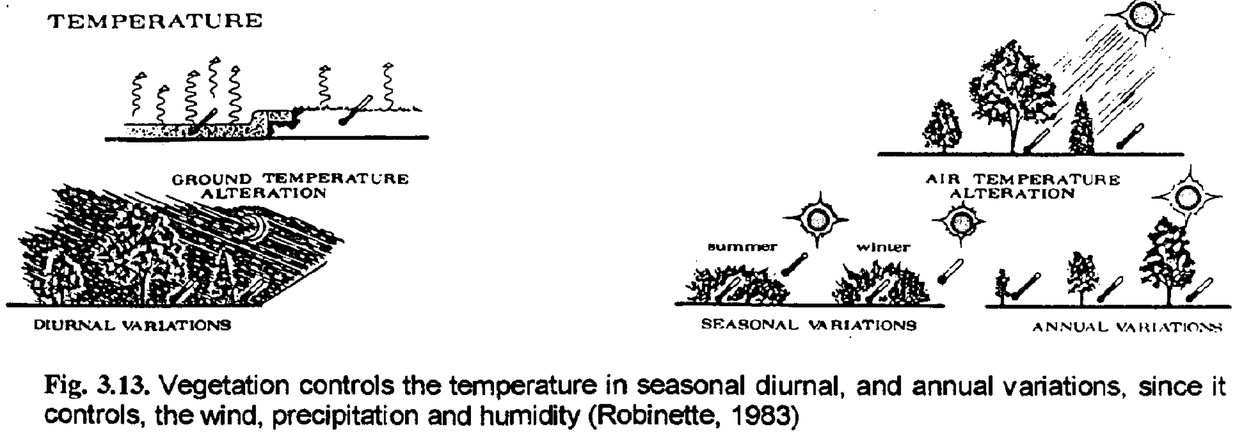


Fig. 3.13. Vegetation controls the temperature in seasonal diurnal, and annual variations, since it controls, the wind, precipitation and humidity (Robinette, 1983)

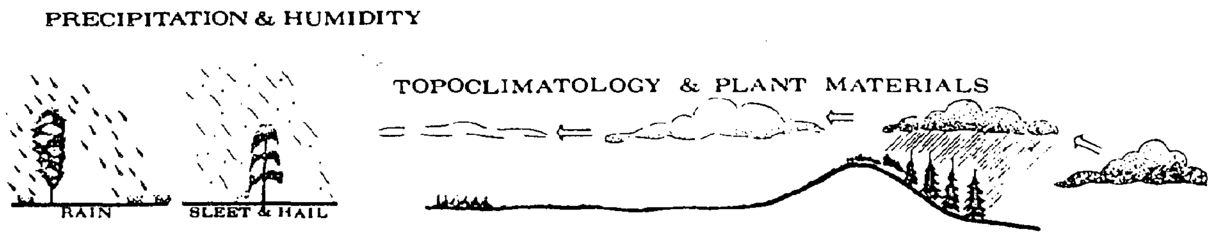


Fig 3.14. Vegetation controls precipitation. Plant materials control the impact of rain, or sleet and hail, the intensity and location of dew and frost, and of the evaporation of moisture from the ground surfaces. (Robinette, 1983)

a) Vegetation for natural ventilation (Wind control)

Vegetation causes pressure differences, thereby, increasing and decreasing air speed or directing airflow. Therefore it can direct air into a building or deflect it away. Moreover, it provides shades and reduces heat gain. To this end it could be used in protection against winter winds and in providing a shade during the summer season.

In protection against winds trees can be used as windbreaks and the following figure describes some of the rules of windbreak design. It is however good to consider that tree windbreaks can possibly impede summer ventilating breezes.

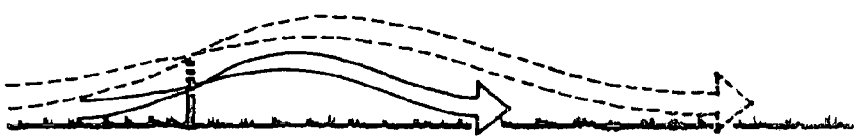


Fig. 3.15. The higher the tree or the fence the longer the "wind shadow" (Watson, 1983)

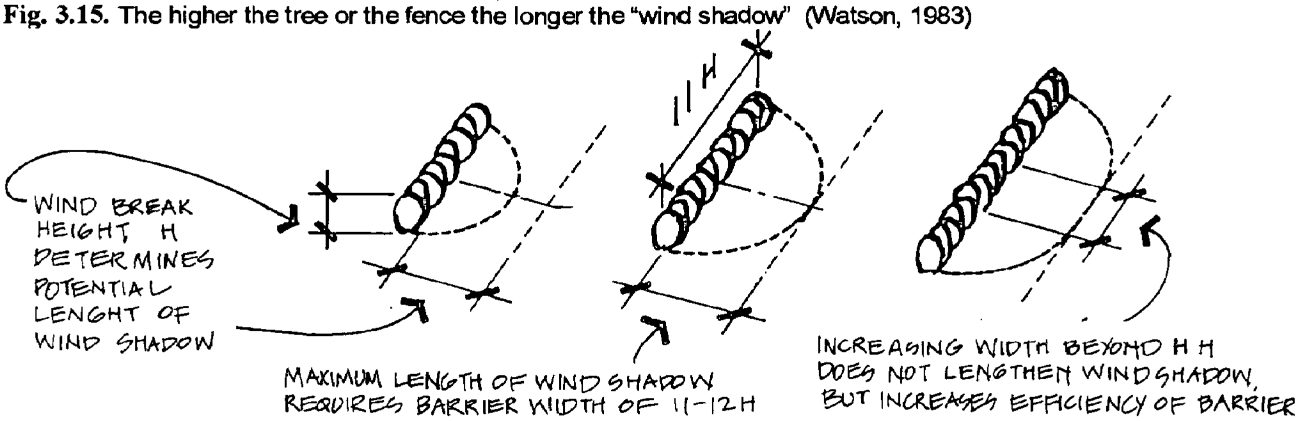


Fig.3.16. The maximum length of wind shadow is developed only when the width of the tree is at least 11-12 times its height (Watson, 1983)

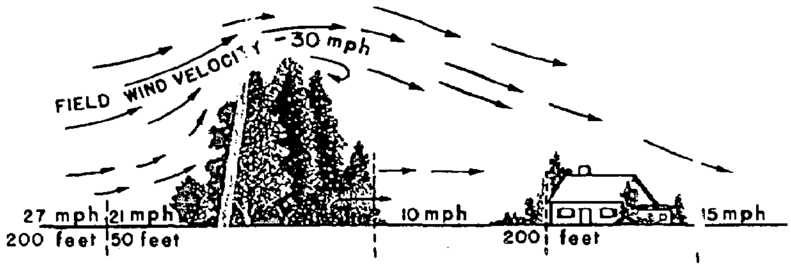


Fig.3.17 An instance of a dense vegetation in reducing the wind velocity (Robinette, 1983)

The pressure differences created by trees effect a change on the air path. The leeward side is a low pressure zone. Air tends to shift towards this. When hedges are planted next to openings the low pressure shifts the path downwards. Airflow below the canopy of a tree is similarly shifted upwards, creating a ceiling wash flow if it is near to the building and if placed at a distance canopy may warp the air stream sufficiently to miss the building.

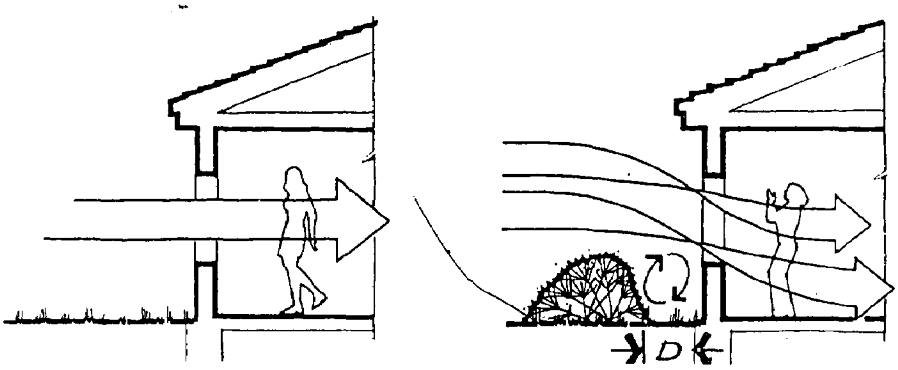


Fig.3.18. Shrub fosters downward deflections. Effective for distances D up to 4.5 - 6 m. (Watson, 1983)

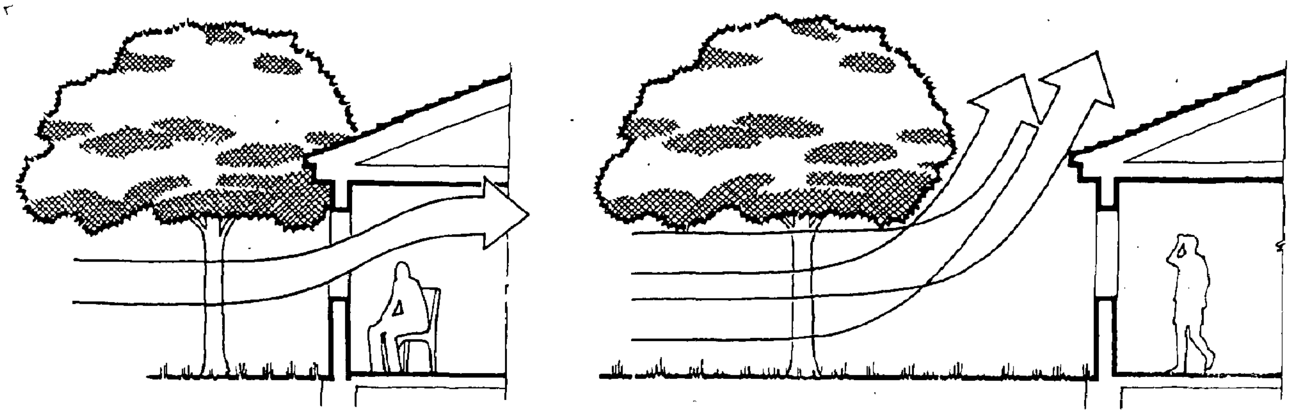
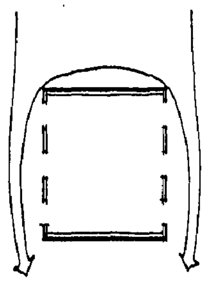
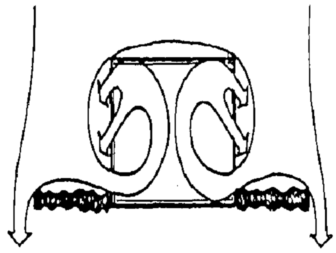


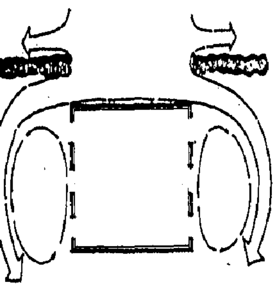
Fig. 3.19. Tree canopy fosters upward deflections. (Watson, 1983)



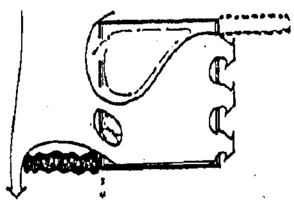
Building turned 90° into the wind with no planting



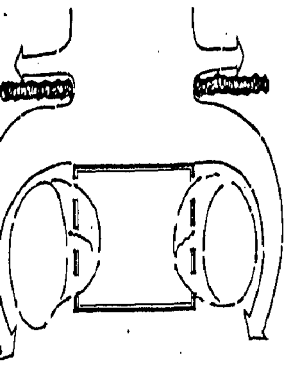
Medium or high hedge.



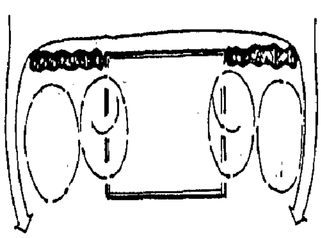
Large hedges 5 feet from building



Medium or high hedge



Large hedges 10 feet from building



High hedge

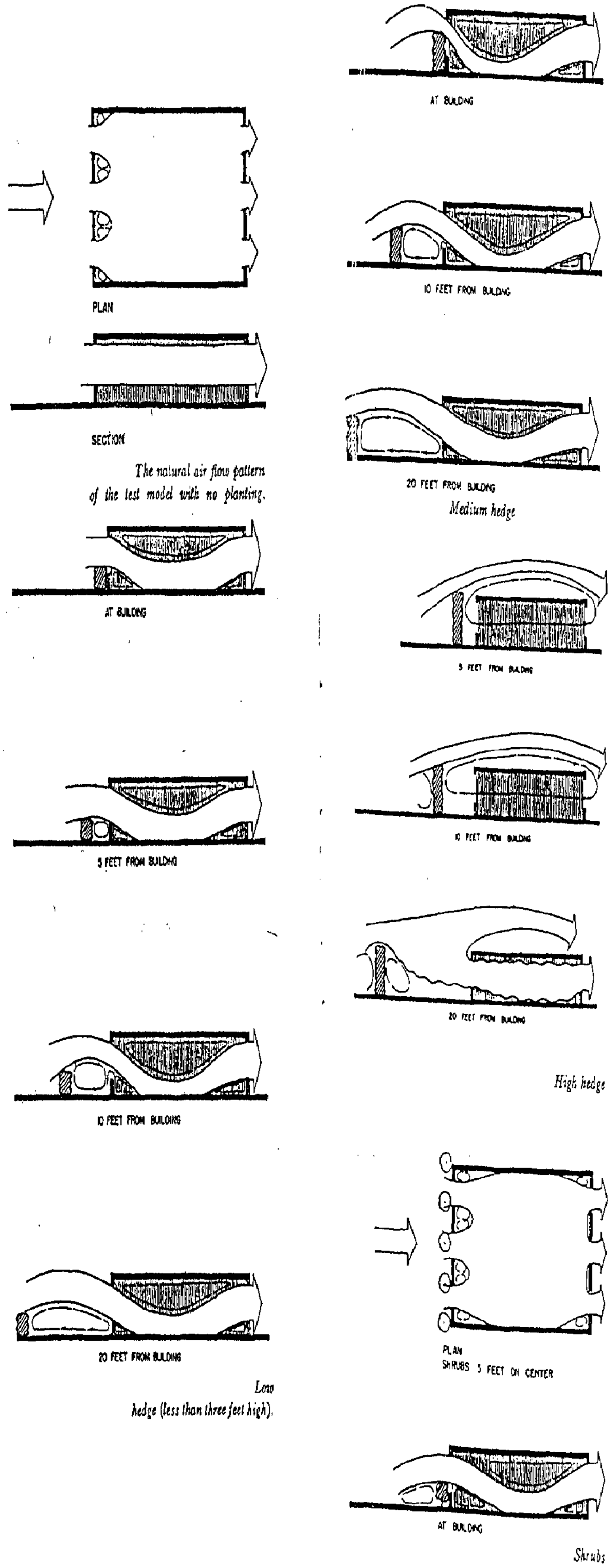


Fig. 3.20. Effect of hedges on the quality of ventilation in buildings. (Robinette, 1983)

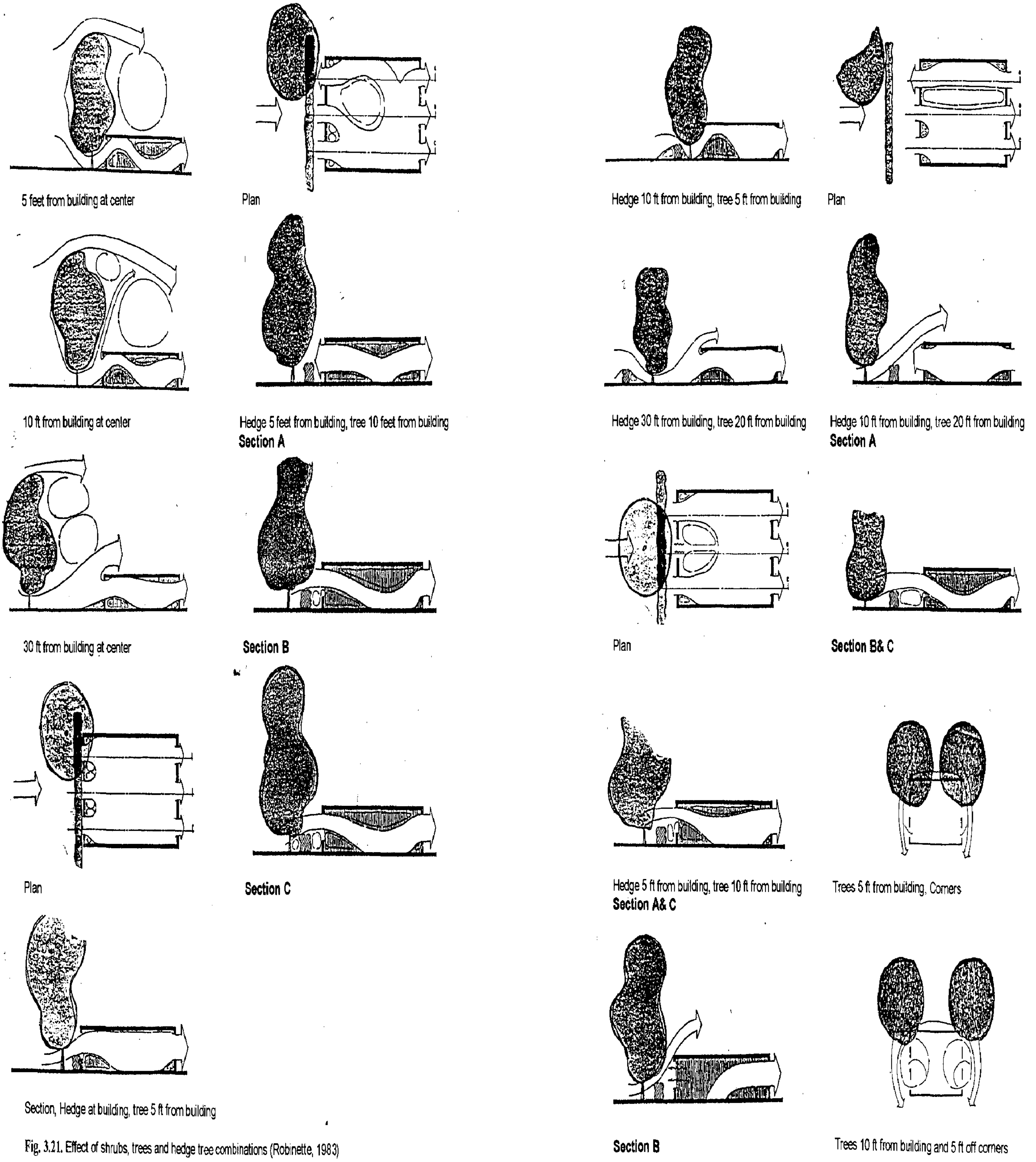


Fig. 3.21. Effect of shrubs, trees and hedge tree combinations (Robinette, 1983)

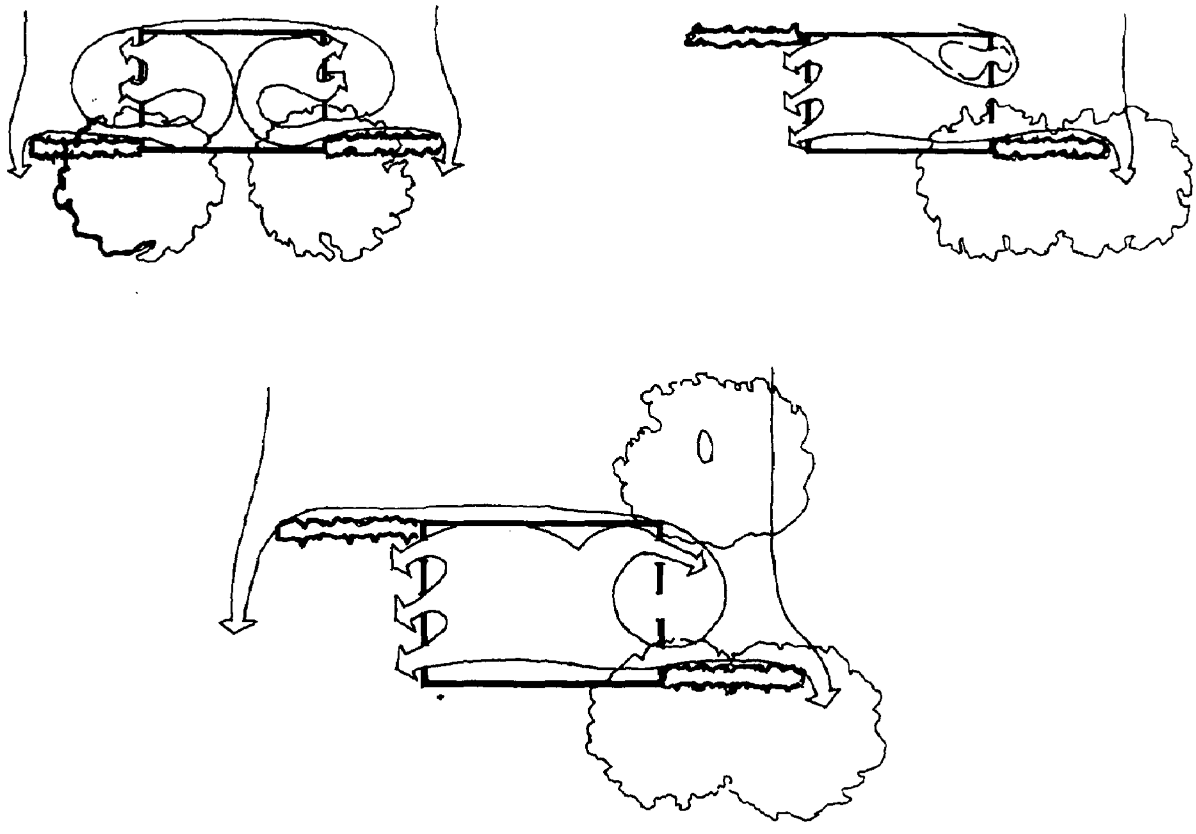


Fig. 3.22. Effect of tree-hedge-building combinations. (Robinette, 1983)

Trees and shrubs can be used to channel and increase airflow towards buildings by funneling air into openings.

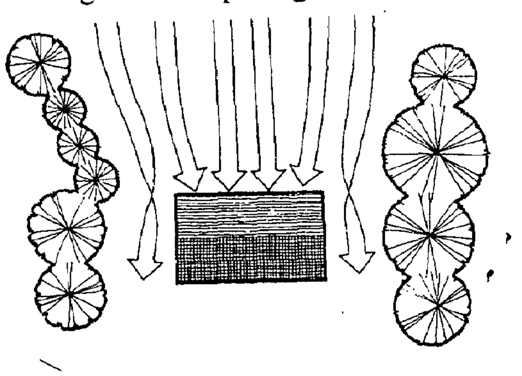


Fig 3.23. Free venting combined with funnel at the front. Narrow corridors operate air jet, a good place for porch or deck. (Watson, 1983)

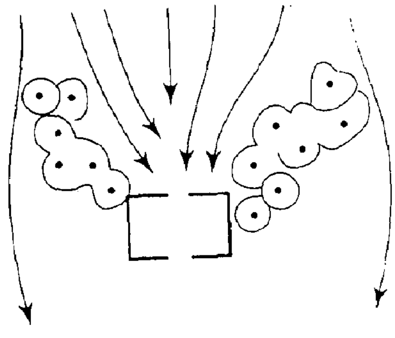


Fig 3.24. Vegetation increasing and directing air flow (Krishan, 2001)

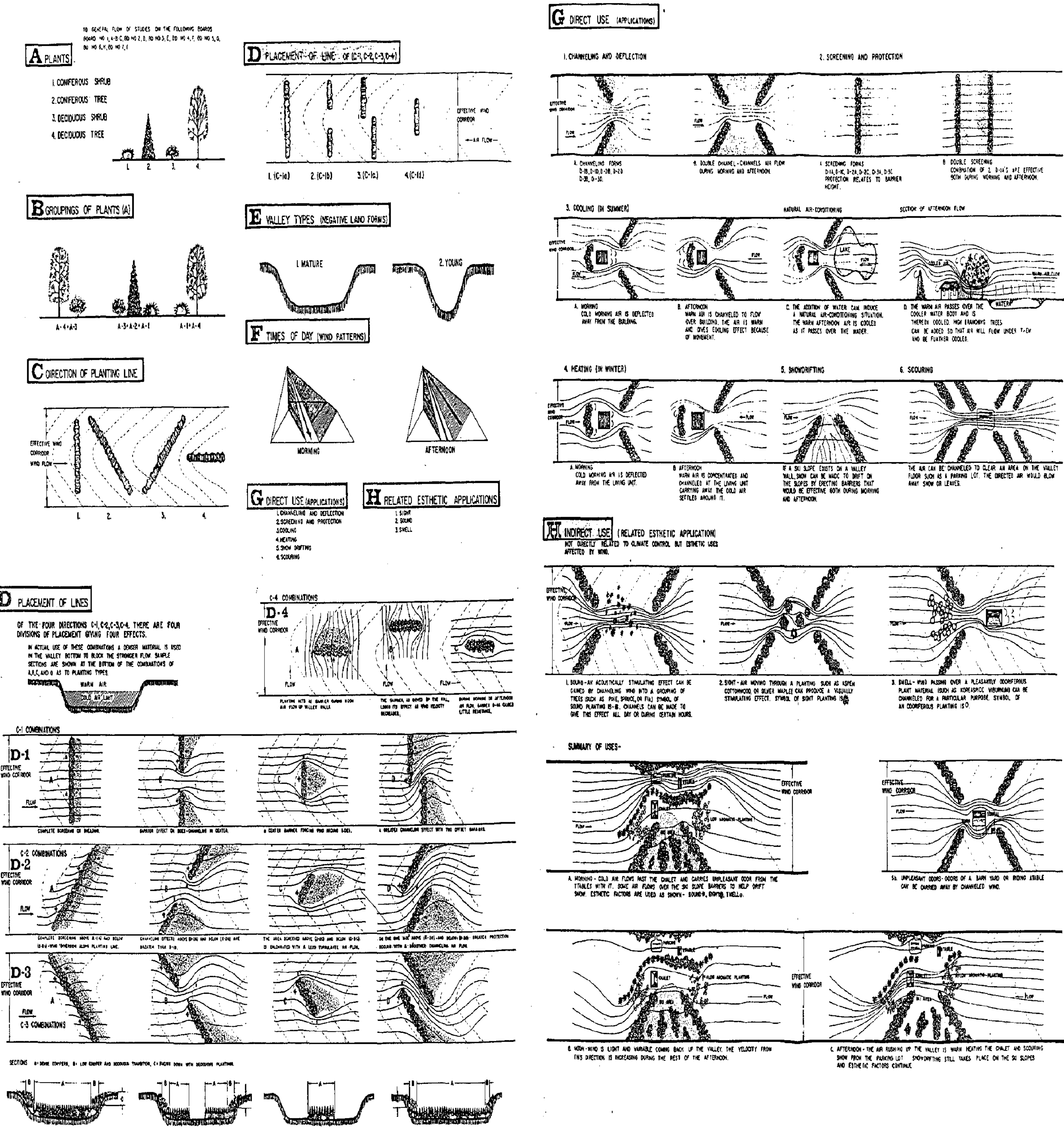


Fig 3.25. Summary of the kinds of plants, their direct application and additional indirect use. (Robinette, 1983)

Prevailing winds may change directions seasonally, therefore, plants used should be the type best shifted for controlling winds from all direction.

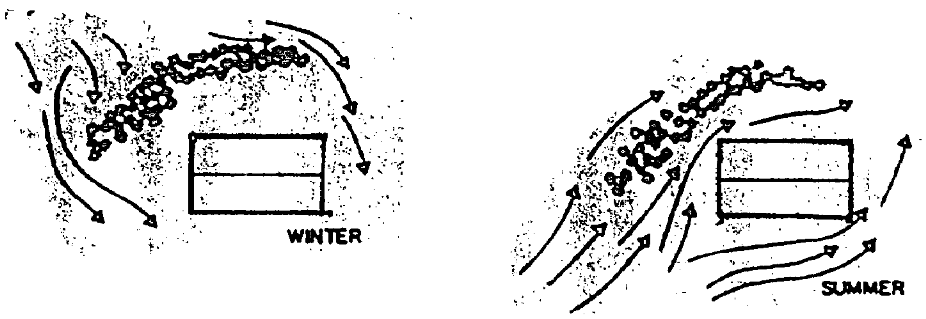


Fig. 3.26. Vegetation for seasonal winds (Robinette, 1983)

b) Vegetation for temperature control.

Ground cover and planting are useful in providing cooling for the whole site. On a sunny summer day, an acre of turf may evaporate about 2400 gallons (9072 litres) of water. The difference in surface temperature between grass and asphalt can easily exceed 25^{0}F (14^{0}C). The "microclimate zone" above these surfaces also differs appreciably.

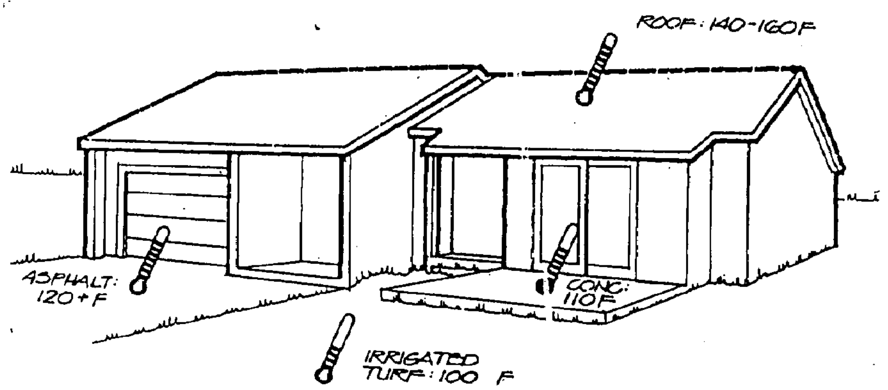


Fig. 3.27. Ground cover and planting are useful for site cooling. (Watson, 1983)

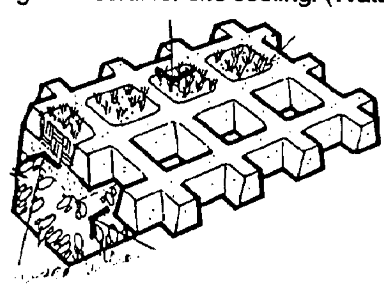


Fig. 3.28. Porous concrete paving with allowance for grass growing can be used when a pavement is needed, which will assist in site cooling. (Lattice block) (Watson, 1983)

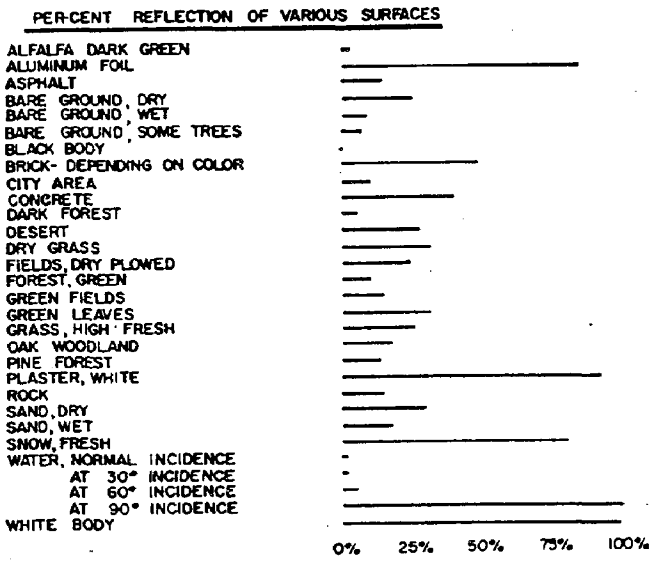


Table. 3.1. Percentage of reflection of various surfaces. (Robinette, 1983)

c) Vegetation for shading. (Sun control)

Shading is another purpose of trees, where they can be planted at the western side of buildings to intercept afternoon sun. Deciduous trees which shed their foliage in winter are useful in protecting the building from overheating in summer and allow direct sunlight in winter.

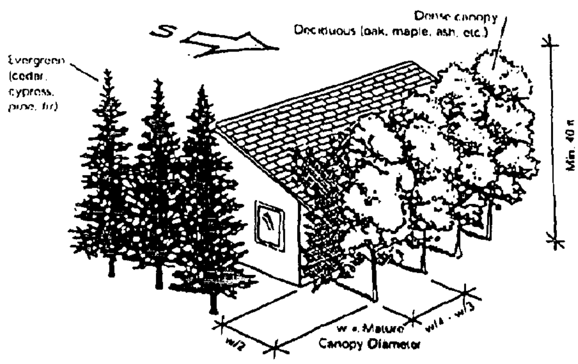


Fig. 3.29. Dense trees at the western sides intercept afternoon sun (Sheltair, 1994)

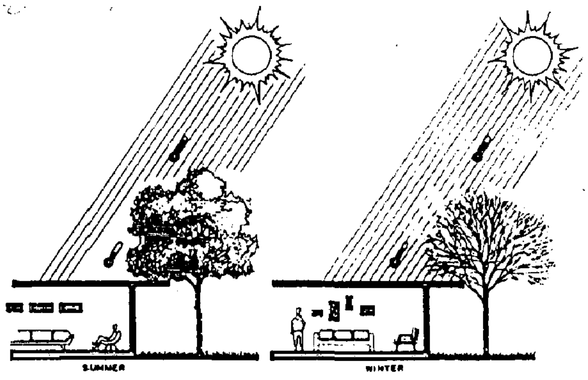


Fig. 3.30. Deciduous trees used in seasonal variations (Robinette, 1983)

3.1.2.2. Landforms

The landform of a site could be open and flat, sloping or undulating. Climatically speaking a flat site has a uniform condition in its entirety. But a site with slopes and valleys will be characterized by variations of temperature and air movement that can be taken advantage of in different climatic regions.

Cooler air has a higher density than hot air and is heavier and tends to settle down in depressions while hot air rises. As a result, the air temperature is lower in depressions or valleys. Air speed increases up the windward slope, is maximum at the crest and minimum on the leeward.

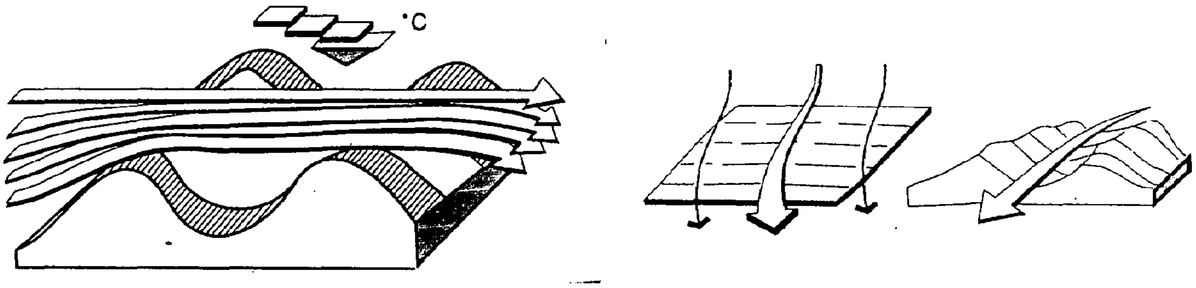


Fig. 3.31. Landform variations and microclimate with respect to air movement. (Krishan, 1983)

Cooler winds flow downhill at night. Dense evergreen plants placed on a slope, trap and hold cold wind flow upwind, thus creating cool spaces. Deciduous or "loose" plants create cool spaces on the down wind side by filtering the air.

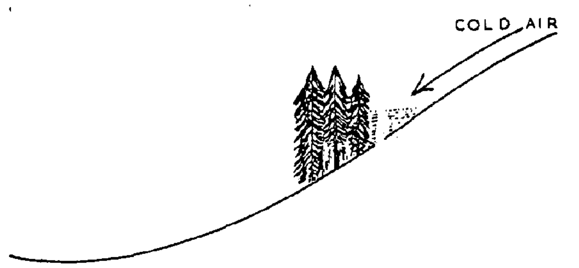


Fig. 3.32. Effect of dense wind break in creating frost pockets (Robinette, 1983)

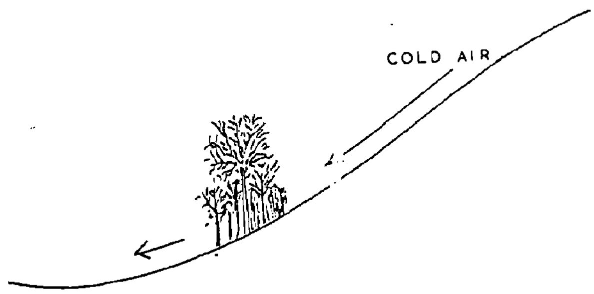


Fig. 3.33. Effect of penetrable windbreak allowing cold air to drain away (Robinette, 1983)

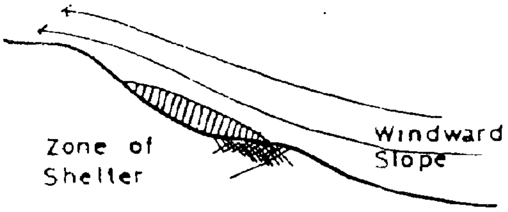


Fig. 3.34. Zone of shelter on windward slope. (WORRB, 2001)

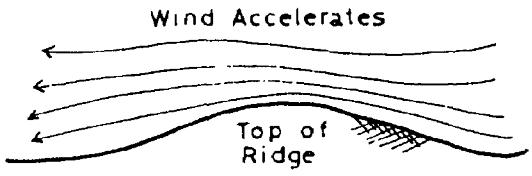


Fig. 3.35. Wind speed are increased by 50-60% towards the top of ridge (3°-10° slope) (WORRB, 2001)

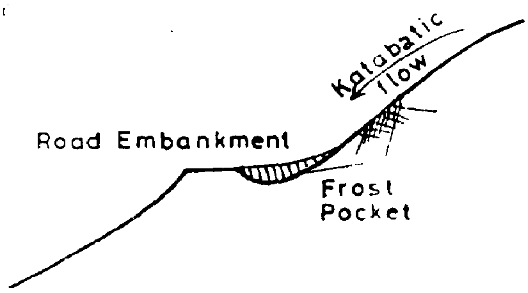


Fig. 3.36. An obstruction (Frost pocket) slows down the flow (WORRB, 2001)

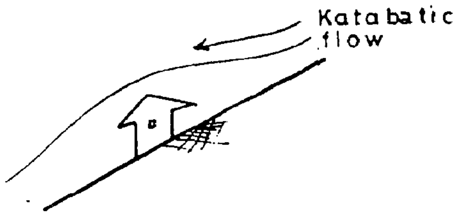


Fig. 3.37. Significant cooling effect on building with no protective shelter (WORRB, 2001)

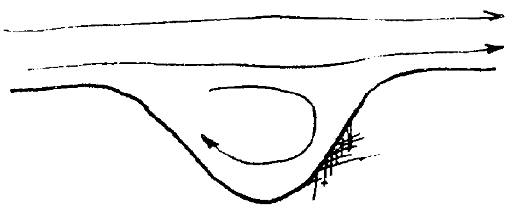


Fig. 3.38. Sheltered wind flow in valley (WORRB, 2001)

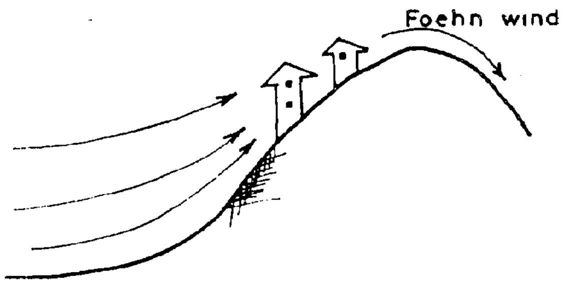


Fig. 3.39. Fohen wind flow (WORRB, 2001)

In considering the landform of the site care must be taken to analyze the orientation of the slope as it may block the solar radiation that is received on the area.

In hot climates it is preferable to place the building in the valley where the air is cool, and when building on a slope the leeward is preferable since the windward slope is exposed to the warm breezes

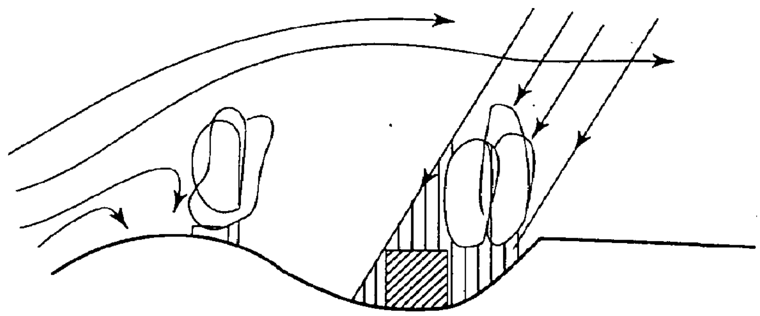


Fig. 3.40. Building in a depression and shading from heat and wind minimizes heat gain and discomfort in hot climates. (Krishan, 2001)

In cold climates, building in the valleys should be avoided and avoid the path of the cool air down the slope by making use of vegetation

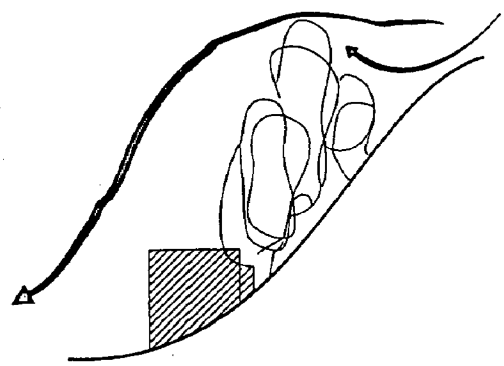


Fig. 3.41. Protection from katabatic winds on slope by the use of vegetation (Krishan, 2001)

Since air movement is required for humid climates, buildings could be placed on top of the windward slope where the air speed would be the highest.

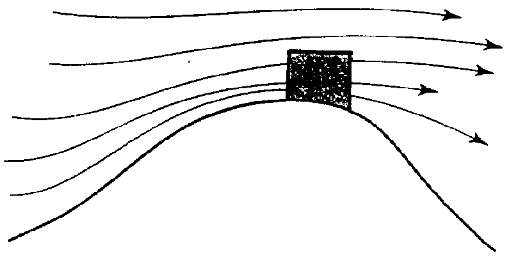


Fig. 3.42. Placing the building at the crest in humid regions (Krishan, 2001)

3.1.2.3. Climatic impact of vegetation and landform combined

Although the landscape changes its configuration more slowly, the vegetation quickly grows and changes its shape. The architect can therefore go for the best configuration that combines the effect of different forms of the landscape and the vegetation.

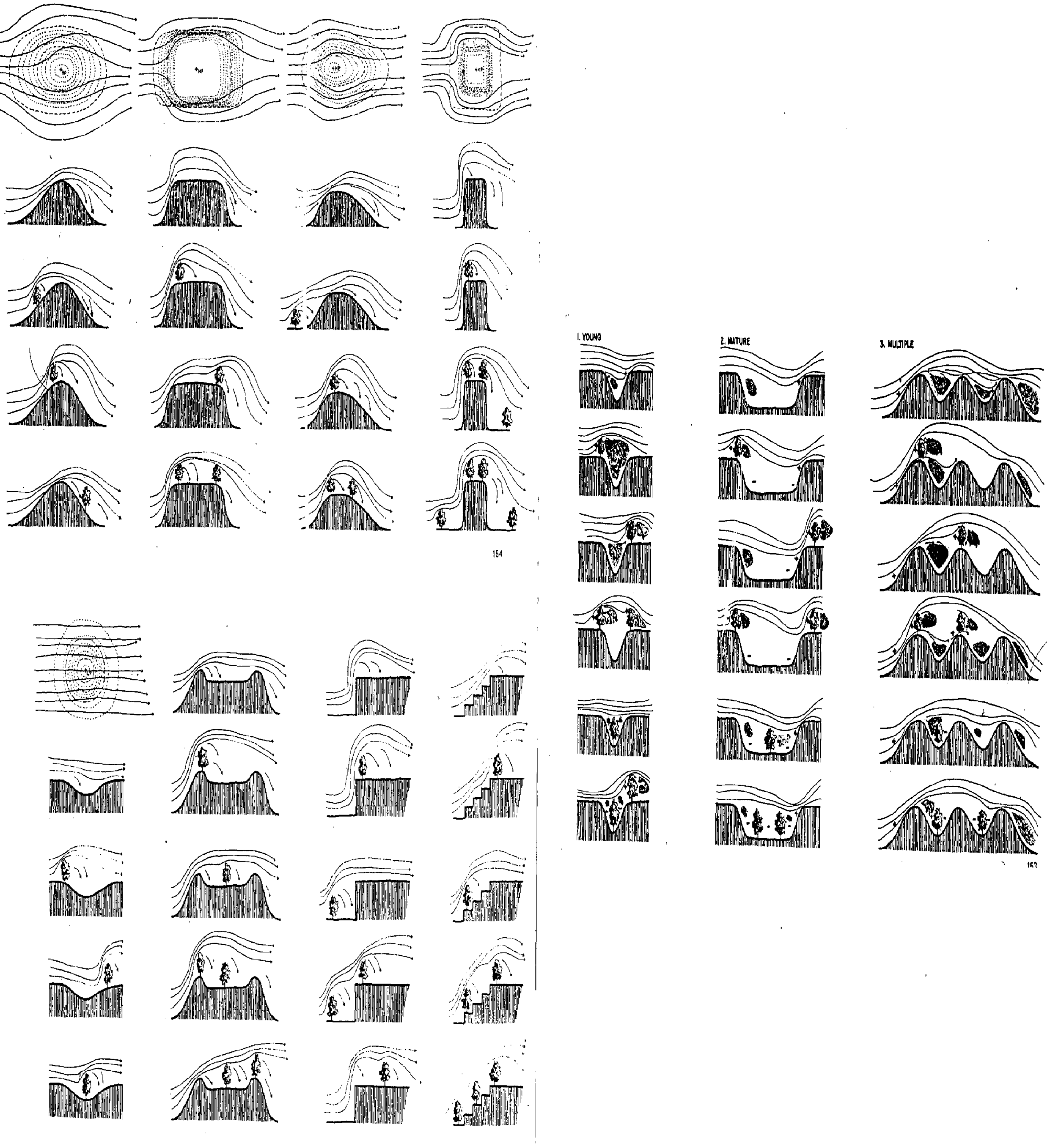


Fig. 3.43. Summary of the combined effects of vegetation and landscape. (Robinette, 1983)

3.1.2.4. Water bodies.

Climatically speaking water bodies are very important since they modify the microclimate first by absorbing large amounts of radiation, and second by taking away significant amount of heat by evaporation. With judicious planning involving the evaporation of water from nearby water bodies like swimming pools and natural lakes and the direction of the prevailing breezes thermal comfort can be achieved.

Water is has a high specific heat, warming up and cooling off slowly. Due to this nature of water, temperature differences between water and ground generate convection air currents, resulting in the offshore breezes which provide relief in hot climates. Breezes flow from the water body onto the shore during the day and off the land area onto the water body at night.

In humid climates the use of water for evaporative cooling is not recommended as it adds up to the existing humidity.

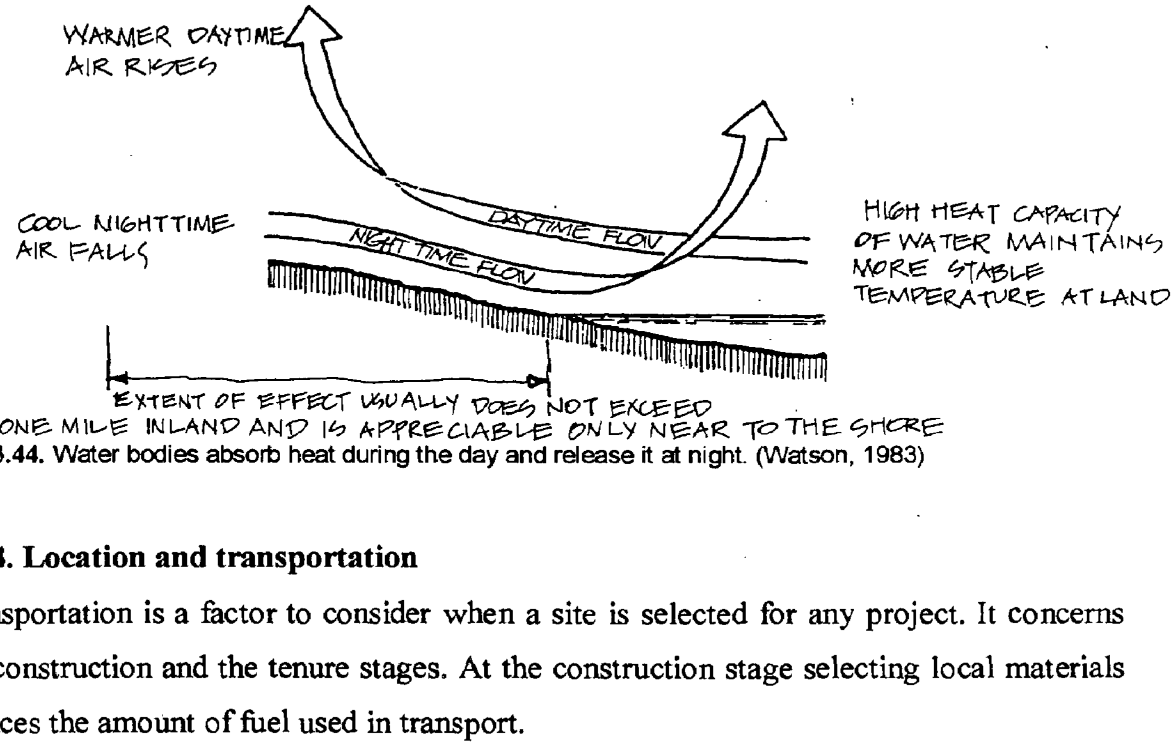


Fig. 3.44. Water bodies absorb heat during the day and release it at night. (Watson, 1983)

3.1.4. Location and transportation

Transportation is a factor to consider when a site is selected for any project. It concerns the construction and the tenure stages. At the construction stage selecting local materials reduces the amount of fuel used in transport.

However green our building may appear because of all the efficient technologies, materials and the integration of all the systems, it may not be environmentally responsive due to its location. The building must be accessible to public transport routes and must not be placed in suburban parts where it encourages the use of extensive private cars, that are one of the major sources of air pollution. Building designers and planners can help reduce automobile use in the following ways:

3.1.4.1. Integration of complementary occupancies (mixed use development)

Locating several complementary occupancies within a project-housing, services, retail, commercial and/or light industry-often eliminates the need for many automobile trips, encouraging more low-impact transportation modes, such as biking, walking and mass transit.

3.1.4.2. Encouragement of pedestrian, bicycle and mass transit use.

Making streets safer and more attractive to pedestrians, providing bicycle facilities at destination and creating safe, continuous bicycle paths also reduce the need for automobiles. Design strategies could help by providing secure bicycle parking, shower and changing facilities.

Buildings can improve the comfort and safety of pedestrians with appropriately scaled and detailed facades and views of the street for building occupants. If pedestrians are also provided with a choice of sun or shade, they are more likely to use these outdoor spaces, and hence encourage pedestrian movement.

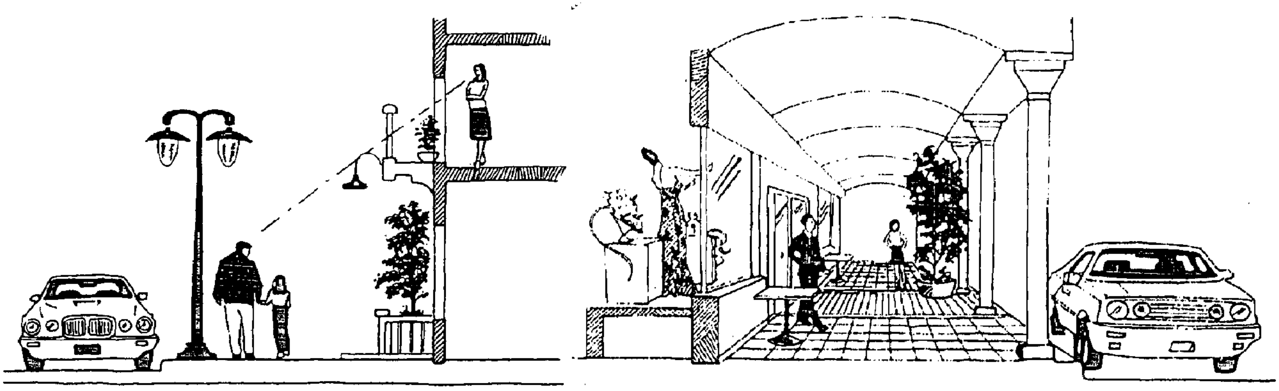


Fig. 3.45. Encouragement of pedestrian (Sheltair, 1994)

3.2. ENERGY EFFICIENT DESIGN

It is shown that 50% of the energy demand in the developed world could be met from renewable energy supplies based on wind, waves, solar, biomass and water power. And 50% of current energy use for servicing buildings, which is under the control of those who design, commission and use buildings. A massive reduction in the energy used in buildings can be achieved through a green approach to architecture. Typical reductions in energy operating for a green building are 25-40% when compared to conventional buildings which translates into a lot of amount of money.

Prior to the industrial revolution, our energy sources were primarily renewable. The industrial revolution was a fossil-based revolution. At present the crisis in non-renewable energy resources and the technologies based upon such sources are not imminent, but can be effectively foreseen. The solution to the energy crisis is found from efficiency that avoids wasteful patterns of production and consumption and a deliberate shift from non-renewable to renewable energy sources.

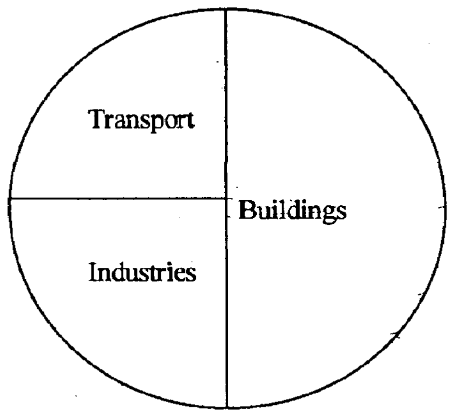


Fig. 3.46. Buildings consume half of the energy that is used by human beings (Global scenario) (Behling, 1996)

Buildings consume half of the energy that is used by human beings. The enormous amount of energy consumed by buildings reflects a continuing increase in the demands placed upon energy resources and symbolizes the problematic relationship between architecture and technology that has emerged during the industrial age. Architectural innovation has increasingly necessitated technological and engineering expertise, coupled with higher energy demands in both construction and operation. Buildings increasingly

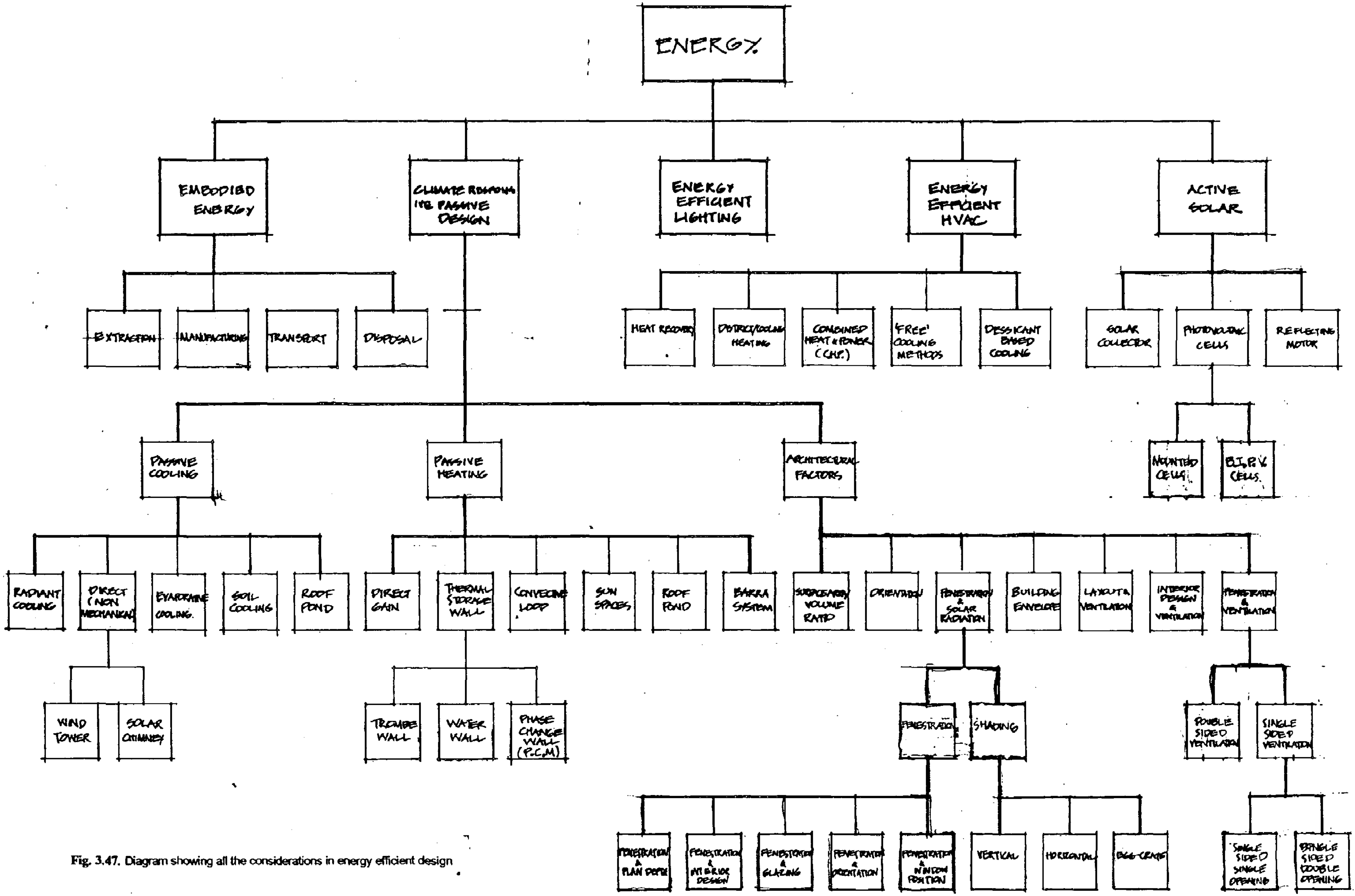


Fig. 3.47. Diagram showing all the considerations in energy efficient design

have become isolated from the environment. Without regard to exterior condition the internal environment was kept constant necessitating considerable energy consumption. The green design team can create energy efficient buildings either through reduction of energy use and demand or optimizing energy supply and systems

Most of the reduction in the use of nonrenewable energy in buildings is achieved by a wise understanding of local climate and an informed practice of designing buildings that are parts of the climate and that harness the already present forces of the sun and wind apart from other climatic features. To this end a considerable amount of space is given in this paper, to the discussion of climate and climate responsive green architecture.

3.2.1. Embodied energy

The energy input required to quarry, transport and manufacture building materials, plus the energy used in the construction process is called the embodied energy and can amount to a quarter of the lifetime energy requirement of a very energy-efficient building. This embodied energy could be reduced without affecting longevity or efficiency through practices like reusing existing buildings, designing for flexibility, using local, low energy and recycled materials.

3.2.2. Climate responsive passive building design

In conformity with the objective put at the outset of this paper, the primary objective of climatic design considered here is the reduction of energy cost of a building through passive building design approaches. This is achievable through the use of natural energy that reduces the dependence on energy from mechanical systems fueled by non-renewable resources. The importance of climate on building performance and energy consumption can't be overemphasized. It has a paramount importance in the whole process of design and due attention must be given to identify, understand and control or adapt to climatic influences at the building site.

Once the microclimate analysis is done with regards to any building site passive climate control strategies could be adopted. When cold discomfort conditions prevail, as in cold climates or in winter season, heat loss should be minimized and heat gain from the sun and internal sources should be utilized. When hot discomfort conditions prevail, as in arid climates or summer season, heat gain should be minimized and heat dissipation should be maximized. These control strategies are summarized in the following table.

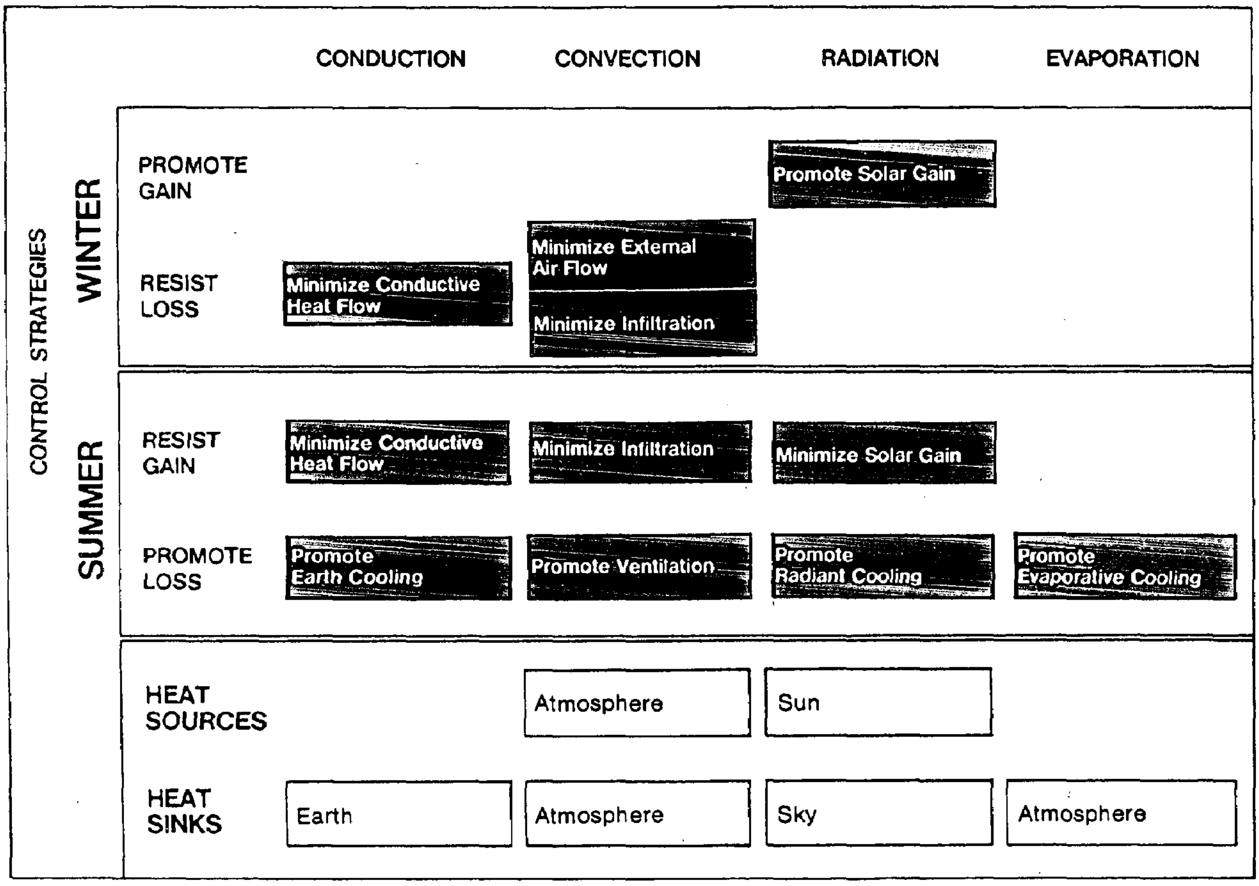


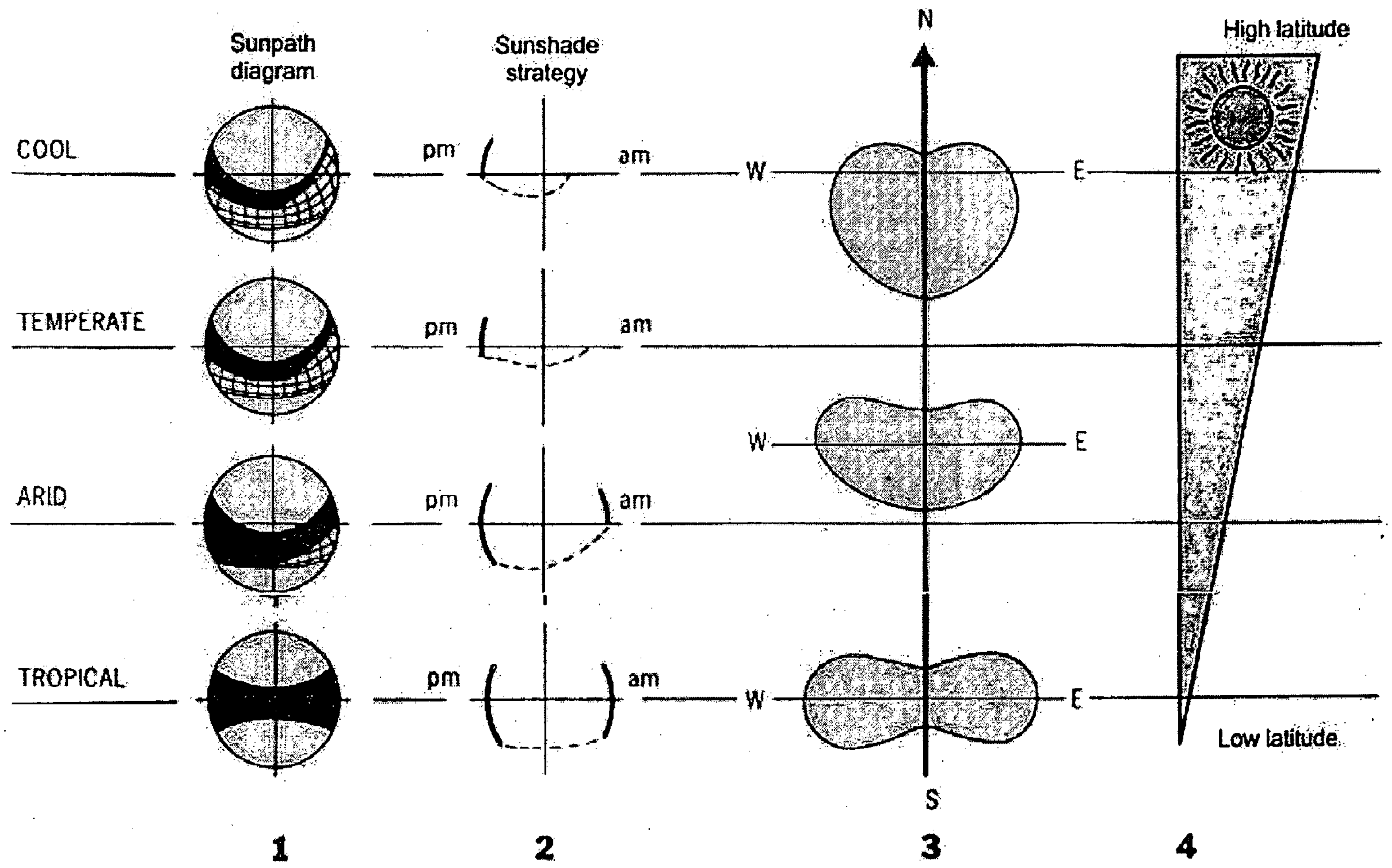
Fig. 3.48. General climate control strategies (Watson, 1983)

3.2.2.1. Climate analysis for energy efficient design.

Climate analysis carried out at the outset of the design process will help reduce energy consumption in accordance with the objectives of green architecture. Corresponding to the four climatic elements namely, solar radiation, wind, temperature, humidity, and rainfall, a thorough analysis should be made to get the most out of the benefits of climate responsive passive building design.

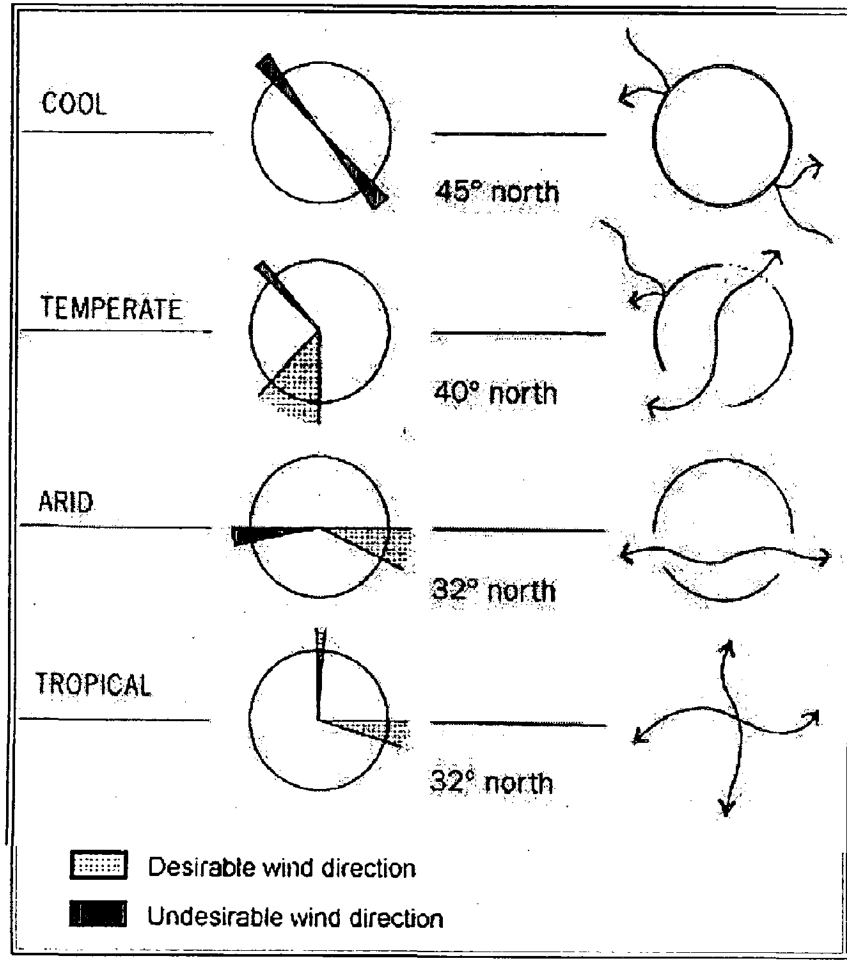
The following is a summary of sunshade analysis, wind analysis, humidity, and rainfall in the different climatic zones and their effect on the design of buildings.

EXAMPLE OF SUNSHADE ANALYSIS



1. Solar paths requiring shade Studying the sunpath diagram for each climatic zone, the shaded areas represent the periods of *overheating*, related to undesirable solar gain. In the lower latitudes there is total overheating, whereas in the higher latitudes overheating only occurs during the summer months.	**3. Insolation** The sunpath becomes more southerly as we move north, changing from a 'bow-tie' pattern near the equator to a heart-shape pattern in the temperate zones.
2. Sunshade analysis (vertical and horizontal) The diagrams show the optimum location of vertical sun shading, shielding the building from low sun angles in the morning and evening, and horizontal sun shading blocking the high midday sun. Tropical regions need both vertical and horizontal shading throughout the year. In higher latitudes, horizontal and vertical shading is only needed during the summer on the south-facing sides of buildings.	**4. Sun requirements during winter** There are obviously seasonal variations near the equator. Solar heating becomes more important than in the upper latitutdes. Beginning at the equator and moving north, the need for solar heating increases while the need for solar shading dimishes.

Wind Analysis



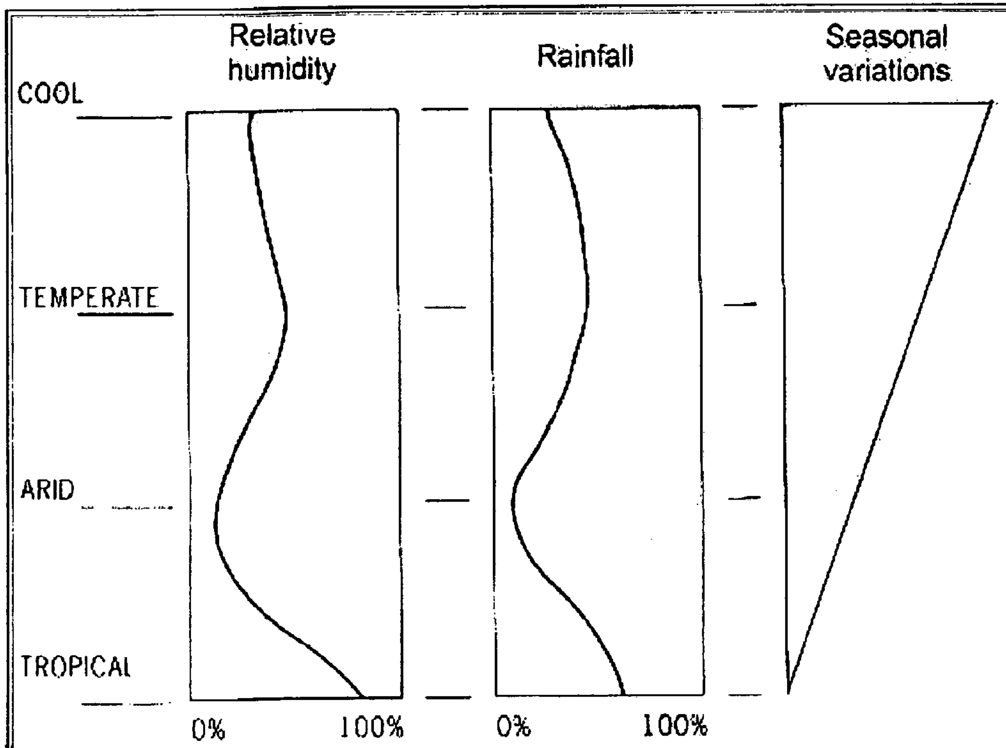
Wind direction

Desirable and undesirable winds in each the climatic zones depend largely on local conditions. Any breeze in the lower latitude (tropical and arid climates) is beneficial for most of the year whereas in higher latitudes most wind is determental and has to be screened. There is also a small percentage of the time in a year (spring and/or autumn) when comfortable conditions can be achieved naturally, without any need for wind screening or additional breezes.

Cross ventilation

Cross ventilation is far more important in the tropics than in temperate zones. The theoretical strategy for blocking or inducing wind flow into a building is based on local *prevailing wind conditions*. Genrally, for the tropical zones as much ventilation as possible is desired. For the arid zone cross ventilation is required, but care has to be taken to filter out high-velocity winds. In the temperate zone, cross ventilation and shielding are both necessary (for summer and winter, respectively). In the cool region, the building should be protected from cold, high-veolcity winds, although cross ventilation is still required.

Humidity, Rainfall and Seasonal Variations

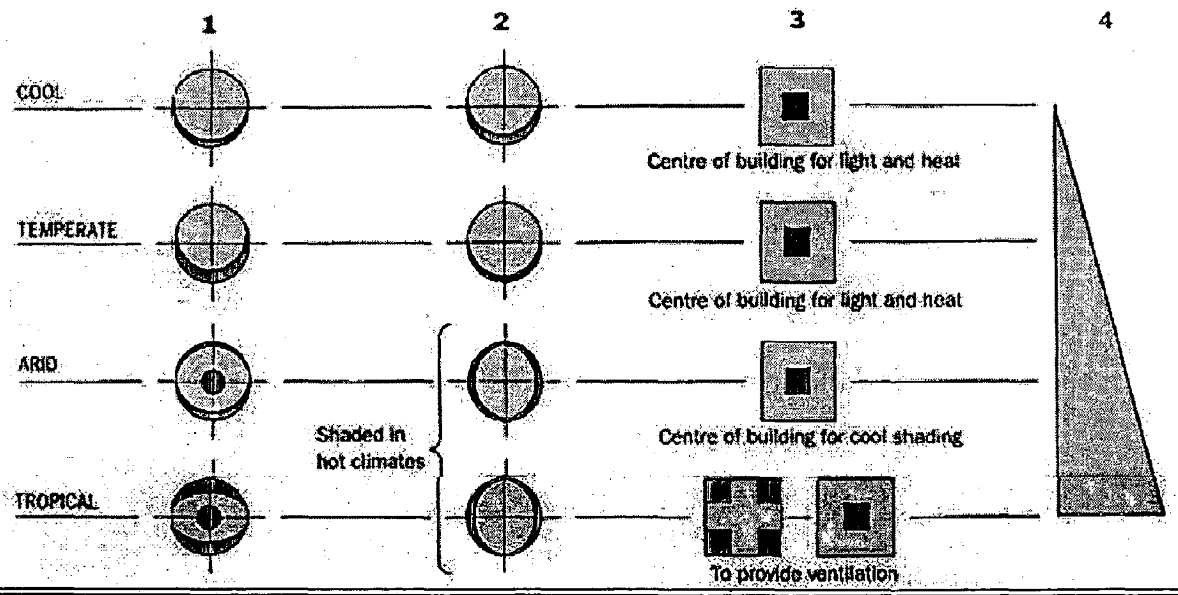


Annual Average Relative Humidity
The curve on the left represents the annual average relative humidty in the four climatic zones. In the arid zone, the low level of humidity can be beneficial for *evaporative cooling* . In the tropical zone the high level of humidity can be very uncomfortable.

Annual Average Rainfall
The middle curve represents the annual average rainfall in the four climatic zones. Rainfall level can be seen to have a direct relationship with humidity levels.

Annual Seasonal Variations
The distance of the angled line from the vertical represents the annual seasonal variations in the four climatic zones. Higher latitudes, the cold and temperate zones, have pronounced seasonal variations. The lower latitudes have constant climates throughout the year.

Influences on Built Form



1. Zoning for trasitional spaces The black areas represent the traditional spaces used for lobbies, stairs, utility spaces, circulation, balconies and any othe areas where movement take place. These areas do not require total climatic control and natural ventilation is sufficient. For the tropical and arid zones, the transitional spaces are located on the north and south sides of the building where the sun's penetration is not as great. An atrium can also be used a transitional space. In temperate and cool zones the transitional spaces should be located on the south side of the building to maximize solar gain.	**3. Use of atrium** The diagram show the optimum position for atrium spaces in each building form in each of the climatic zones. in the tropical zone the atrium should be located so as to provide ventilation within the built form. In the arid zone the atrium should be located at the centre of the building for cooling and shading purposes. For the cool and temperate zones the atrium should be at the centre of the building form for heat and light.
2. Zoning for solar gain The black areas are spaces that can be used for solar heat gain. They follow the varying path of the sun in each of the climatic zones: in the tropical and arid zones the east and west sides; in the temperate and cool zones the south side.	**4. Potential of roof/ground floor as useable exterior space** The distance of the angled line from the vertical represents the potential of each zone's roof and ground planes to be used a exterior spaces. In tropical and arid climates there is a high potential to make use of all external spaces, whereas moving towards the northern latitutdes the external spaces have to be covered to be used.

Table. 3.2 . Climate analysis and its effect on building design. (www.hku.hk/teaching.html)

3.2.2.2. Architectural factors affecting climate performance of buildings

Architectural features of buildings are among the major considerations to improve the climate performance of buildings so that the degree of thermal comfort in the interiors of buildings would be enhanced without or with little mechanical assistance, thereby culminating in the design of green buildings that are less dependent on non renewable energy resources. Architectural features improve thermal performance by modifying four forms of interaction between the building and its environment/

- Solar exposure
- Solar heat gain
- Rate of conductive and convective heat gain
- Ventilation and passive cooling.

The major design features affecting the above conditions are discussed below

a) Surface area to volume ratio. (S/V ratio) (building massing)

Surface area to volume ratio expresses the outside surface area and enclosed volume and is used to compare equal amount of interior volumes with differing exterior surfaces (wall and roof). The building with less S/V ratio has the more compact area and implies minimum heat gain and heat loss.

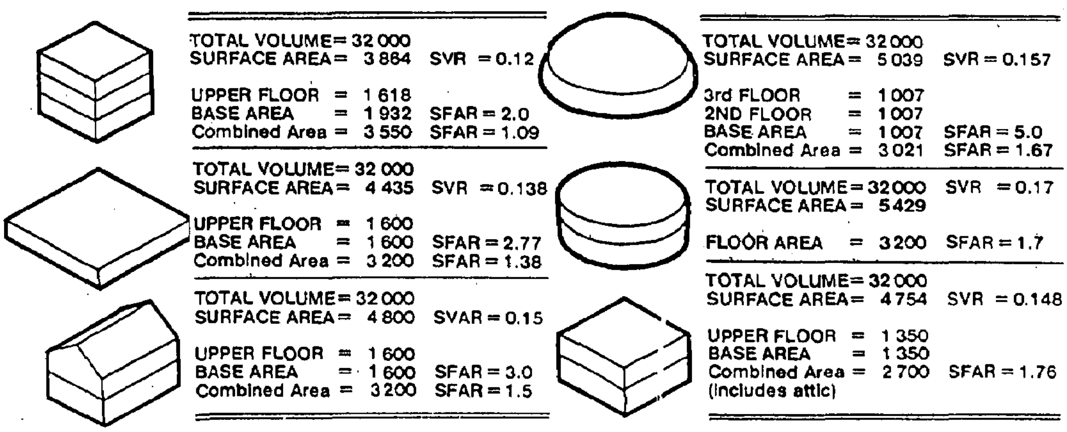


Fig. 3.49. Comparison of different configuration of spaces with different S/V ratio, space volume kept constant. (Watson, 1983)

But in the case of hot warm climates, more free form is required to ventilate the building for thermal comfort without minimizing S/V ratio

In the cool zone closed compact forms are preferable. Elongated unilateral buildings are not advantageous. In temperate zones there is the least stress from any specific direction. There are no many problems in this zone allowing freedom of form, although the east-west axes are preferable.

In hot-dry like as in cold climates the S/V ration is better kept as low as possible to minimize heat gain and heat loses. Cubical forms, or slightly elongated toward the east-west axis are preferable.

In hot humid zones buildings are better elongated freely in the east west axis.

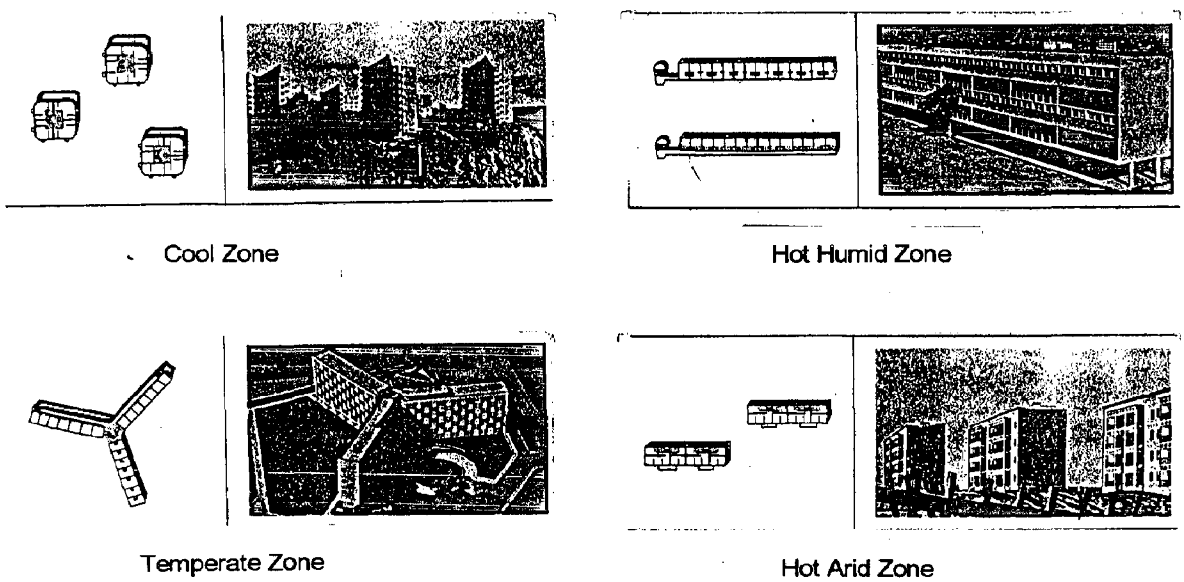


Fig. 3.50. Building massing in different climatic regions. (Olgyay, 1963)

b) Orientation for solar radiation.

Buildings must be planned to get the most out of the sun's radiation in the different seasons of the year, which has great importance in providing natural lighting and creating thermal comfort in the building interiors. Different functions in different building have unique requirements of light and heat in different hours of the day and in different seasons of the year. In all climates the north south axis should be avoided since the east and west faces of buildings will receive the maximum amount of direct solar radiation .

making the interior uncomfortable. The following table summarizes the recommended orientations of buildings in the four climates.

Zone	Building's main orientations	Directional emphasis
Tropical	On axis 5° north of east	North-south
Arid	On an axis 25° north of east	South-east
Temperate	On an axis 18° north of east	South-south-east
Cool	On an axis facing south	Facing

Table. 3.3. Showing the recommended building orientation for different climates with regard to solar radiation (www.hku.hk/teaching.html)

c) Fenestration and shading for solar radiation.

- Fenestration.

The location, number, size, quality and shading details of the windows determine the ~~quality and quantity of the interior lighting~~. Electrical lighting that is spent on lighting purposes can be substantially reduced by using proper design of fenestration.

i. Fenestration and floor plan depth

Floor plan depth affects the requirement of natural daylighting of a building design. Therefore the interior that can be well daylit is limited to the building depth and floor-to-ceiling height. Meaningful daylight can reach only to the depths of 4.5 to 7.5 metres, within spaces of heights of 2.4 to 2.7 metres.

Floor plans deeper than 17m (two rooms flanking a double-loaded corridor) will require constant electric lighting.

The maximum distance of workstation from any building exterior should not exceed to 7.5 metres (25 ft), to make use of natural light that will immensely decrease the dependency on unsustainable sources of energy.

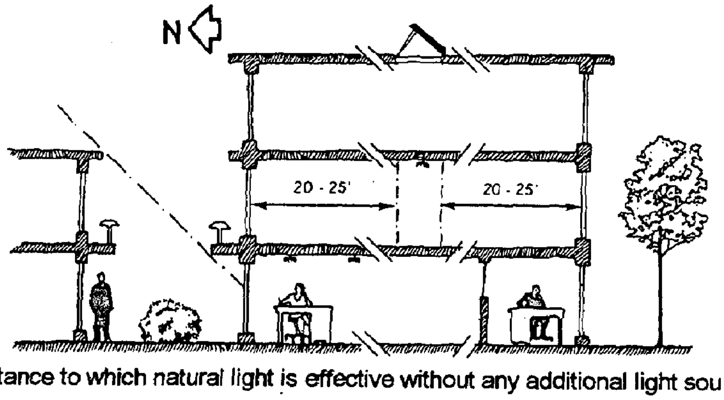


Fig. 3.51. The distance to which natural light is effective without any additional light source (Sheltair, 1994)

Daylit spaces could extend to 9m-10.5metres, if reflective systems such as lightshelves, prismatic glazing etc... are used.

Light shelves, which are horizontal projections in a window, could be placed inside or outside of the glazing so that they could be used to reflect light into the building spaces placed remote to the perimeter of the wall. In hot climates, windows should be shaded, whereas in cold climates shading might be undesirable where light shelves would be effective due to the low sun angle.

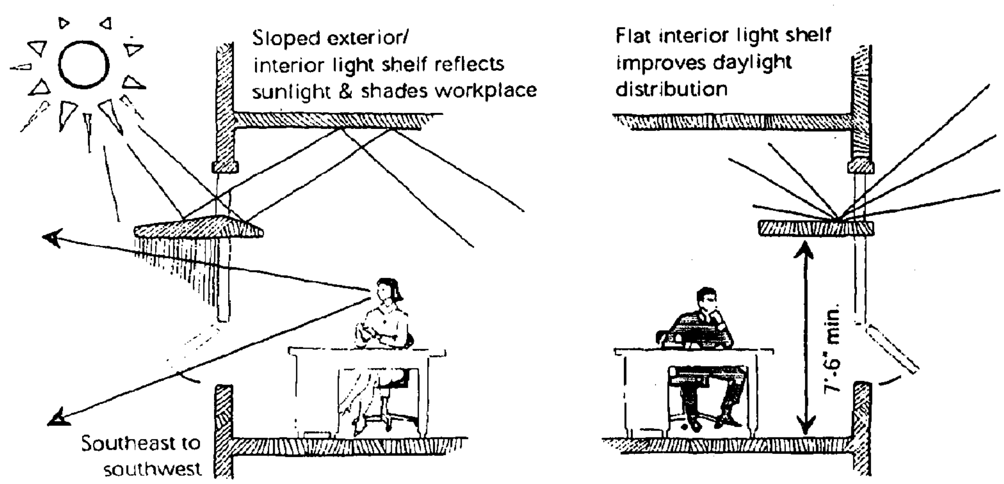


Fig. 3.52. Interior and exterior light shelves. (Sheltair, 1994)

Light shelves placed outside serve as shading devices as well. In this case the shelves should be light colored and should slope to direct light into the interior.

ii. Fenestration and interior feature

Among other things, daylight is dependent on the ceiling height of the interior space, which gives more flexibility allowing devices such as lightshelves to redirect light deeper into the interior. Ceilings heights 3m or bigger are recommended regarding this aspect. The interior surfaces should be finished with light colors to increase the daylight that reaches areas remote from windows.

Splayed, light-colored window sills and reveals reduce contrast and glare.

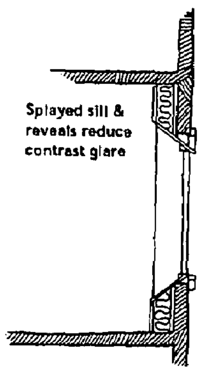


Fig. 3.53. Splayed window sill to avoid glare (Sheltair, 1994)

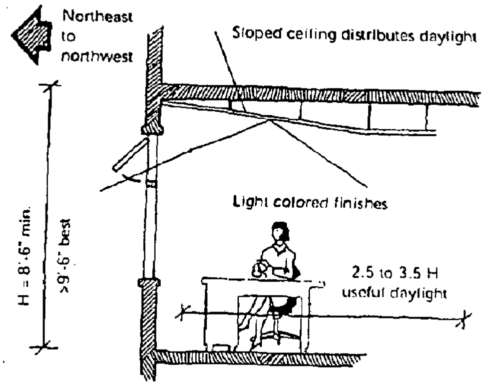


Fig. 3.54. Ceiling shape for diffuse daylight (Sheltair, 1994)

iii. Fenestration and glazing quality

The type of glazing material used on windows will have a decisive role on its thermal performance. The following are some of the most commonly used glazing materials and they are summarized in a table form.

- Normal transparent glass.
- Double glazing
- Absorbing glass
- Dark glass
- Reflective glass (Mirror)
- Polycarbons
- Double polycarbonate with air space
- Corrugated fibreglass
- Acrylic sheets

	Glass thickness (mm)	Light penetration (%)	Total solar radiation (%)
GLASS			
Single, transparent	3	90	86
	5	88	77
Double, transparent	3	82	71
	5	78	60
Absorbent	3	84	65
	5	76	48
Dark	3	62	63
	5	42	44
Reflective/mirror	–	8–34	11–37
POLYCARBONATES			
Single	3	86	89
	5	82	86
Double	–	73–80	21–60
CORRUGATED FIBRE GLASS			
Absolutely transparent		93	82
Translucent		87	81
White		32–66	21–60
ACRYLIC SHEETS			
Transparent		83	83
White		20–70	19–67

Table. 3.4. Properties of glazing materials (Krishan, 2001)

There is a difference in the selection of glazing design, for cooling-load dominated buildings and for passive solar heated buildings to avoid winter heating requirements.

- Cooling-load dominated

Increase window with visible transmissivity on north facing walls to let more daylight. Tinted or reflective glasses that reduce solar heat gain and daylight must be avoided. High-performance low-emissivity glazing with visible transmissivity greater than 0.6 and solar transmissivity less than 0.4 must be specified, which can reduce annual operating energy by 20%. (Fig. 3.58)

Interior shelves on north orientations could be used to improve light distribution in spaces with high floor-to-ceiling dimensions.

- Passive solar heated

The glazing used to admit winter solar gains need to have high solar transmission (>0.8) and high thermal resistance (R-value >2.0 sq.ft.hour/Btu)

iv. Fenestration and orientation

Window area and glazing could be increased in the northern facades for more daylight in northern cold climates. Amount of glazing should be limited on east and west facades.

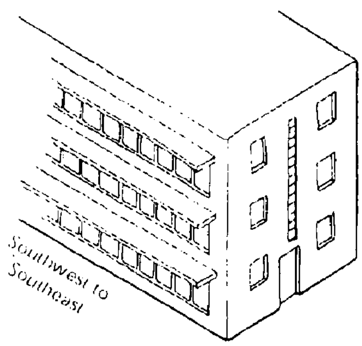


Fig. 3.55. Façade exposure and window design (Sheltair, 1994)

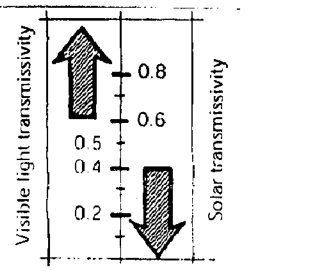


Fig. 3.56. Glass selection and transmission of light and heat (Sheltair, 1994)

v. Fenestration and window position.

Window placed close to a side wall improves the light quality received in terms of uniformity of light, and in terms of reduction of glare caused by the difference between the exterior and interior light intensities, due to reflection from the wall.

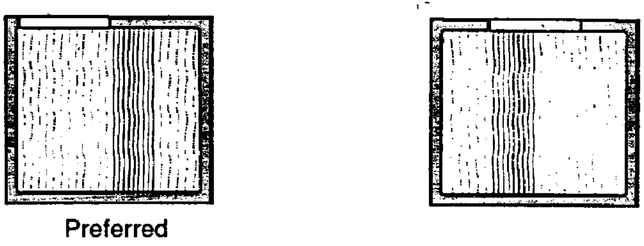


Fig. 3.57. Effect of window position on schematic plan (Krishan, 1983)

High windows allow better light distribution from overcast skies, and lower windows allow for reflected light from the ground.

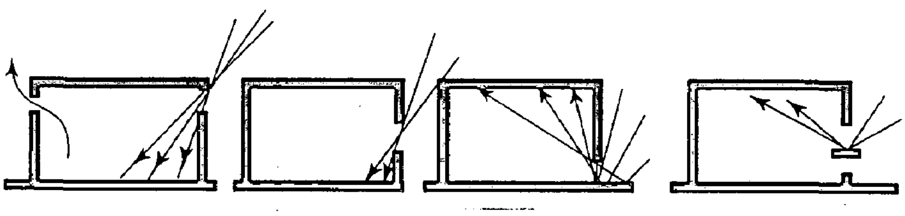


Fig. 3.58. Effect of window position on schematic sections (Krishan, 1983)

Roof monitors and other top lighting could be used, since they provide relatively uniform light distribution. They can be designed to admit light and sun light, but since it is difficult to control sunlight they should be designed to allow northern daylight. The southern faces of the roof monitors could be mounted with photovoltaic collectors

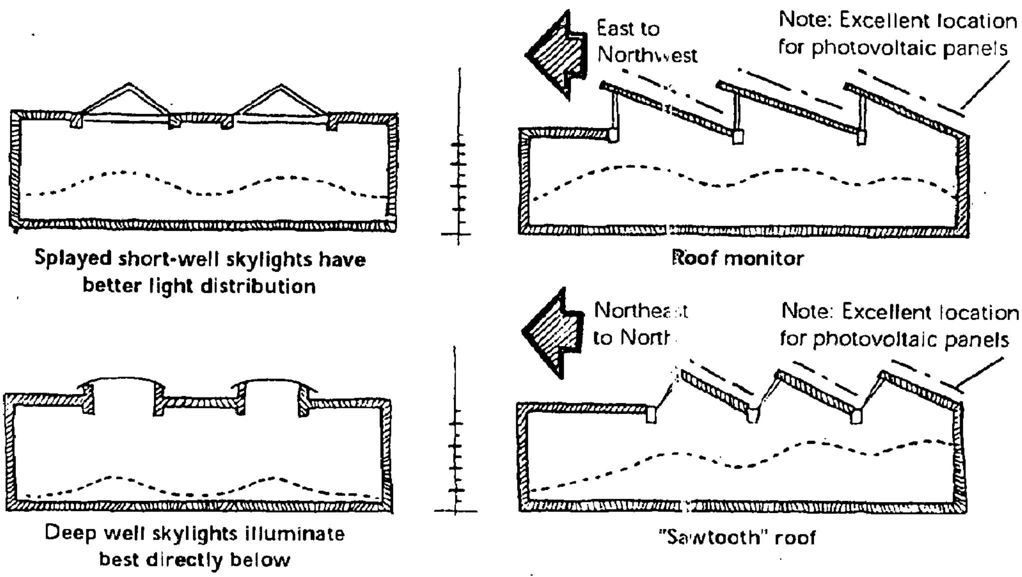


Fig. 3.59. Sky lights. (Sheltair, 1994)

- Shading devices

When ambient temperatures are within or above the comfort zone, solar radiation will cause discomfort. Shading design therefore is the method of avoiding the unwanted solar radiation and allowing comfortable levels of daylight into the interiors. But in cool seasons the solar radiation should be admitted into the interiors. As a result a movable shading device could be designed

The following strategies could be adopted for shading and sun control.

- *External projections (overhangs and side fins)*
- *External systems integral with the window frame or attached to the building face, such as louvers and screens*
- *Specially treated window glass,* such as hat absorbing and reflecting glass.
- *Internal treatments*, either opaque or semi-opaque, such as curtains and blinds.

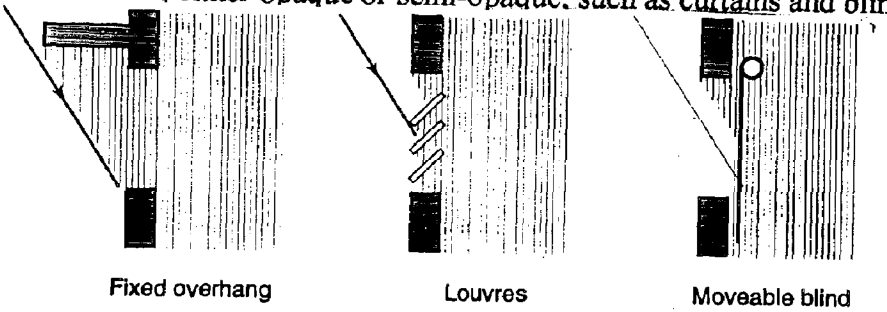
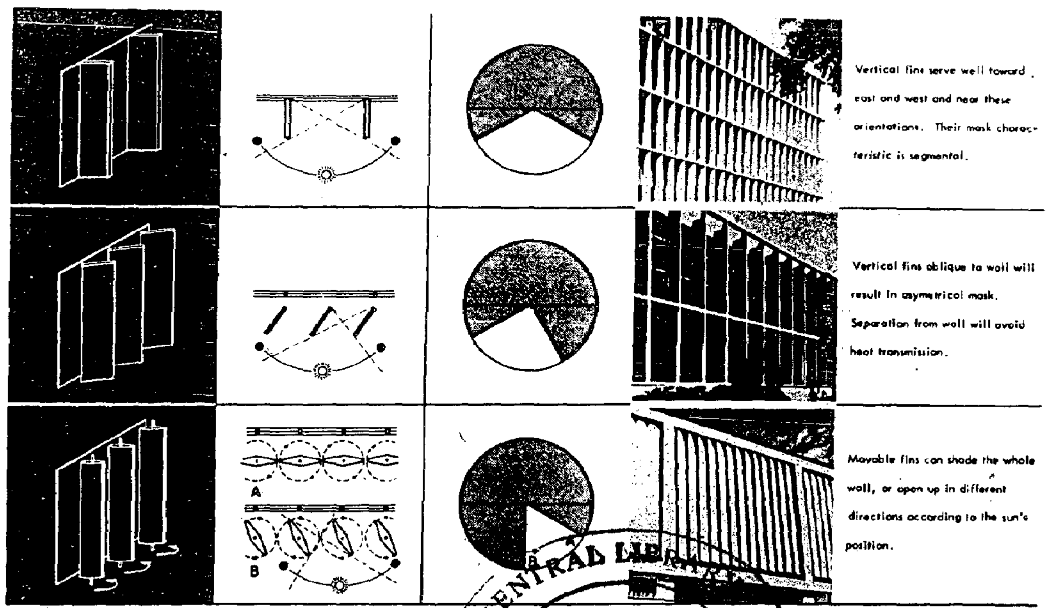
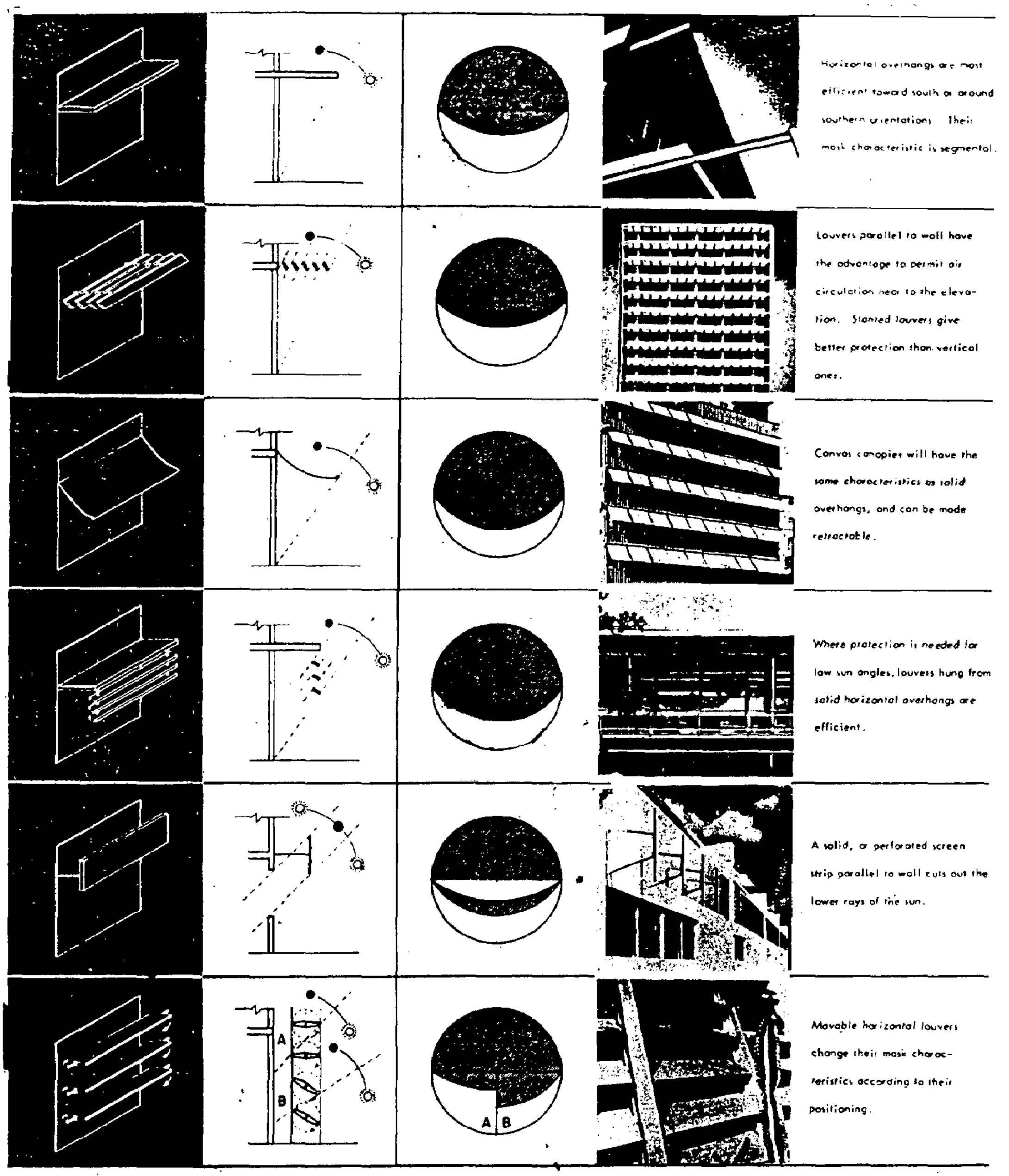


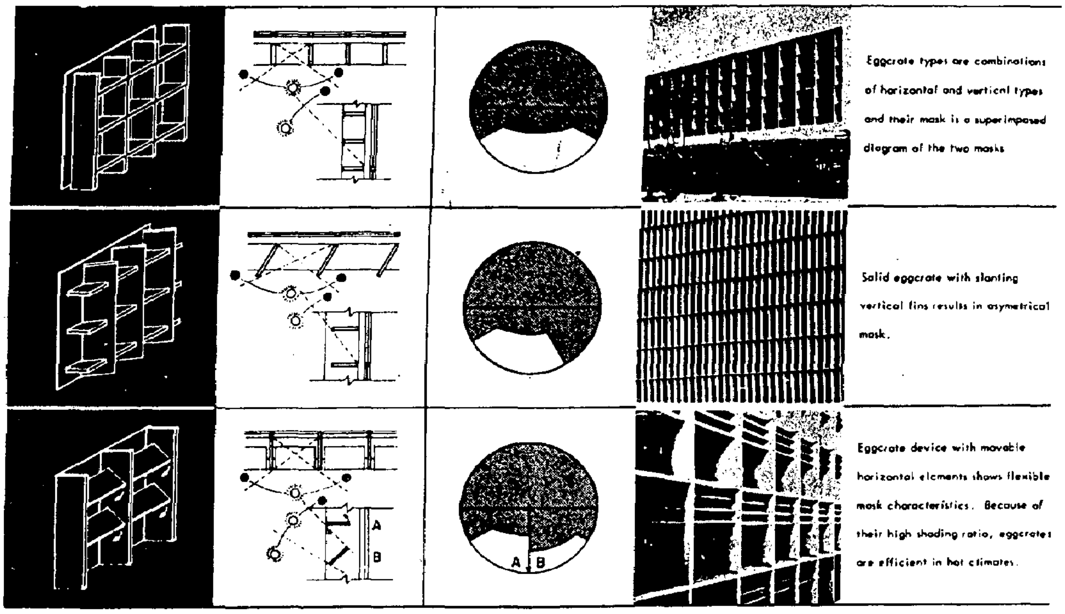
Fig. 3.60. Different strategies for shading (Krishan, 2001)



Vertical shading solutions



Horizontal shading solutions



Eggcrate shading solutions

Fig. 3.61. Types of shading solutions. (Olgyay 83)

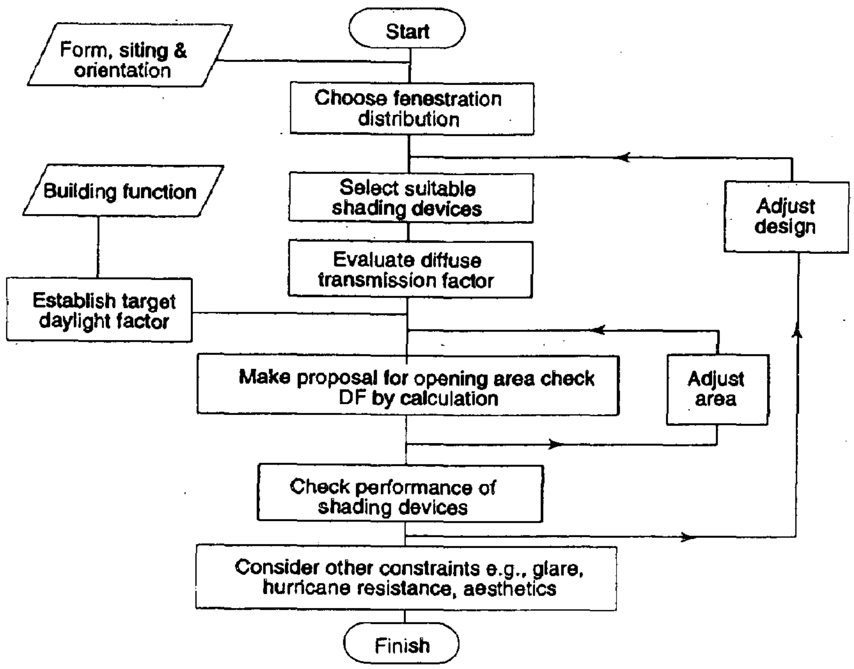


Fig. 3.62. Flow chart for daylight and shading design. (Krishan, 2001)

d) Building envelope (Insulation and thermal storage)

Building envelope has control of the heat flow by reflective, resistive or capacitive insulation. The envelope consists of the roof, wall, windows and floors. Designing for good thermal comfort regarding these elements requires the understanding of their thermal insulation properties.

In cool climates heat loss is to be reduced, that can be done by an airtight envelope and good insulation. The solar heat should be increased by equator facing windows. The thermal storage mass helps in reducing heat at daytime and providing heat at daytime.

The use of thermal mass is very important in hot dry climates, as the diurnal temperature variation is very large.

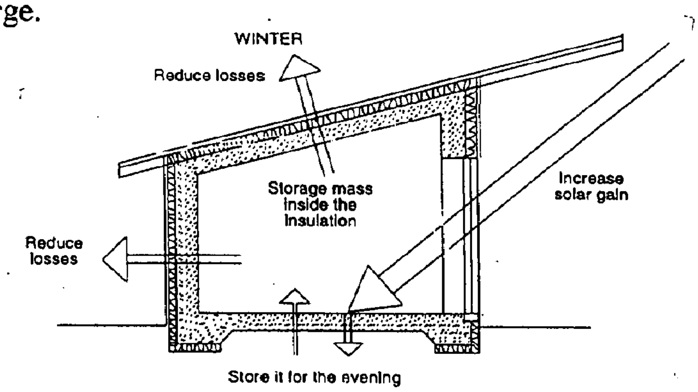


Fig. 3.63. Envelope for cold climates (Krishan, 2001)

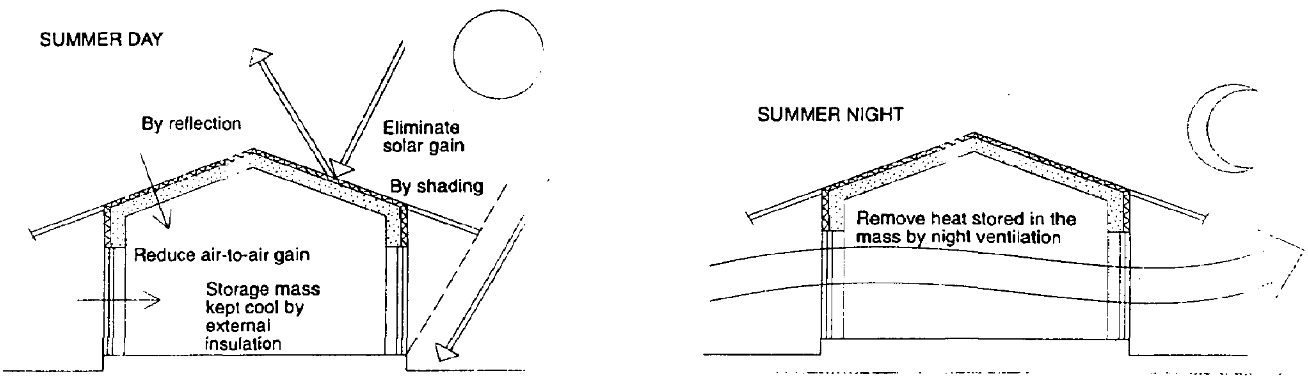


Fig. 3.64. Envelope for hot climates (Krishan, 2001)

Thermal mass moderates interior spaces, and minimizes the need of mechanical systems in hot and cold seasons. The most cost-effective method in this wise is the incorporation of thermal mass in the building structure. To this end, poured concrete or cellular precast slabs and shear walls are the largest thermal mass.

There is little performance beyond 10 cm thickness. High density concrete provides more thermal mass than low-density concrete. Improving airflow across the surface is usually the most economical mans of using thermal mass. The amount of heat transferred across walls and floor slabs can be increased by maximizing the exposed surface area. The use of coffered ceilings or waffle slabs to increase surface area are useful in this aspect. Moreover, the underside of floor slabs should be exposed to the interior space.

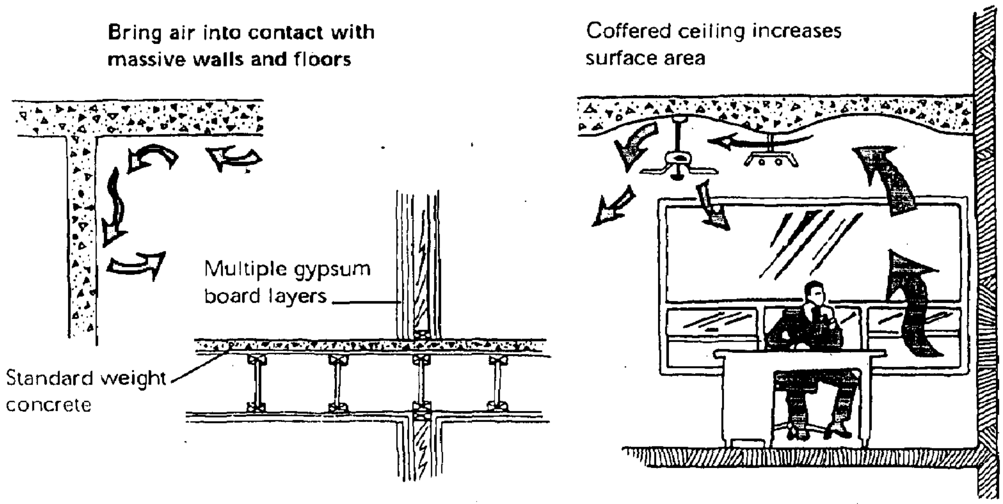


Fig. 3.65. Design details for thermal performance (Sheltair, 1994)

e) Layout for natural ventilation

Natural ventilation with regards to the thermal comfort of building interiors is the flow or the exchange of air between the interior environment and the outside space. This has the following three purposes a) to satisfy fresh air requirement (health ventilation) b) to increase rate of evaporative heat loss from the body (comfort ventilation) and c) to cool the building interior (structural ventilation).

Natural ventilation needs a pressure difference between the inside and outside of the building or across the building envelope. This pressure difference is caused by

- Wind effect

Wind induces high/positive pressures on upwind faces, and low/negative pressures on downward faces;

- Stack effect (difference in air density due to temperature difference between indoor and outdoor air)

Hot air rises due to buoyancy and the temperature difference causes density differentials, and therefore pressure differences, that drive the air to move.

To expose the different faces of a building to high and low pressure areas, it is good to stagger the layout of the plan in order to catch the wind from different directions and ventilate more interior spaces independently. Apart from this, high and low pressure areas could be created using such features as bay windows, recesses and projections, roof monitors and clerestories.

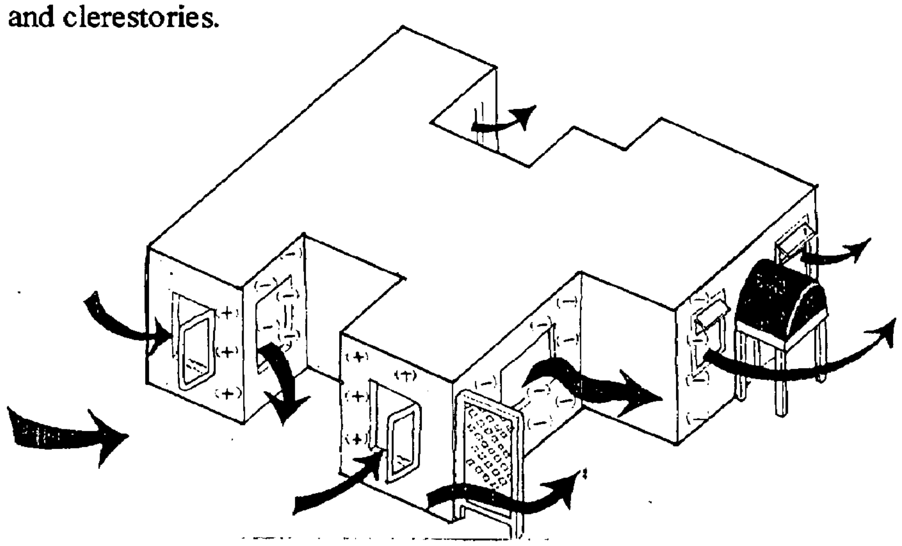


Fig. 3.66. Staggering layout and the use of architectural features for natural ventilation (Sheltair, 1994)

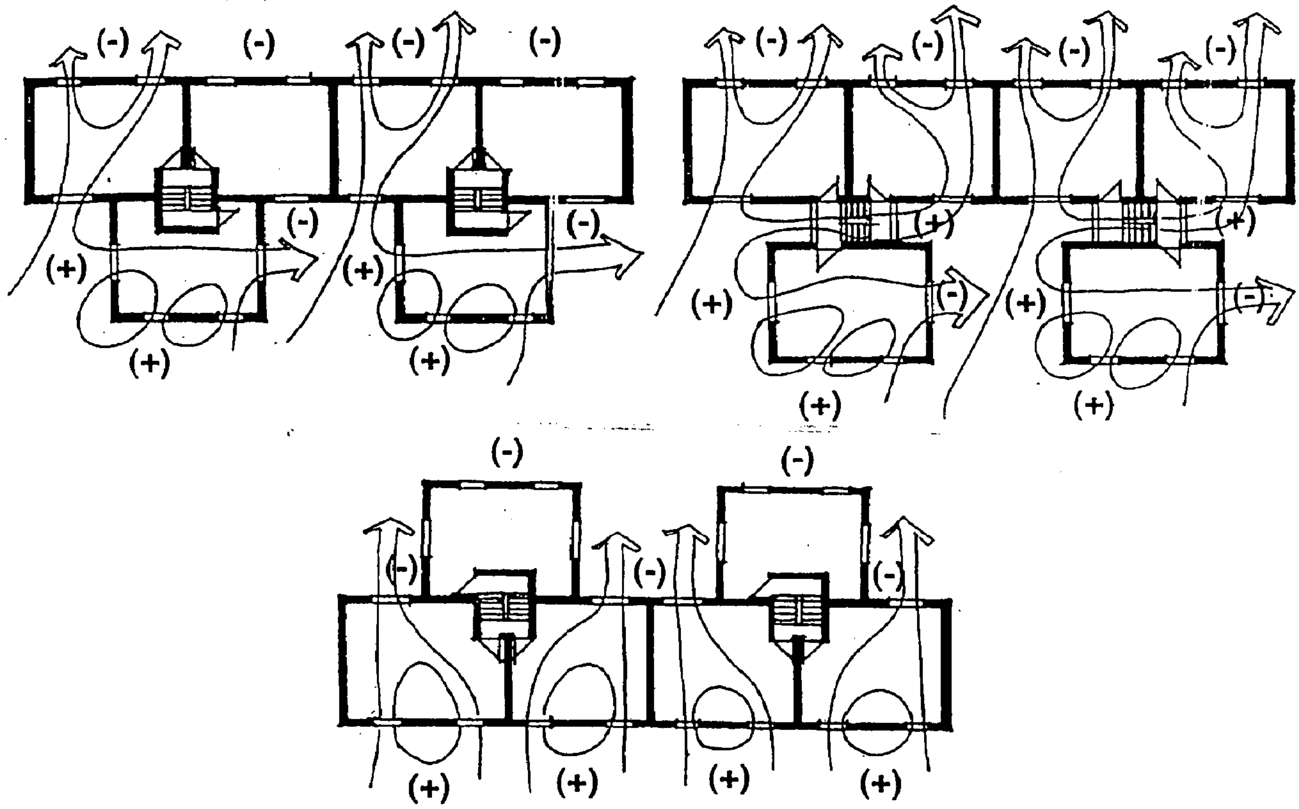


Fig. 3.67. Different ventilation potentials for different configurations of spaces of the same size (Givoni,1998)

The orientation of the building should be considered to avoid the cold winter breezes and to welcome the summer breezes. This will help cut energy demands that will be used to cool and heat building interiors. Façade of the smallest areas should face into the direction of prevailing winter winds, and windows and doors should be located in zones of minimum pressure.

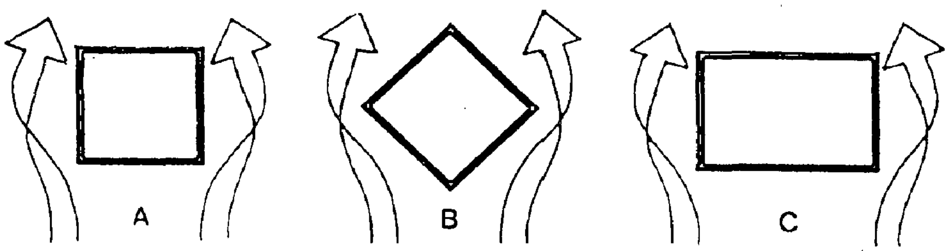


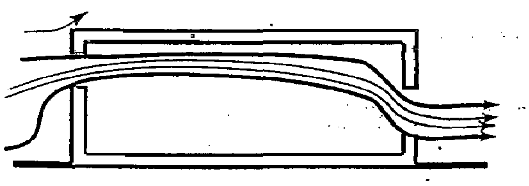
Fig. 3.68. Plan A and B have the same area but B is as exposed as C to the prevailing winds (Watson, 1983)

f) Fenestration for natural ventilation.

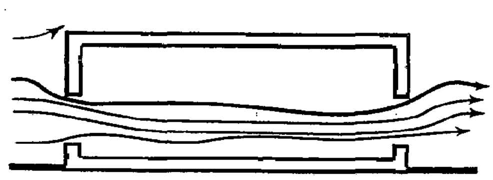
i. Double sided ventilation

The following diagrams clearly elucidate the effect of fenestration detailing and their positions on the path of internal airflow and their cooling value.

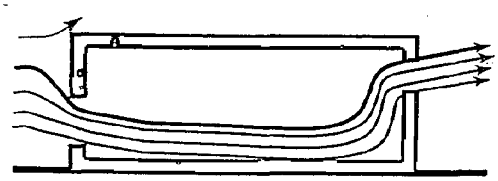
- Air flow relating to the position of the inlet in wall.



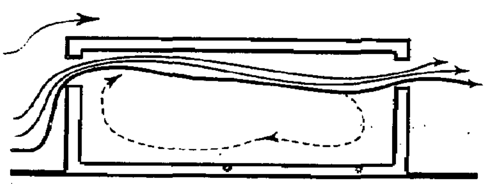
High inlet and outlet do not produce good air movement at body level.



Low inlet and outlet produce a good pattern of air movement, when it is required for cooling



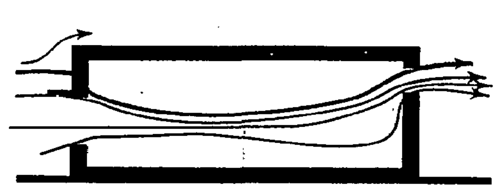
Low inlet and high outlet also produce a low level Wind pattern



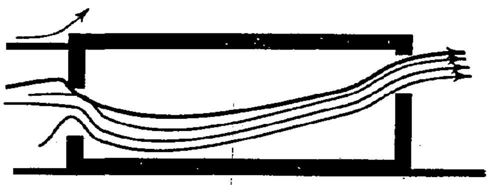
The air flow at ceiling height produced by a hgh inlet is hardly affected by an outlet at low level

- The effect of external sunshades.

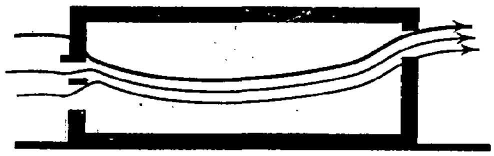
Projection shading devices produce an upward air flow in the room



A slot between wall and shade results in a more direct flow of air.

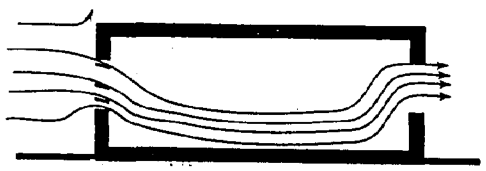


Moving the position of the shade has the same, effect but a larger shade is required

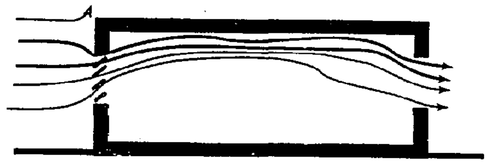


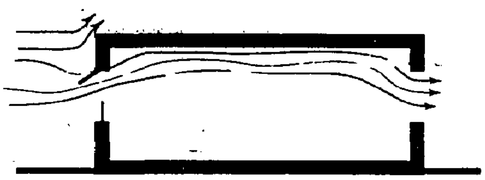
Louvers in the window give a more direct flow, but the sun may heat the louver and the louver may heat the air as it enters the room.

- The effect of different types of window openings.



Louvers can deflect the air stream up to the ceiling, or down to the floor





Top hung, outward opening windows cause an upward flow, desirable in cold weather

Partially open roller blinds can cause a downward flow

Fig. 3.69. Fenestration detailing and pattern of internal flow in schematic sections (Bansal, 1994) (Krishan, 2001)

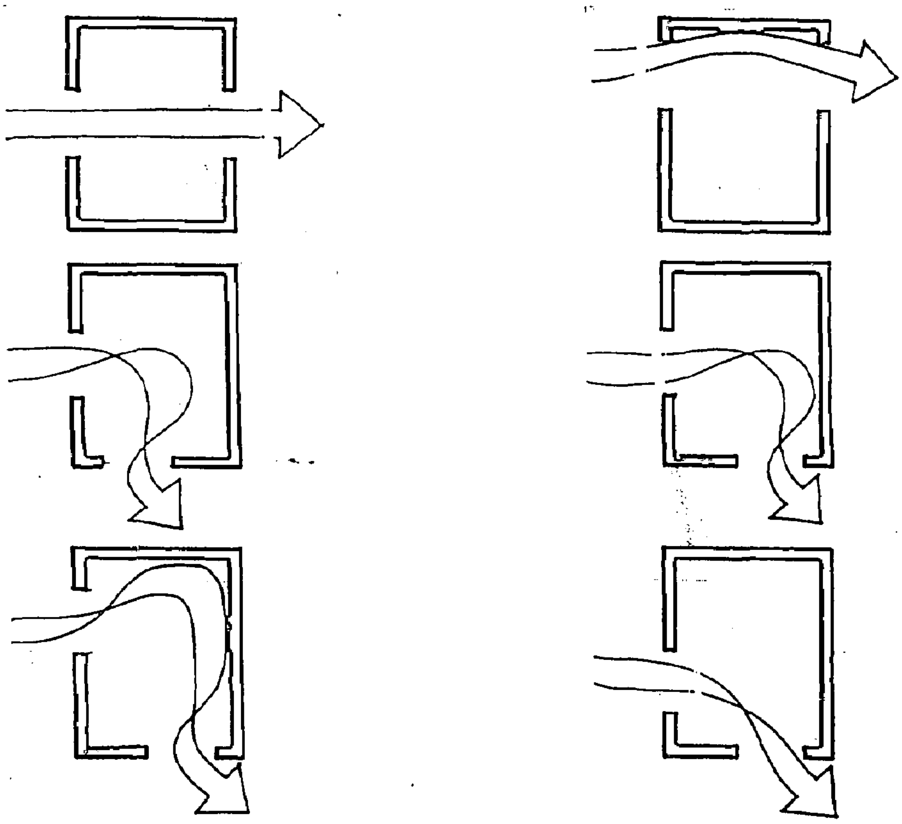
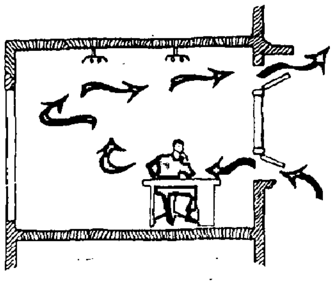


Fig. 3.70. Fenestration detailing and pattern of internal flow in schematic plans. (Watson, 1983)

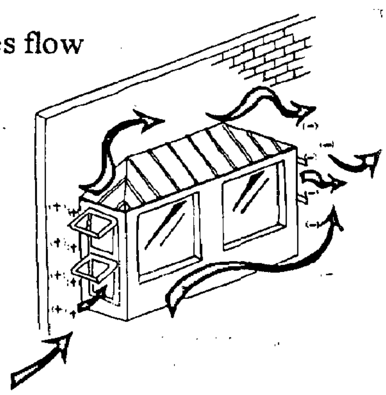
ii. Single sided ventilation

In case the room has only one exterior wall, or the wind is at very low angle to the walls, natural ventilation could be improved by the following

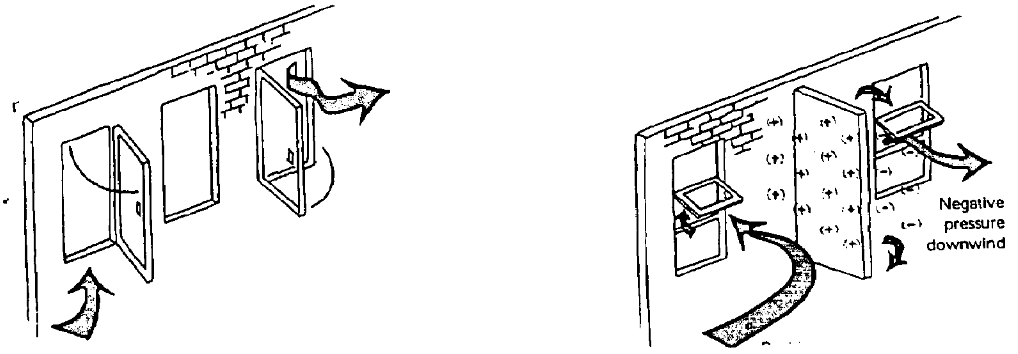
- Use of vertical fins. Provide two separate operable windows on upwind and downward sides of fins, for inlet and outlet
- Articulate the building façade to create localized pressure differences. Place windows on adjacent or opposite faces of the protrusion as inlets and outlets.
- Height separation of inlets and outlets promotes flow



Height separation of inlets and outlets promotes flow



Locate inlets upwind and outlets downwind



Inlets open into prevailing winds and outlets open away from prevailing winds

Positive pressure upwind and negative pressure down wind

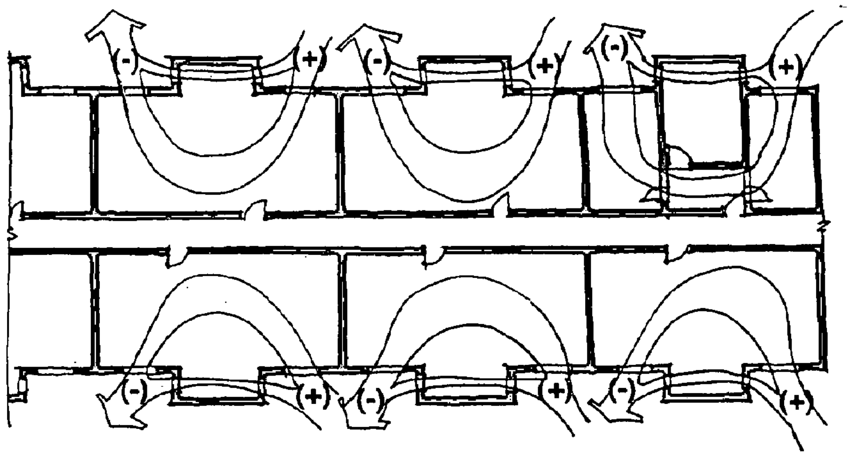


Fig. 3.71. Natural ventilation where there is only one wall and when the wind is at very small angle to the walls (Sheltair, 1994), (Givoni, 1998)

g) Interior design for natural ventilation.

Narrow floor plans are good for cross ventilation induced by pressure differences across a building. Cross ventilation is effective in moving air over deep floor plans, but this will lessen the air quality and increases the air temperature. The practical limit for the length of the airflow path, however is five times the ceiling height (15m for a 3m ceiling).

Single sided ventilation, is possible but is less effective, since air speed is lower than in cross-ventilation.

Single operable window, uses wind turbulence and buoyancy, for ventilation, instead of pressure difference, as is the case with cross ventilation. Here air flows in the bottom, is heated within the space, and flows out at the top of the same opening. The larger the height of the opening, and the higher the temperature change, the greater the airflow.

In the case of single sided single opening, natural ventilation is effective to a depth of two ties the ceiling height. This means that a maximum room depth of 6m for 3m ceiling height with a window 1.5m high.

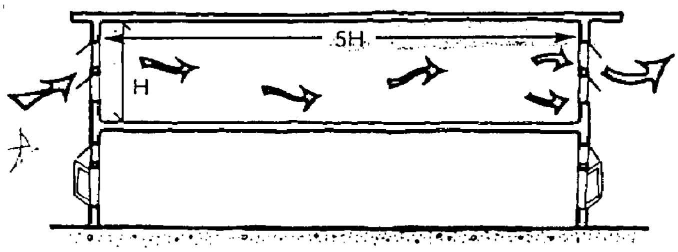


Fig. 3.72. Proportion of the interior spaces of a room for natural ventilation. (Sheltair, 1994)

In the case of single sided, double opening, warm air leaves through the upper vent, inducing inflow through the lower vent. Here, if the vertical separation between the two is 1.5m, ventilation is effective for up to 2.5 times the ceiling height. This gives a maximum room depth of 7.5m, if the ceiling height is assumed to be 3m.

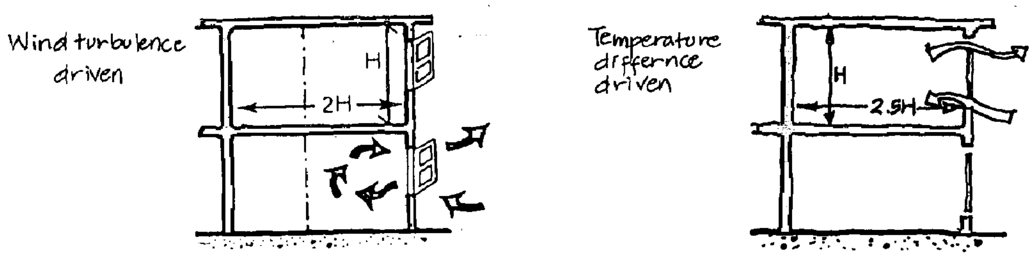
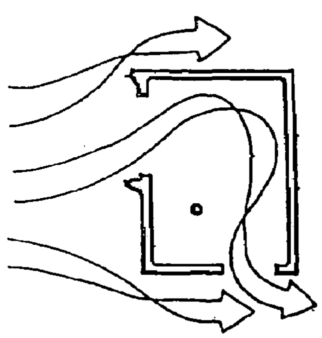
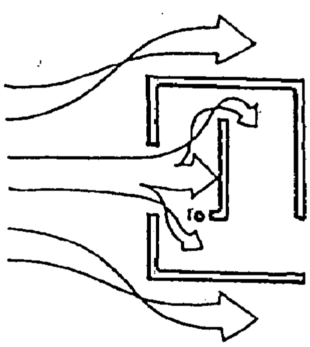


Fig. 3.73. Proportion of the interior space of a room with single sided, single and double openings for natural ventilation. (Sheltair, 1994)

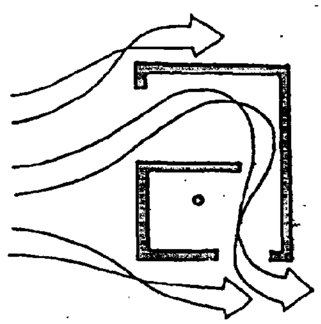
Open plan should be adopted in the interior to promote interior airflow. The partitions should be placed so as to offer the least resistance to the airflow for ventilative cooling. Interior partition should be designed to channel air movement where it is needed. The following figures illustrate the effect of interior partition design to help promote airflow.



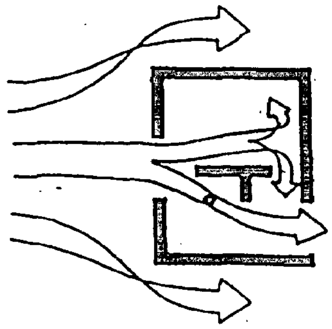
Unobstructed air flow path.



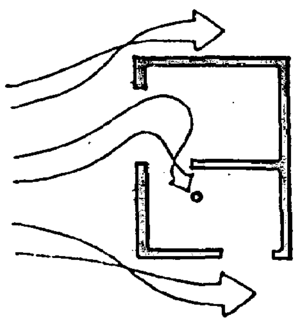
Inflow is blocked by partition resulting in minor cooling effect



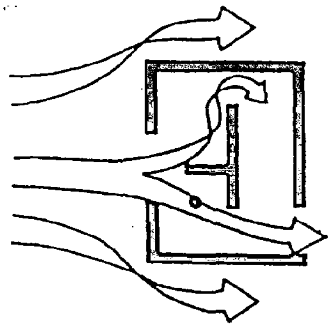
Partition in static area will have little effect on air flow pattern



Partition splitting inflow dissipates little energy resulting in overall adequate ventilation



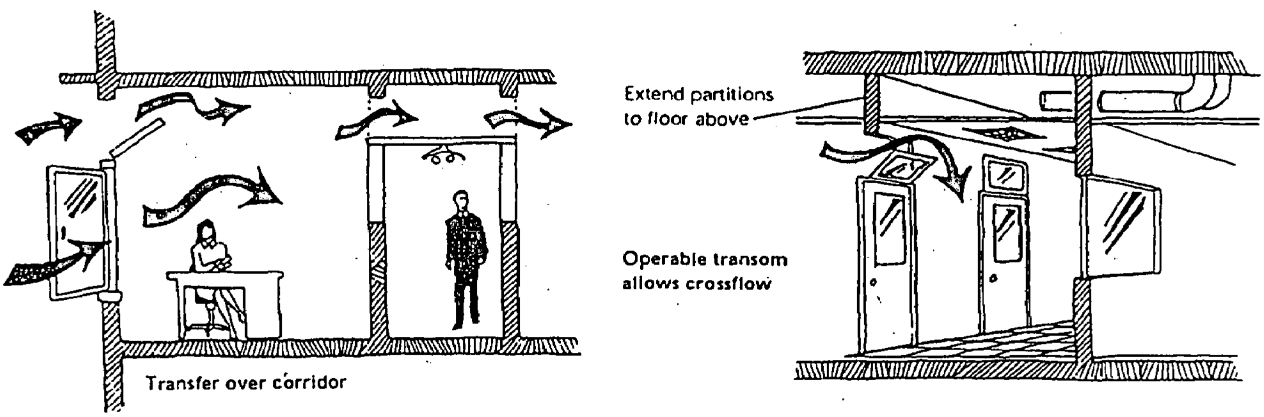
Partition placed in flow zone absorbs force. Resulting in neither room receiving adequate ventilation



Divider partition splits airflow. Lower room is well ventilated back room receives little air flow

Fig. 3.74. The effect of interior partition in blocking and channeling airflow. (Watson, 1984)

If it is not possible to design open plan layouts, rooms could be designed to allow airflow from one big space into other adjacent small spaces, this could be achieved through the use of false ceilings and operable transom.



Fig, 3.75. False ceiling and operable transom to allow free airflow between spaces (Sheltair, 1994)

3.2.2.3. Passive cooling technologies

Cooling of buildings by passive systems can be provided through the utilization of several natural heat sinks; the ambient air, the upper atmosphere, and the under-surface soil. Some of the cooling technologies apart from what were discussed above are

a) Radiant cooling

This simple system utilizes the process of night time long-wave radiation to the sky. It reduces the heat gained during the daytime, by the removal of heat from the building. The cool medium is the sky; a net cooling effect is achieved at night. Horizontal surfaces have the best exposure to the sky.

Any ordinary surface which faces the sky, such as roofs, and ground surface around buildings, lose heat by the emission of long wave radiation toward the sky, and can be regarded as a heat radiator. Thus clear sky conditions allow these surfaces to reach temperatures well below that of ambient air. Heavy weight concrete roof can serve as the heat store and radiator. Movable and reflecting insulation above the concrete will protect it from daytime solar gains.

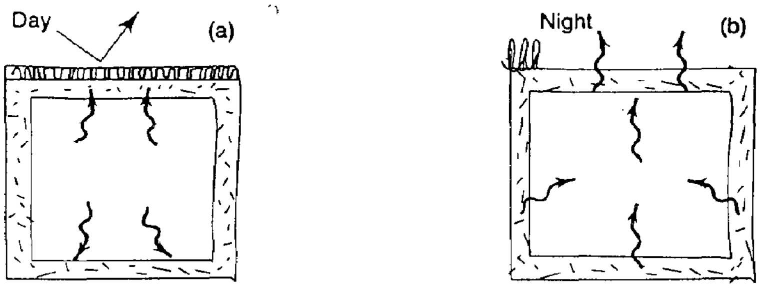


Fig. 3.76. Radiant cooling by roof elements (Krishan, 2001)

b) Direct, non mechanical

Evaporative cooling of the ventilation air, for example by cooling towers and wind towers or solar chimneys.

i. Wind tower

Wind tower uses the stack and reverse stack effect principle of encouraging air to move from the inside to the outside and vice versa of a building. In the afternoon, the wind tower will be hot inside and will draw cool air from the courtyards by the stack effect, and in the morning, the cold tower will draw air from the outside warmer air by the reverse stack effect. The intake and exhaust of air by a wind tower depend upon the pressure differential between the exterior and interior air, and on the two temperatures (length of tower).

Their advantage is that

- They can reach up into the faster wind flows above the roof of buildings in densely packed settlement
- They allow cross ventilation of spaces while excluding unwanted solar gain.

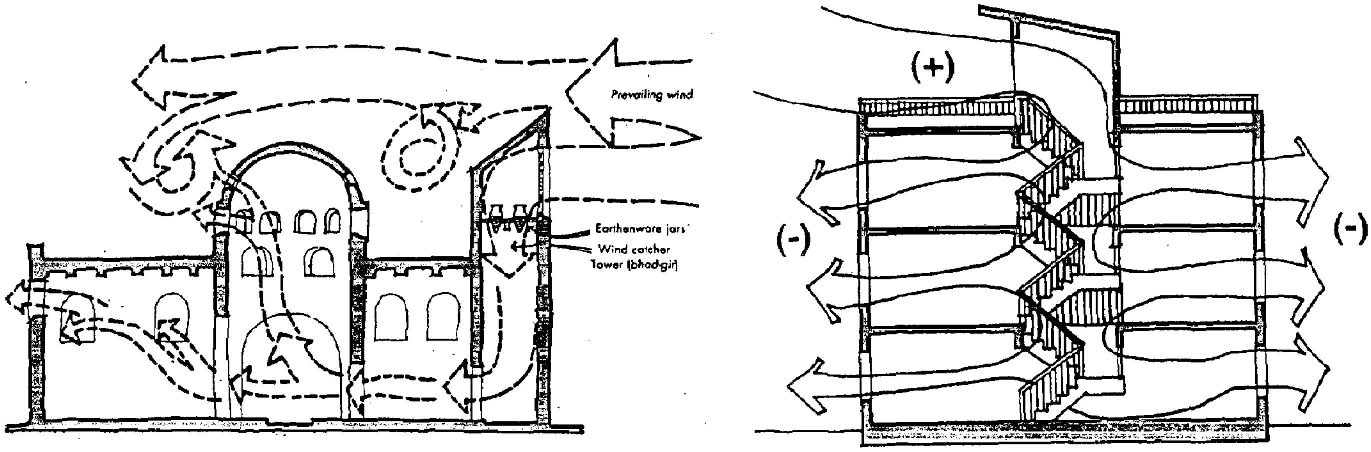


Fig. 3.77. Wind towers (Baggs, 1996) (Givoni, 1998)

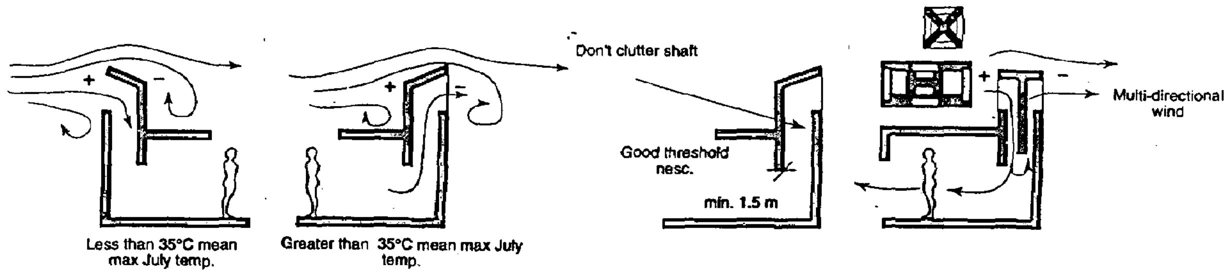
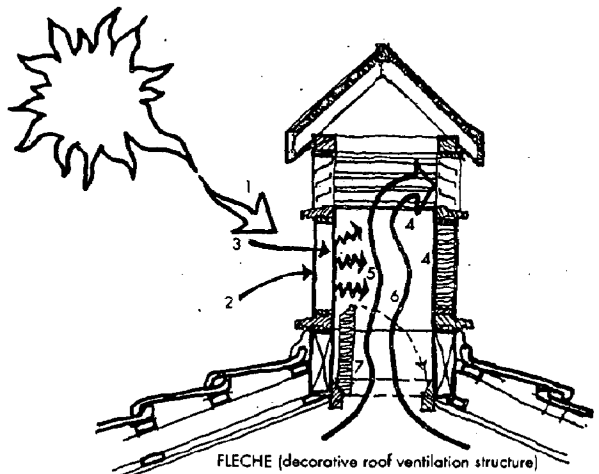


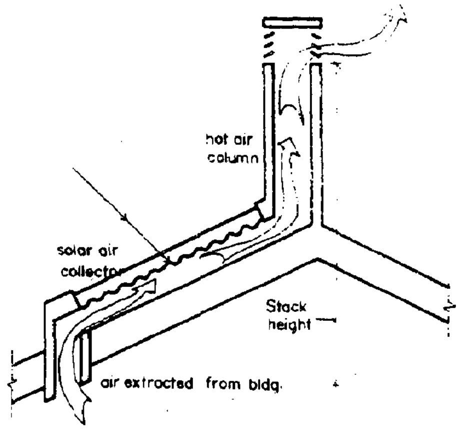
Fig. 3.78. Some rules of thumbs on wind towers. (Krishan, 2001)

ii. Solar chimney

Solar chimneys can stimulate ventilation even when the air is still. This chimney is equipped with a solar heating element and creates a natural draft as the heated air in it rises. It is a chimney covered on the outside with black metal which absorbs solar heat. Its effectiveness can be increased by lining the chimney with glass and thermal-mass materials so that even after the sun has set, the chimney continues to function on stored heat. The parameters affecting the ventilation rates are height between inlet and outlet, cross-sectional area of the inlet and the outlet, the geometrical construction of the solar absorbing place and the inclination angle.



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 updraught ventilates room; 7. in cold, draughty conditions, insulated hatch is lowered (with rod or line and pulleys).



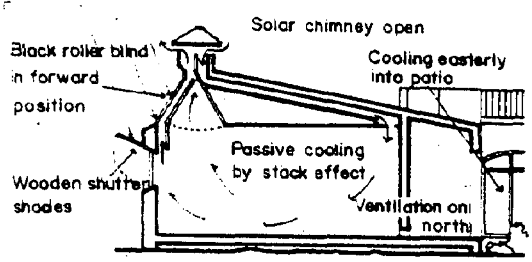


Fig. 3.79. Solar Chimneys (Baggs, 1996) (Bansal, 1994)

c) Indirect Cooling (Evaporative cooling)

Evaporative cooling of the building is achieved by water surfaces which are in direct contact with the building fabric such as roof ponds and wetted conductive impermeable walls. The heat energy is taken from the air, and the temperature of the affected air is lowered.

Trees and vegetation promote evapotranspiration. Natural or man-made pools of water direct evaporative cooling to the surrounding air. Open courtyards fitted with ponds or fountains can also serve this purpose. Evaporative cooling can be combined with wind towers to enhance their cooling effect.

Roof wetting is another method to get the benefit out of evaporative cooling.

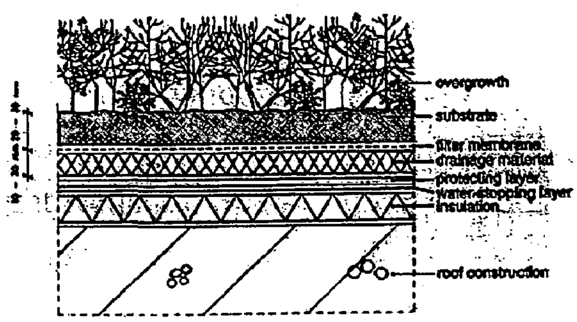


Fig. 3.80. Roof planting for evaporative cooling. (www.hku.hk/teaching.html)

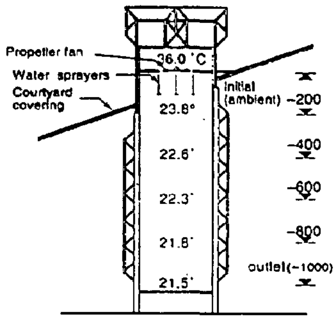


Fig. 3.81. Evaporative cooling tower (Krishan, 2001)

d) Soil cooling

Soil cooling utilizes the soil as a cooling source for buildings such as Earth-tube air-cooling. In hot climates the air is passed through shafts of tubes that are passing through the soil at a depth that is considerably less than the desired temperature within the building. The air could be passed across an air locked volume of water in an underground storage tank or the system can draw air from an external or internal garden or from the earth itself. The air movement could be induced by the stack or chimney effect, where the outlet of the earth coupled loop is placed in the direction of the prevailing wind. The other option is to use a fan powered by PV panels to draw the air into the room

Daily temperature variations don't affect the earth's temperature at a depth of more than one meter. For example the earth's temperature in New Delhi at a depth of about four meters is nearly constant at a level of about 23° C (Bansal, 1994). The temperature of earth decreases at 1° C for every meter down the earth. A tunnel of clay pipes with a diameter of 30-60mm sunk within 3-10 meters could be used. This loop is able to introduce air that is at least 5° C cooler than ambient temperature (Krishan, 2001).

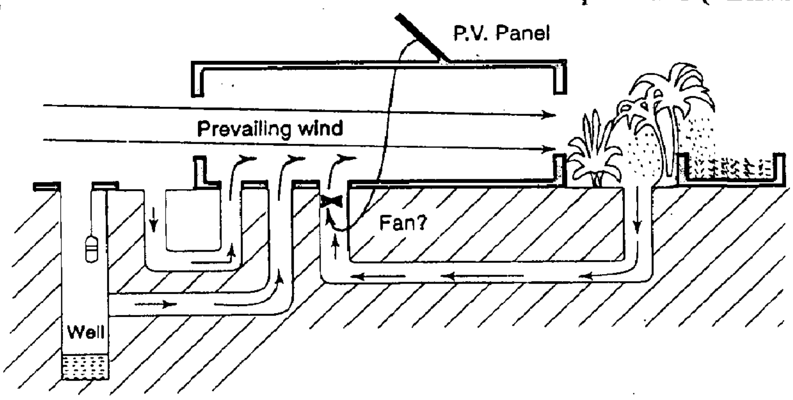


Fig. 3.82. Soil cooling assisted by PV panels (Krishan, 2001)

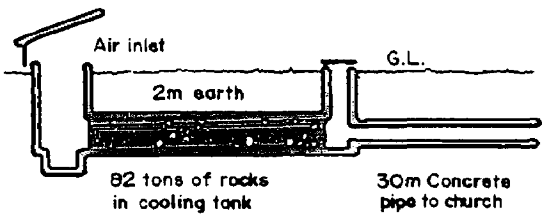


Fig. 3.83. Earth tunnel cooling system for a church in Normal, Illinois (Bansal, 1994)

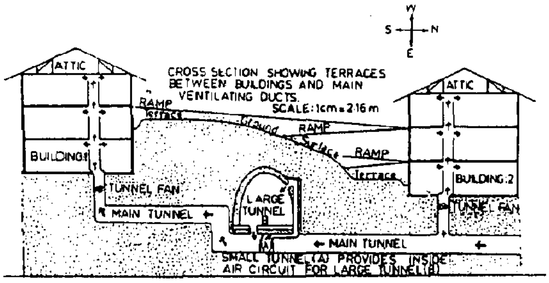


Fig. 3.84. Earth air tunnel system in New Delhi (Bansal, 1994)

e) Roof ponds

The basic principle of a roof pond (skytherm) is that of a horizontal water storage area placed on top of a flat roof. The water is either kept in small bags or in one large container. In winter daytime, the water is exposed to the sun and gets heated. In winter nighttime, the insulation covers the water to reduce heat losses, and the heat radiates downwards to the living spaces.

In the summer daytime, the reflecting insulation keeps the solar heat away, the heat inside the house rises and is absorbed by the insulated roof pond. At night the insulation is removed and the heat radiates to the cool night sky naturally. Due to this, it is well adapted to both hot and cold areas, and is both a passive cooling and heating strategy.

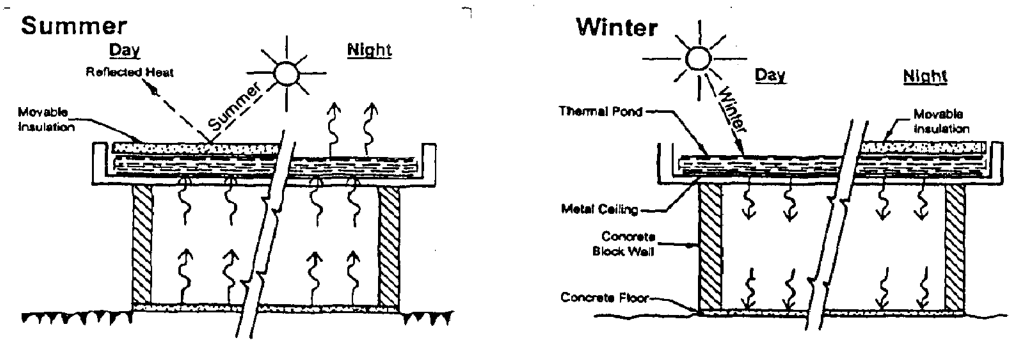


Fig. 3.85. Roof ponds (ICIMOD, 2000)

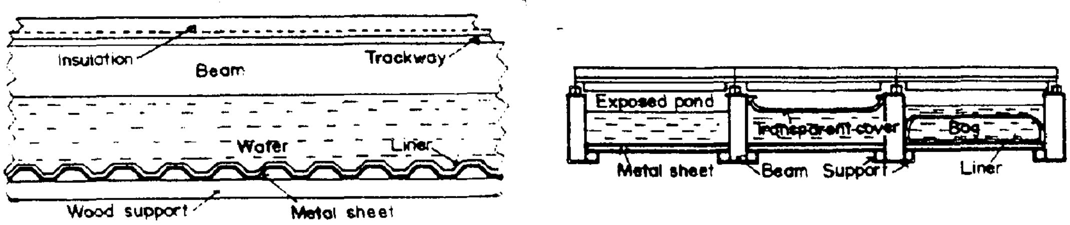


Fig. 3.86. Cross-section of ceiling ponds. (Bansal, 1994)

3.2.2.4. Passive Solar Heating technologies

There are two basic types of solar heating systems that retain heat once it has been converted from sunlight. They are passive and active solar heating technologies. The active systems use an additional source of energy to pump a liquid or blow air over the absorber. The passive system has absorbers that also store heat, but they require no additional energy source.

Passive solar systems use a material to both absorb and store solar energy. This material is commonly referred to as thermal storage mass and is usually heavy, dense, and dark brick, stone, cement, or containers of water are used. When sunlight strikes, the surface of the thermal storage mass, it begins to heat up, heating the area around it. Much of the heat from the surface of the mass is slowly conducted inward, penetrating deeper and deeper, gradually warming up the cooler interior of the mass. When the mass becomes hot, it starts radiating and convecting heat to the surroundings slowly in the same manner in which it was heated by the sunlight. Lightweight, low-density materials, even if darkly colored, are not good thermal storage materials.

a) Direct gain

The sun is admitted directly into the inhabited spaces through conventional windows, daylights, clerestoreys, etc that face the south in the northern hemisphere or vice versa in the southern one. The mass of the building fabric itself acts as the necessary thermal storage material, storing excess solar energy during the sunny hours and releasing it back during the night. Floors and walls used for thermal storage should be only four to six inches thick, as heat doesn't penetrate deeper than that. The main advantage of this system is its efficiency. Which is superior to other passive options in delivering heat to the living space.

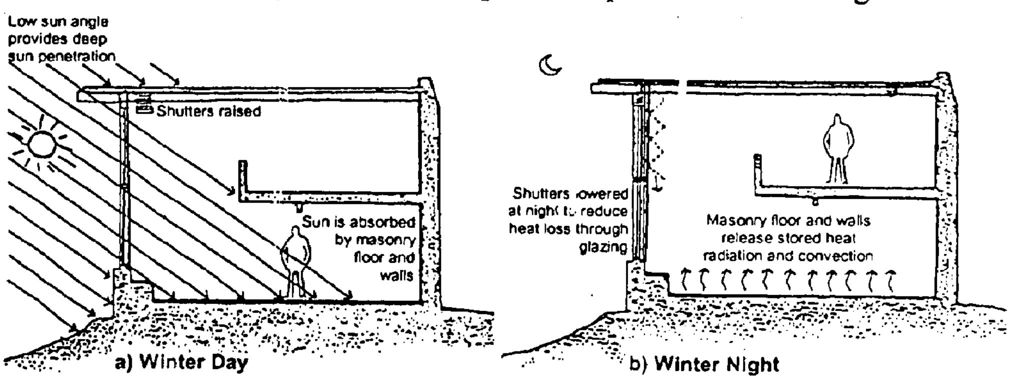


Fig. 3.87. Direct passive solar heating. (ICIMOD, 2000)

b) Thermal Storage walls

The thermal storage wall is placed about four inches behind glass area that is about the same size as the wall. The space should be sealed tight to prevent air leakage. The sunlight passes through the glasses and strikes on to the dark-colored mass, which begins to heat. The heat then penetrates through to the living space on the other side. Since the wall is intermediary between the sunlight and the living space, it is also known as an indirect solar gain system. These are of two types. Trombe wall and Water wall.

i. Trombe walls or Solar induction walls

The trombe wall is useful for both convection cooling in summer and warming in winter. Trombe wall in its simplest form consists of glazing placed in front of a sun-facing massive, conductive wall, with an air gap in between. The exterior surface of the wall is painted a dark color to enhance absorption of radiation. Operated as a passive heating system the outside openings at the bottom and the top of the glazed surface will be closed, the interspace between glass and massive wall will heat up and the heat will be directed into the room through openings in the upper section of the wall. At the same time openings/holes in the bottom of the wall near the floor will suck out the cooler air by the chimney –effect of the heated up space behind the glass. This creates a thermosiphoning effect. The wall is about one foot thick and can be either one or two stories high. The vents are small rectangular holes in the wall (about 1-3m^2 for every 100m^2 of wall area) separated with about 2.5m.

Vented Trombe walls are appropriate if the living space is to be heated in the early afternoons. Flexible dampers are used to prevent a reverse thermosiphon loop at night. The damper only permits air to travel in one direction.

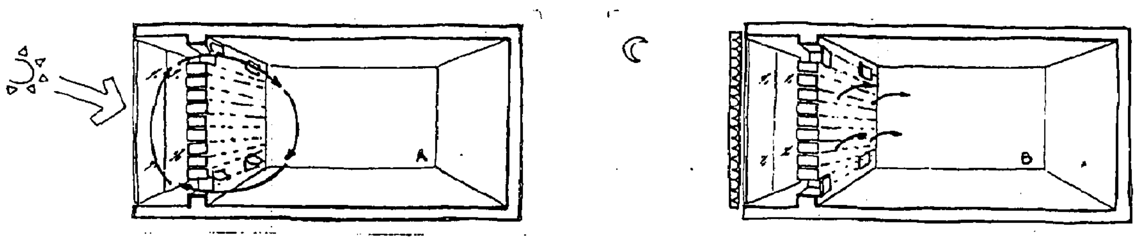


Fig. 3.88. Trombe walls (Givoni, 1998)

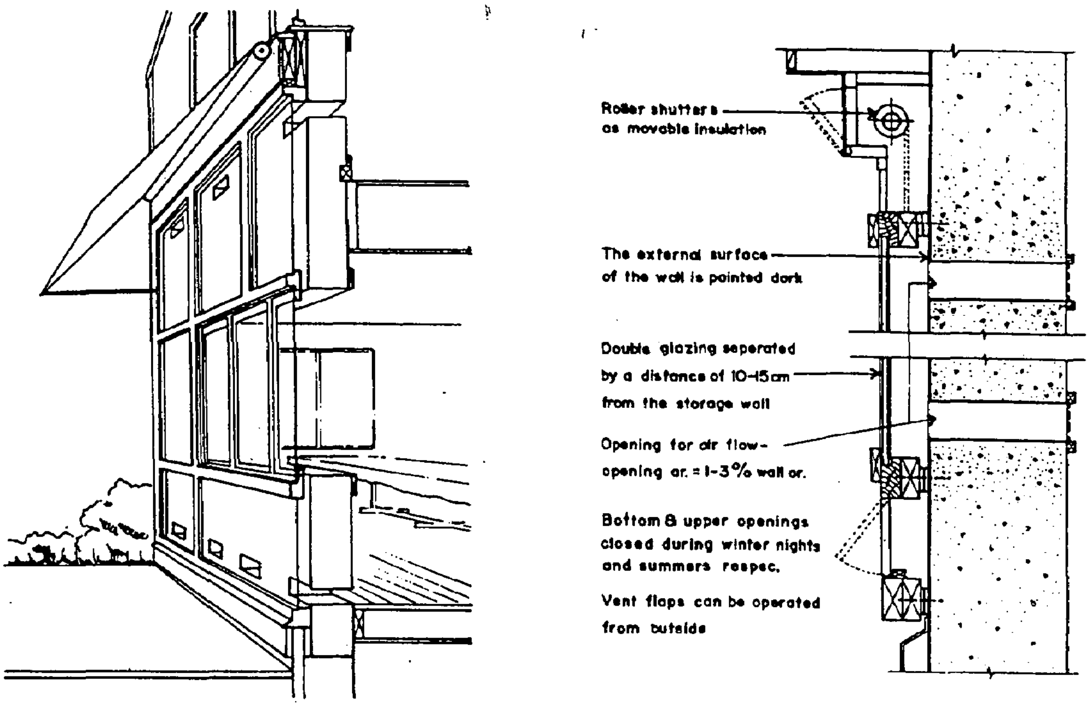


Fig. 3.89. Construction detail of a Trombe wall. (Bansal, 1994)

ii. Water walls

Water walls are not part of the structural component of the building but are portable. Metal or plastic containers house the heat-absorbing water. The containers are painted with dark colored paint. Water has a greater heat capacity, is more efficient, and, because it is a better conductor, distributes heat more quickly to the living space in the early hours of the day in contrast with the trombe walls which heat the space in the early afternoons. Due to its conduction properties the outside surface will have a lower temperature, not only through conduction, but also convection.. This minimizes the loss of heat through the glazing to the outside air. Therefore the 'Water wall' is more efficient than the 'Trombe wall'.

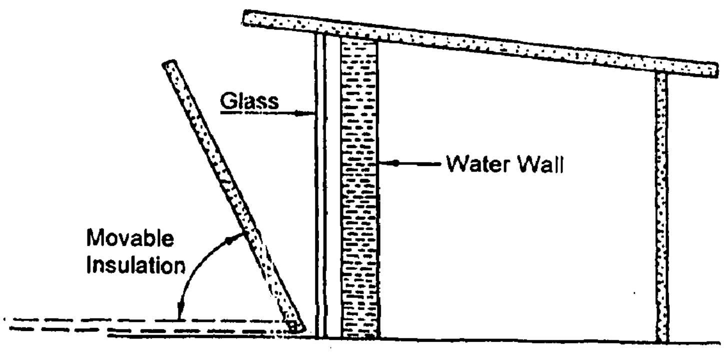


Fig. 3.90. Water wall (ICIMOD, 2000)

iii. Phase change walls.

This is achieved by the use of phase change materials (PCMs) that change from solid to liquid, when they are heated. Only after all of the materials have changed phase does the temperature start to rise significantly and vice versa. These materials store more heat than masonry and water, and they are available in tubes or as floor tiles and are also lighter. The PCMs change phase between 25 and 40^0 C. This is warm enough for the heat released to be warmer than the air in the room and cool enough so that heat loss through glass is minimal.

The advantage the Phase change wall has over Trombe or Water walls is the constant lower temperature, so less that is lost through the glass than with the latter two devices. It's disadvantage however is that, PCMs over time lose the ability to change phase back and forth.

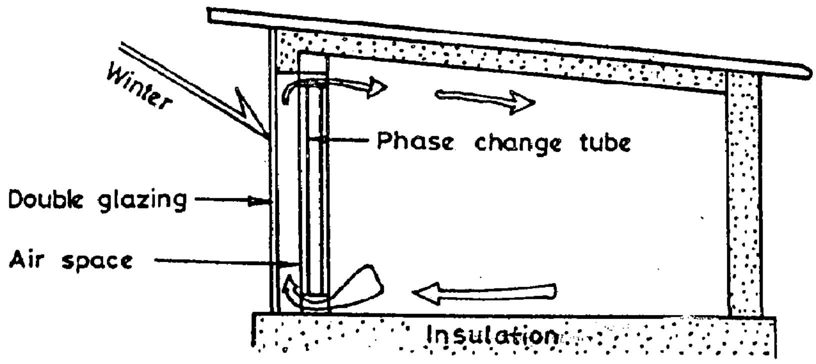


Fig. 3.91. Phase change wall. (ICIMOD, 2000)

c) Convective loops

Convective loops use an absorber surface to absorb incident radiation and then convect warm air into the building space. Air heating solar collector and a rock storage bin are located below the level of the building's floor. The airflow can follow three different paths, according to the needs for space heating and the availability of solar radiation. The airflow is driven completely by temperature differences. The following figures show the daytime heating mode, the charging mode and the night heating mode respectively

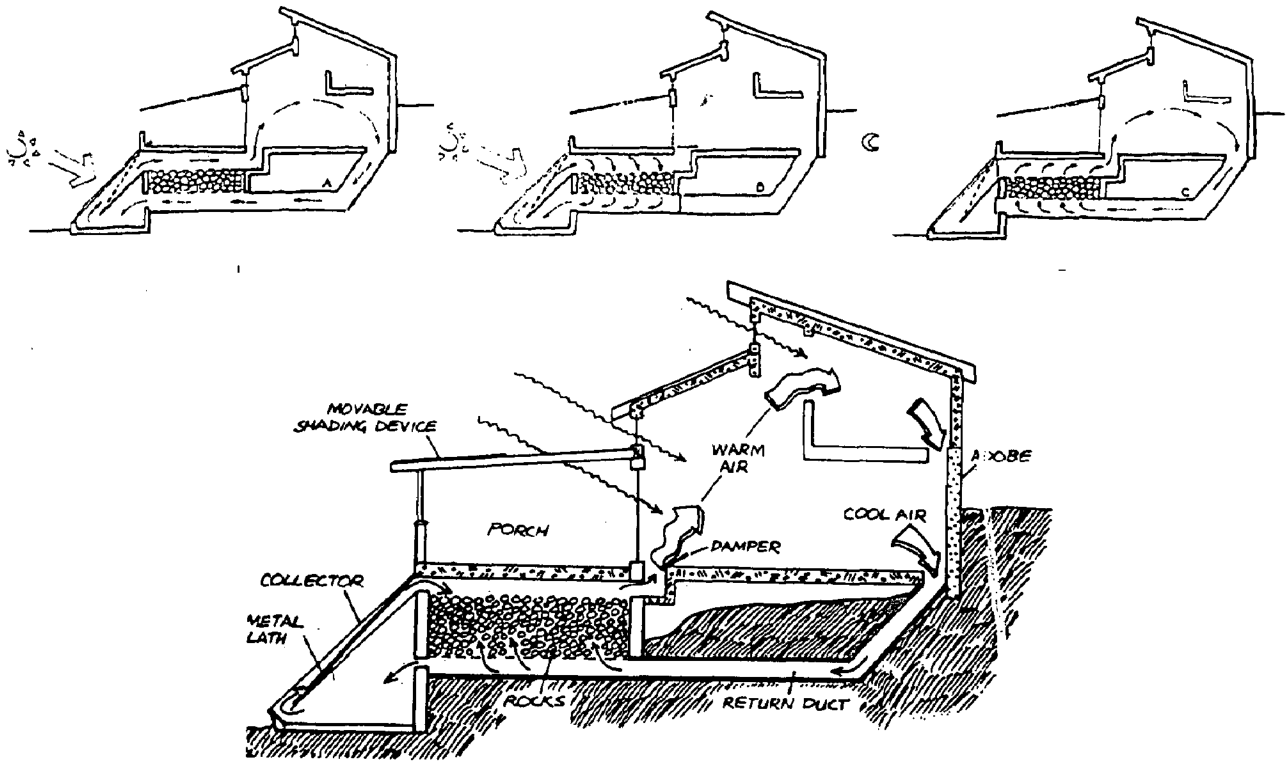


Fig. 3.92. Convective Loops (Givoni, 1998), (Littler, 1984)

d) Sun Spaces

Sun spaces, (solar greenhouses, solariums and sunrooms) are intermediate usable spaces between the exterior and interior of the building. Being separated from the main spaces of the building, a much greater temperature swing, resulting from a large glazing area, may be acceptable within sun spaces, more than can be tolerated in direct-gain spaces.

Although there is a diffuse radiation, this space gets hot due to the green house effect and in the absence of radiation, there is a substantial heat loss. To this end it is good to provide a movable insulation. It can provide more energy by

- natural convection
- blowing the warm air into a rock bed storage, either in between the sun space and the living spaces or under the building.

A glass roof tilted to the optimum angle (angle of latitude plus 15) can provide more energy in winter than vertical glass. In winter, sunlight passes through the windows and warms the darkened surface of the floor, wall, and water-filled drums or other storage elements. The air temperature in the space during a winter day rises to between 30-40° C.

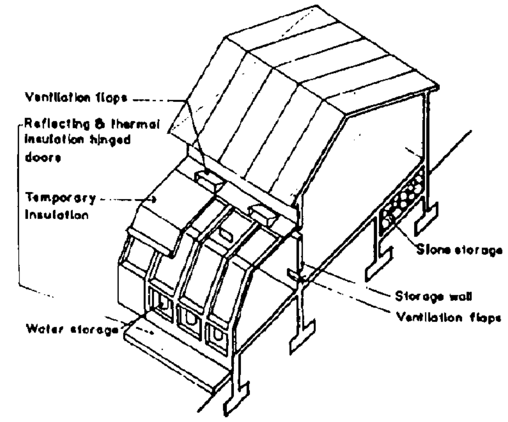


Fig. 3.93. Sun space configuration (Bansal, 1994)

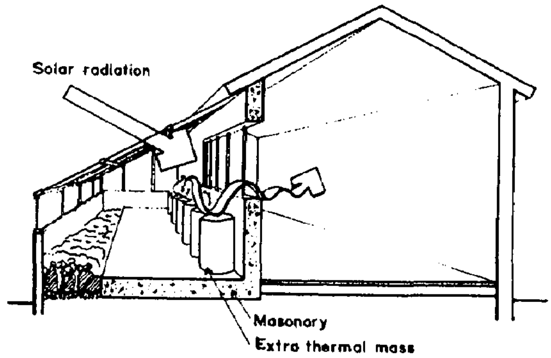


Fig. 3.94. Sun space with added water storage (Bansal, 1994)

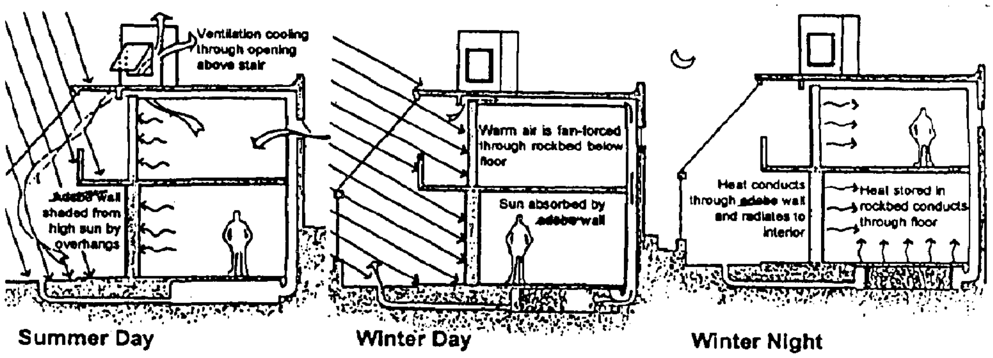


Fig. 3.95. Sun spaces during different seasons (ICIMOD, 2000)

e) Roof Ponds.

The principle of the roof pond for the purpose of passive heating is already discussed along with its importance in cooling. The process of heating the living space is just the reverse of the process of cooling the same.

f) The Barra System

This system contains insulated glazed solar wall and storage in concrete ceilings. The southern wall acts as the solar collector, which when heated heats the air getting out of the wall into channels embedded inside a concrete ceiling, while the still warm air exits from the channels in remote parts of the building which don't receive solar radiation. The air will then warm the remote rooms and come back through the rooms to the inlets in the lower part of the collecting wall on the south. Hence this works as a thermosiphoning air heating system. It can be applied to multistorey buildings.

The northern walls could be used as collecting walls, since the majority of the heat is transferred to the northern side by convection

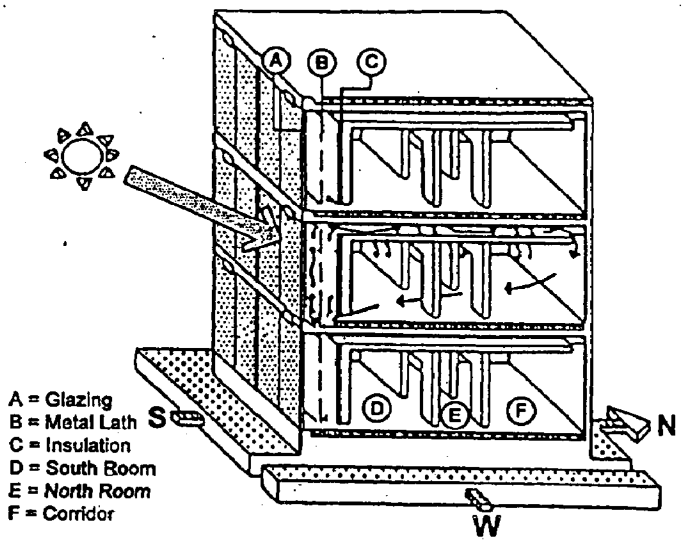


Fig. 3.96. The barra system. (ICIMOD, 2000)

	Options						
	Thermal storage					Surface treatment	
	Storage walls			Storage under floor	Insulated isolated storage		
Capture strategy	Isothermal	Non-isothermal	pcm[a]			Painted	Selective coating[b]
Direct gain	✓	✓	✓	–	✓	✓	
Attached sun space	✓	✓	✓	✓	✓	✓	–
Mass wall	✓	✓	✓	–	–	✓	✓
Trombe wall	✓	✓	✓	–	–	✓	✓
Thermosiphon	–	–	✓	✓	✓	✓	✓
Double envelope	–	–	✓	–	–	✓	–
Roof-space collection	–	–	✓	✓	✓	✓	✓

[a] Phase-change material, for example melting at 25 °C.
[b] Solar absorptive, but with low emissivity in the infra-red (for heating), or the converse (for cooling).

Table. 3.5. Summary of passive design strategies for heating (Littler 1984)

3.2.3. Active solar systems

Active solar design uses purpose-designed and manufactured systems in addition to the design of the building to make use of solar energy. The solar collectors are best oriented to the direction where the maximum amount of solar radiation is received on the building. To this end there are some movable systems being developed, which follow the movement of the sun throughout the day to get maximum amount of incident rays hitting their surfaces.

3.2.3.1 Solar collectors

Preparation of warm water is one use of solar collectors

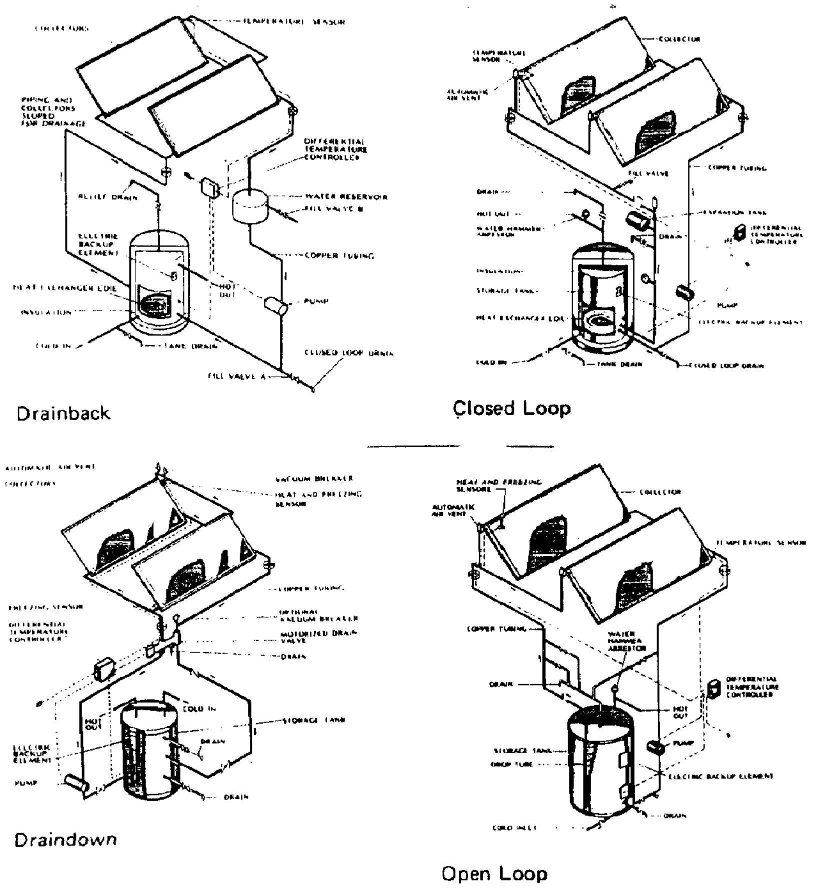


Fig. 3.97. Different kinds of solar collectors for heating water (Littler, 1984)

3.2.3.2. Photovoltaic cells

Photovoltaic cells are solar panels used to harness the suns energy, and turn it electricity that can be stored in batteries and used to power a buildings electrical systems, there are two types of these systems.

a) Mounted

These are wall or roof mounted or placed on some appropriate surfaces. They convert sunlight into electricity in solar cells.

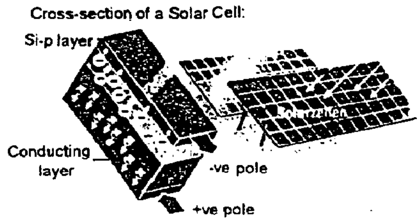


Fig. 3.98. Mounted solar cells. (Krishan, undated)

b) Building integrated photovoltaic cells (BIPV)

BIPVs are photovoltaic cells that convert sunlight into electricity but are part of the building envelope itself.

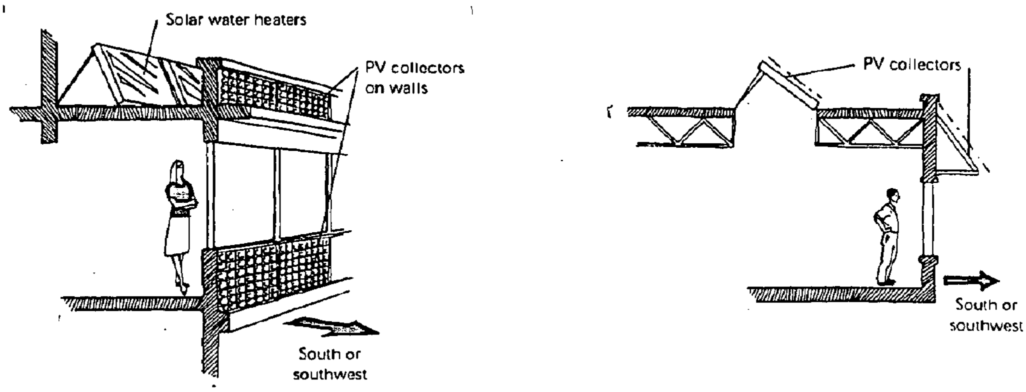


Fig. 3.99. BIPV systems (Sheltair, 1994)

<u>*3.2.3.3. Reflecting motors*</u>

Generation of electricity is possible with hot-air-motors in reflecting mirrors

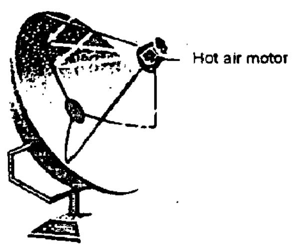


Fig. 100. Reflecting mirrors. (Krishan, undated)

3.2.4. Hybrid Systems

Certain mechanical measures enhance the performance of passive buildings. When the operation of a passive system relies on mechanical means, like a fan, it is called a hybrid system, for it mixes the concepts of designing with both the passive and active means to get the most out of both.

A solar greenhouse that collects the solar energy, but does not make use of thermal walls to store the same is an example of an hybrid system. Instead of the thermal mass the building uses mechanically assisted heat storage (The fan draws off the heated air into the building, to be stored in a heat storage).

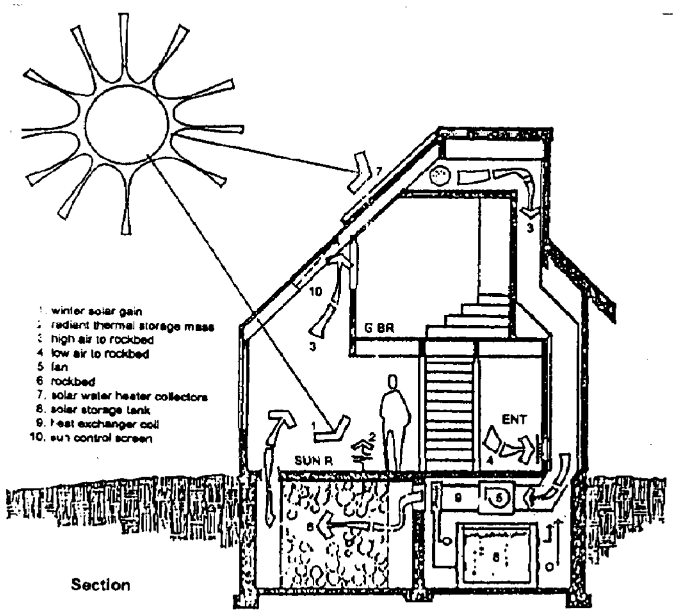


Fig. 3.101. Hybrid system. (ICIMOD, 2000)

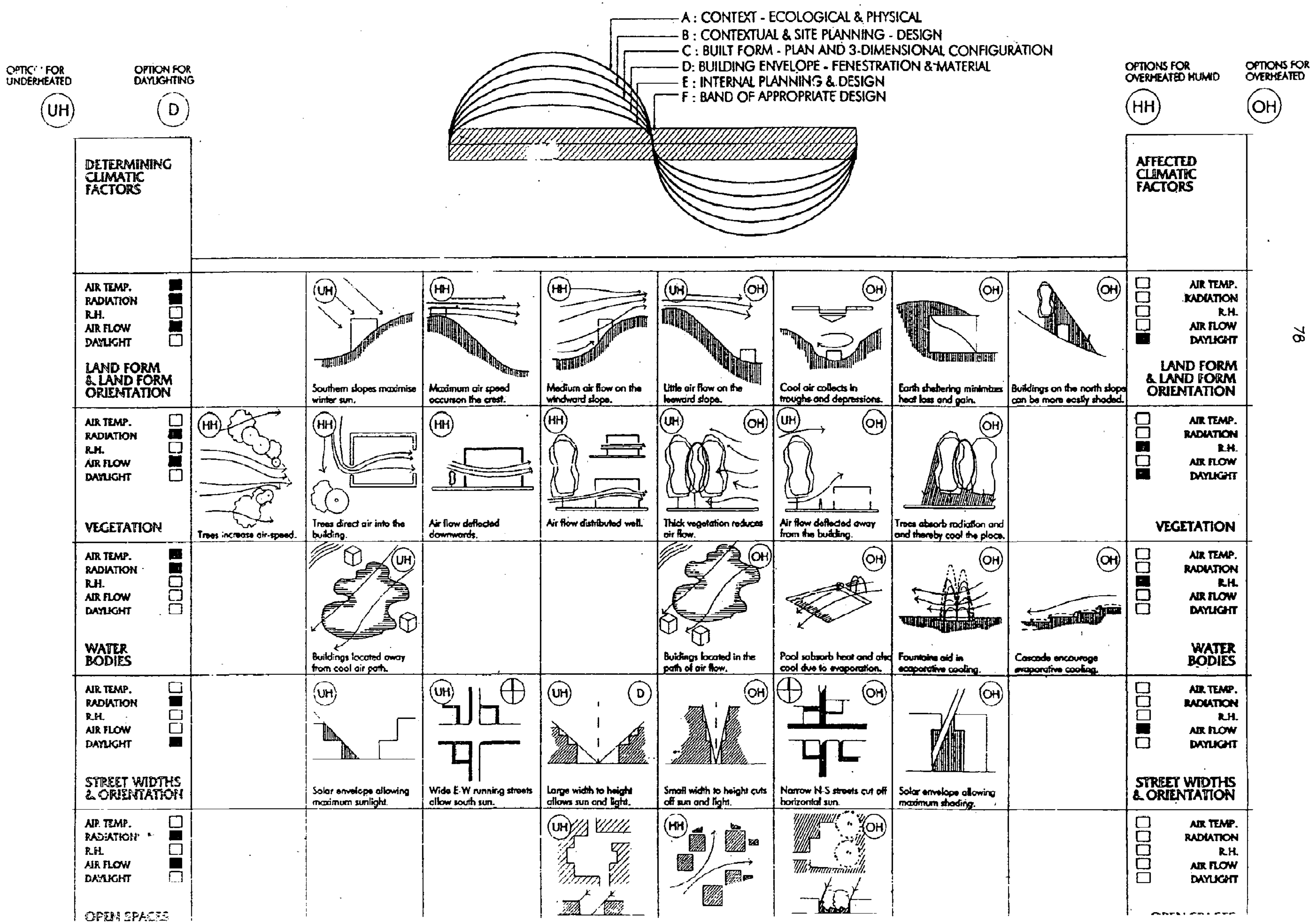
The table in the following pages shows the integrated approach to climatically responsive architecture and can be used as a checklist while designing climatically responsive passive buildings. It examines about 19 aspects of climatic building design in relation two three climates, namely underheated, overheated, and overheated humid, and in relation to daylighting.

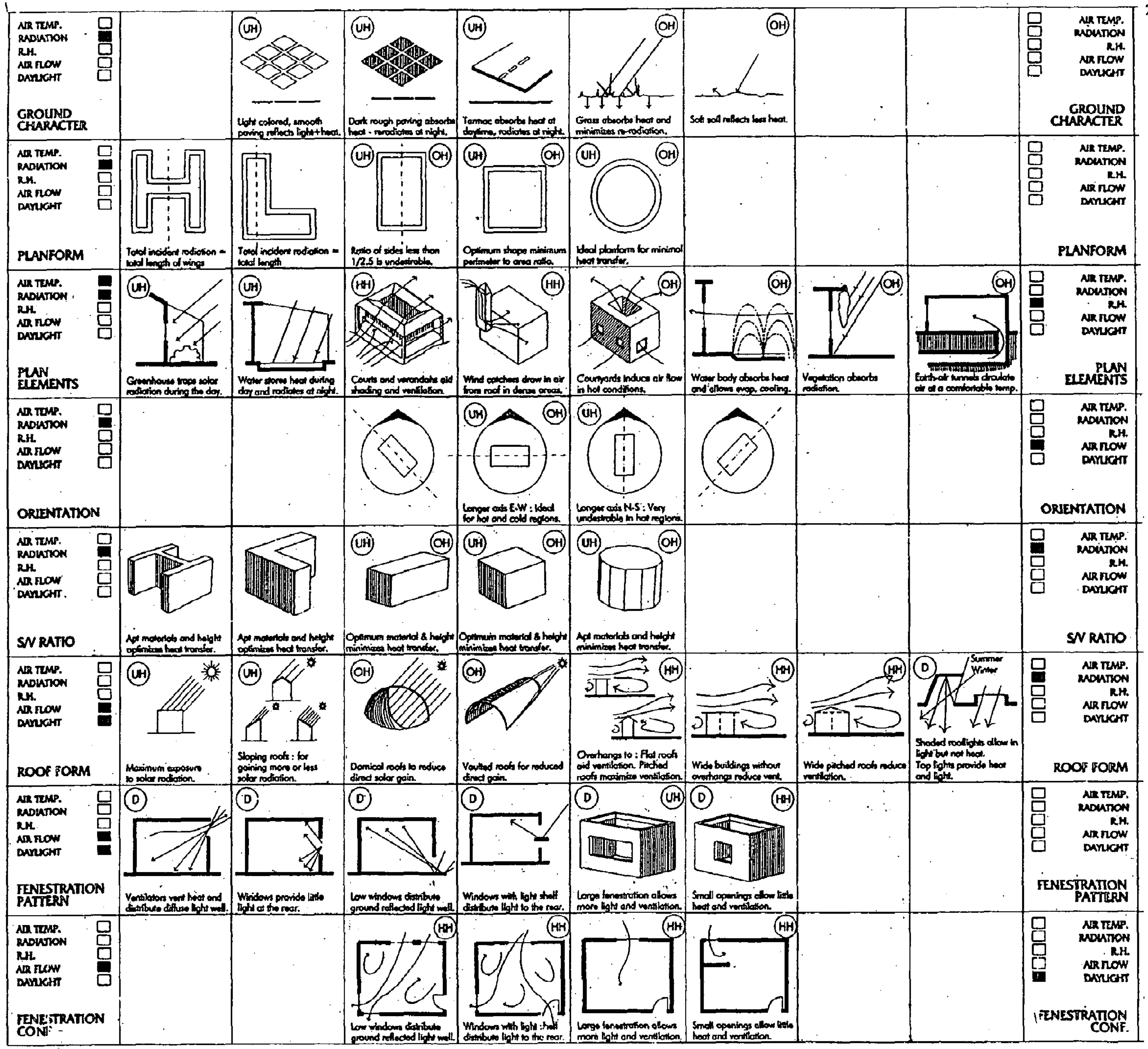
The 19 considerations begin with macrolevel detail and ends with microlevel ones

i. Landform:
ii. Vegetation
iii. Water bodies
iv. Street widths and orientation
v. Open spaces and built spaces
vi. Ground character
vii. Plan form
viii. Plan elements
ix. Building orientation
x. Surface area to volume ratio
xi. Roof form
xii. Fenestration pattern and configuration
xiii. Fenestration orientation
xiv. Fenestration controls
xv. External colors and textures
xvi. Roof materials
xvii. Walls
xviii. Internal layouts and partitions
xix. Internal materials
xx. Internal finishes

CLIMATICALLY RESPONSIVE ARCHITECTURE

AN INTEGRATED APPROACH




AIR TEMP.
RADIATION
R.H.
AIR FLOW
DAYLIGHT
GROUND CHARACTER
Light colored, smooth paving reflects light+heat.
Dark rough paving absorbs heat - reradiates at night.
Tarmac absorbs heat at daytime, radiates at night.
Grass absorbs heat and minimizes re-radiation.
Soft soil reflects less heat.
PLANFORM
Total incident radiation = total length of wings
Total incident radiation = total length
Ratio of sides less than 1/2.5 is undesirable.
Optimum shape minimum perimeter to area ratio.
Ideal planform for minimal heat transfer.
PLAN ELEMENTS
Greenhouse traps solar radiation during the day.
Water stores heat during day and radiates at night.
Courts and verandahs aid shading and ventilation.
Wind catches draw in air from roof in dense areas.
Courtyards induce air flow in hot conditions.
Water body absorbs heat and allows evap. cooling.
Vegetation absorbs radiation.
Earth-air tunnels circulate air at a comfortable temp.
ORIENTATION
Longer axis E-W : Ideal for hot and cold regions.
Longer axis N-S : Very undesirable in hot regions.
S/V RATIO
Apt materials and height optimizes heat transfer.
Apt materials and height optimizes heat transfer.
Optimum material & height minimizes heat transfer.
Optimum material & height minimizes heat transfer.
Apt materials and height minimizes heat transfer.
ROOF FORM
Maximum exposure to solar radiation.
Sloping roofs : for gaining more or less solar radiation.
Domical roofs to reduce direct solar gain.
Vaulted roofs for reduced direct gain.
Overhangs to : Flat roofs aid ventilation. Pitched roofs maximize ventilation.
Wide buildings without overhangs reduce vent.
Wide pitched roofs reduce ventilation.
Summer
Winter
Shaded rooflights allow in light but not heat.
Top lights provide heat and light.
FENESTRATION PATTERN
Ventilators vent heat and distribute diffuse light well.
Windows provide little light at the rear.
Low windows distribute ground reflected light well.
Windows with light shelf distribute light to the rear.
Large fenestration allows more light and ventilation.
Small openings allow little heat and ventilation.
FENESTRATION CONF.
Low windows distribute ground reflected light well.
Windows with light shelf distribute light to the rear.
Large fenestration allows more light and ventilation.
Small openings allow little heat and ventilation.

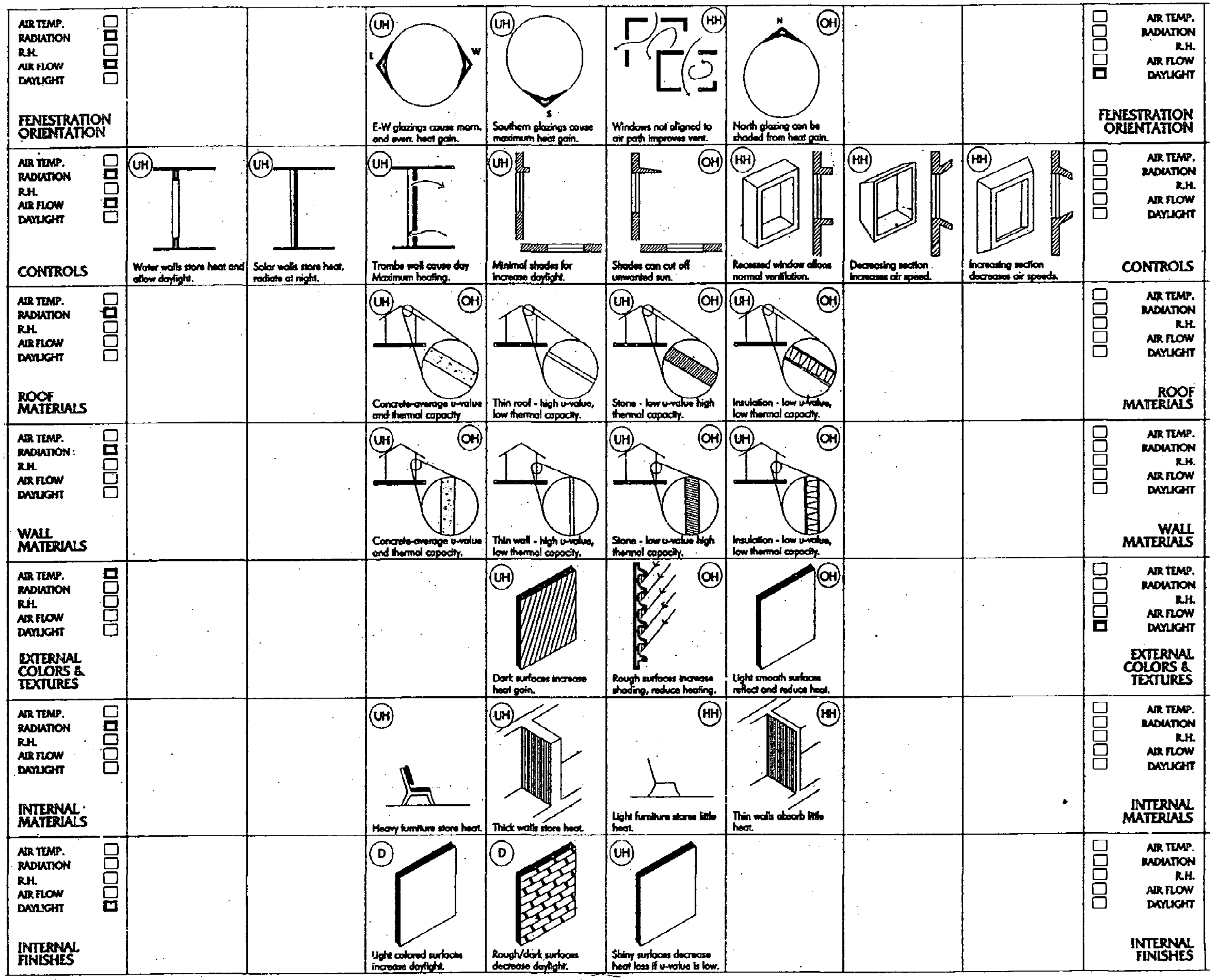


Table. Climate responsive architecture [12]

3.2.4. Energy efficient lighting technology

Lamp and fixture choices should optimize light distribution and fixture spacing. Efficiency of lightbulbs would reduce the quantities of raw fuel required to light a nation. The compact fluorescent lamps use only about one fifth as much electricity as a tungsten bulb for the same light output. In normal domestic use they have a life of at least five years before needing replacement.

The use of low-energy lightbulbs has far reaching impact beyond the immediate building user. Every time a tungsten lightbulb is replaced with a low-energy lightbulb, the amount of generating capacity needed by the electricity industry to produce that light is also reduced. An 18 watt low-energy bulb give the same light as an 80 watt tungsten bulb, making a saving of about 60 watts per bulb. Every bulb replaced therefore reduces the need for power station generating capacity by 60 watts.

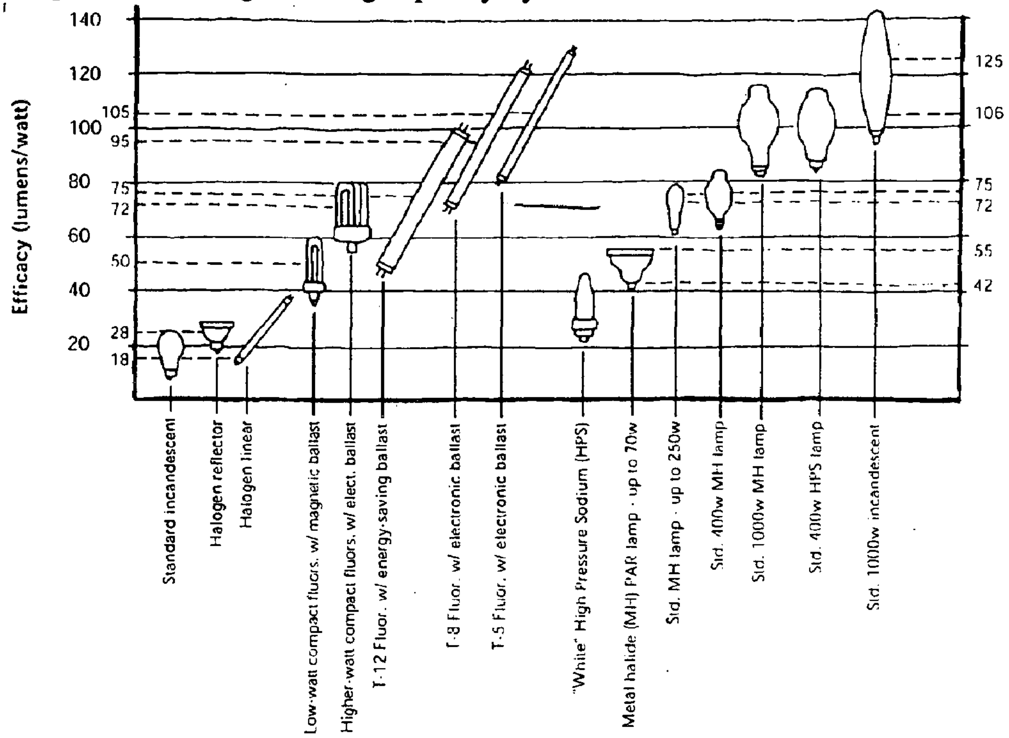


Fig. 3.102. Efficiency of different lighting fixtures (Sheltair, 1994)

3.2.5. Energy efficient HVAC system (Heating, ventilation and air conditioning)

Green buildings have minimal HVAC systems since their form, structure and envelope provide comfort. Most modern urban buildings, with their site and program constraints, require more extensive electrical and mechanical systems with automatic control.

Climate-responsive building design reduces heating and cooling loads, and thus the size of HVAC systems and equipment. Selection of more efficient HVAC equipment can further conserve non-renewable energy, and reduce air pollution from electricity generation and on-site combustion. Energy efficient HVAC systems are more expensive and require greater capital investment but this can be balanced by other factors which reduce capital and life cycle cost, and enhance marketability of the building.

3.2.6. Integrated design for energy efficiency

While designing green buildings for energy efficiency designers must take into consideration the interactions and dependencies of all the factors that directly or indirectly contribute to the energy efficiency of buildings. These interactions are illustrated in the ecological circle. The circle clearly identifies the fabric, and technology, and their respective subtopics. The figure illustrates how many options for energy efficiency exist: in technical investment, operation and upkeep, and possibly even construction costs. However, in green design, one must go beyond the current practice of superimposing individual approaches to design and, instead, aim for true integration. The figure illustrates these interactions for the aspect of cooling. Such topics as natural ventilation, groundwater cooling energy, gray water, surface/lake water, evaporative cooling, night cooling with surrounding air, storage masses in facades and construction, and more, can all come into play.

Computer energy simulations can be used to assess energy conservation measures early and throughout the design process. The expanded design team collaborates early in conceptual design to generate many alternative concepts for building form, envelope and landscaping, focusing on minimizing peak energy loads, demand and consumption. Simulations are used to refine designs and ensure that energy-conservation and capital cost goals are met; and to demonstrate compliance with regulatory requirements.

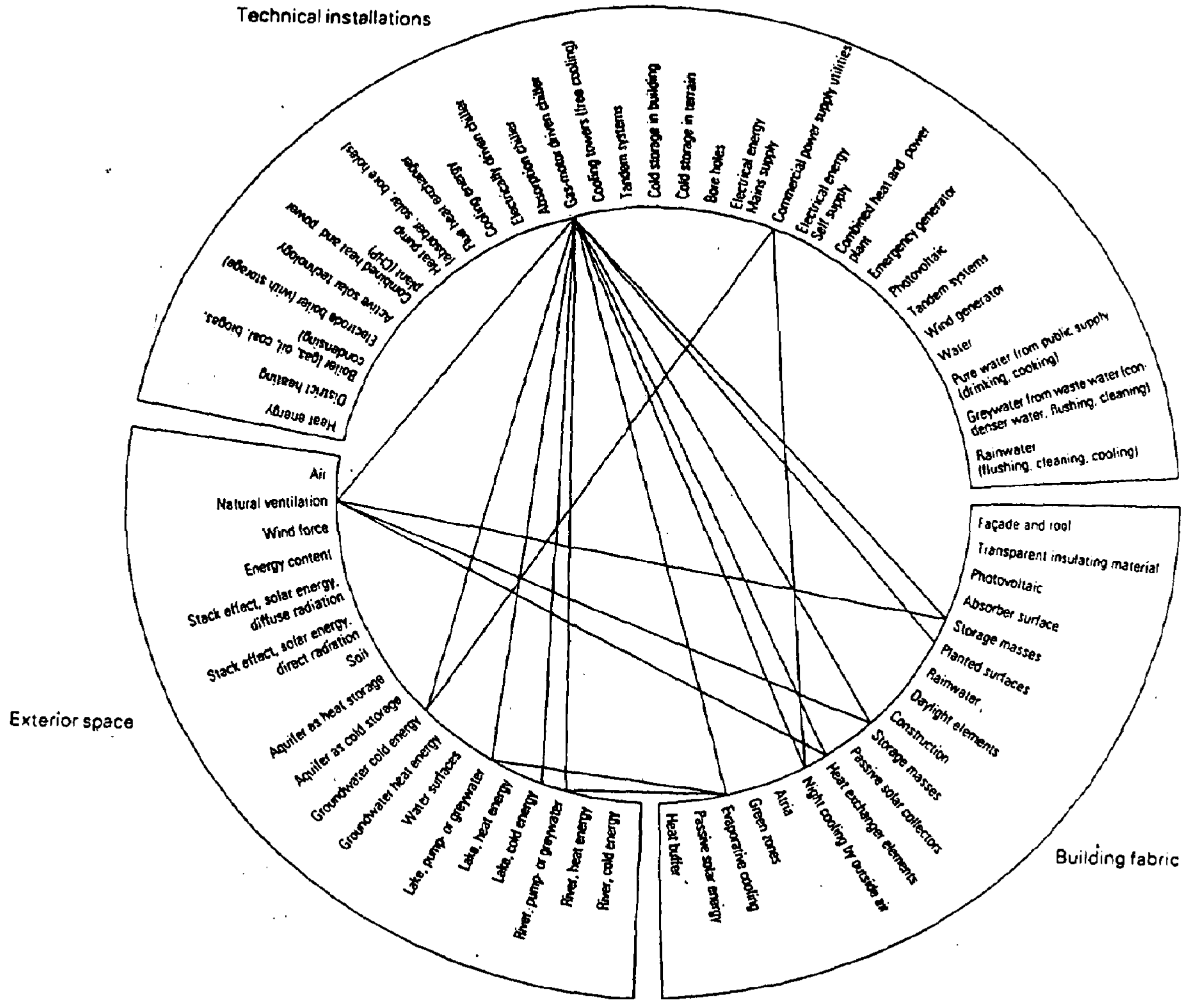


Fig. 3.103. The Ecological Circle illustrates the interactions between environment, building and building technology- the factors which influence building design for energy efficiency. (Klaus, 1994)

3.2.7. Building energy simulation

Building energy design often requires the analytical power to study complicated design scenario. Computer-based building energy simulation will provide this power and allow greater flexibility in design evaluation. The simulation method is based upon load and energy calculation in HVAC design. The purpose is to study and determine the energy characteristics of buildings and their systems. The cost effectiveness of any energy conservation measures will be a compromise between initial, maintenance and energy costs. Simulation techniques can provide the tools for assessing different design options based on their energy performance and life cycle costs.

To this end there are many computer programs available that will help designers produce energy simulation for their buildings and come up with the most optimized energy efficient buildings.

3.2.8. Building energy audit.

Building energy auditing is the measuring and recording actual energy consumption, at site, of a completed and occupied building (expressed in units of energy, not monetary value); fundamentally for the purposes of reducing and minimizing energy usage.
Energy audits identify areas where energy is being used efficiently or is being wasted, and spotlight areas with largest potential for energy saving. They are useful for establishing consumption patterns, understanding how the building consumes energy, how the system elements interrelate and how the external environment affects the building.

A proper energy audit is useful for more than energy conservation goals. Energy audits can be employed to assist in areas such as:

- Establishment of data bank and consumption records
- Estimating of energy costs
- Determining of consumption patterns and utility rates
- Establishment of an operational overview.

The following checklist for energy efficiency tries to summarize the number of options that are at the disposal of various professionals at the various stages of the life of buildings, to help them design buildings that are energy efficient. It is clear from the table that the role of architects in the design of energy efficient buildings is part of the total picture. This confirms the principle of holistic design strategy in which the design of green buildings in all its stages should be carried out by a team of professionals in considering the synergy of all the green elements.

Checklist for Energy Efficiency in Buildings

(Note: **P** = planning; **D** = design; **C** = construction; **M** = maintenance and management.)

1. Architecture

Item	Key points	P	D	C	M
Siting and surroundings	• Thermal environment of surroundings	X	X		
	- sunshade, sunlight, wind, reflecting surfaces				
Thermal design of outdoor environment	• Effect of plants	X	X		
	- shading by trees and plants				
	- wind shielding by trees and plants				
	• Cooling effects by ponds and fountains	X			X
	• Reflection from road or floor surfaces and plants	X	X		
Shape of the building	• Ratio of envelope surface area to total floor area	X	X		
	- usually the smaller the better				
	• Aspect ratio of floor plan	X	X		
	- usually the smaller the better				
	• Number of floors and building height	X	X		
	- floor-to-floor height, light well's height				
Orientation of facades	• Desirable orientation from thermal viewpoint	X			
	• Optimal strategy of orientation	X	X		
	- for the same floor plan, east-west axis is better than north-south one				
	- main wall openings to face south	X			
Design of building plan and section to enhance thermal performance	• Zoning and location of air-conditioned and non-air-conditioned spaces	X	X		
	- non-air-conditioned spaces and spaces without occupants may have more exterior walls				
	- plant rooms to be placed on the topmost floor				
	• Appropriate provision for different building functions	X	X		
	- hours of using the space				
	- moving of heavy objects by occupants				
	- provision of smoking lounge				
	- provision of store room				
	- spaces with high internal loads (lights, people and equipment) may compensate heat loss at the building envelope				
	• Use of transit areas for thermal buffer zones	X	X		
	• Design of wind-shielded area under openings	X	X		
Thermal insulation and thermal storage of the roof	• Thermal insulation	X	X		
	- material selection				
	- thickness				
	- thermal properties (and moisture barrier)				
	• Construction of the roof	X	X	X	
	- double slab				
	- thermal bridge prevention				
	• Treatment on the roof	X	X		X
	- soil and planting				
	- drainage of rainwater				
	• Sunshade provision	X	X		X
	• Glare control	X	X		
	• Thermal storage	X	X		
	- heavy structure (thermal mass)				
	- interaction with thermal insulation				

1. Architecture (continued)

Item	Key points	P	D	C	M
Thermal insulation and thermal storage of the exterior walls	• Thermal insulation - material selection - thickness - thermal properties (and moisture barrier)	X	X		
	• Construction of the walls - use of air cavity - ventilation of air cavity - location of thermal insulation - thermal bridge prevention	X	X	X	X
	• Sunshade provision - louvres and shading devices	X	X		X
	• Reduce radiant heat - use of trees for shading and shielding - select materials for glare control - provision of ventilated cavity	X	X		X
	• Thermal storage - heavy structure (thermal mass) - interaction with thermal insulation	X	X		
Thermal insulation, air tightness, ventilation properties and daylight properties of windows and doors	• Thermal insulation - Type and construction of window glass: plain glass, insulating glass, reflective glass, tinted glass, double glazing, low-e glass, etc. - window-to-wall ratio - shading coefficient - use of trees, sidewalls, louvres and balcony for shading - use of internal shading devices like blinds and curtains - orientation (south facing is preferable, and if in other directions, the facing angle of window glass may be adjusted)	X	X		
	• Air tightness - air leakage properties - shape and design of door openings: double door, automatic door and rotating door	X	X	X	X
	• Ventilation (natural) - possibility of windows being opened - openings and path have less resistance to air flow	X	X		X
	• Daylight penetration - reflective louvre - skylight - design of light wells - light transmission properties of window glass - array of window openings	X	X		
Glare control of exterior and interior walls	• Solar absorptivity, control of glare from sunlight and artificial lighting	X	X		

2. Heating, Ventilating and Air-conditioning (HVAC)

Item	Key points	P	D	C	M
Overall planning	• Suitable zoning strategy to prevent unnecessary losses - zoning of air-conditioned and non-air-conditioned spaces - zoning for spaces with different air change rates - zoning for spaces with different air-conditioning hours	X	X		
	• High efficient operation of system equipment	X	X		X
	• Zoning for spaces with different conditions: temperature and humidity, lighting density, air cleanliness, occupant density and equipment used	X	X		
	• Zoning for spaces with different load characteristics - peak hour, load lagging	X	X		
	• Balance of building air pressure - positive and negative air pressure	X	X		X
	• Sources of energy - consider local energy structure and form of energy available	X	X		X
Indoor environment	• Design indoor temperature and humidity - setting of design conditions - use of thermal comfort index - reset conditions at night, before and after occupying hours - reset according to actual outdoor conditions - setting of control tolerance bands	X	X		X
	• Outdoor fresh air rate - minimum outdoor air requirement - primary fresh air cooling	X	X		X
	• Lighting power density - setting of design maintained illuminance	X	X		X
	• Changeover of heating and cooling, and period of air-conditioning - optimize the design and review the necessity				X
	• Distribution of air (and temperature) - air supply method and location, return air location	X	X		
System and equipment	• Reduce energy losses from inappropriate mixing - setting of perimeter and interior zones - effective air supply method (avoid cooling and reheat)	X	X		
	• Matching of load characteristics - for design of cooling and heating plants - heat recovery method	X	X		
	• Correct use of multiplying factors - safety factor of climatic conditions (in load calculation), equipment and systems; diversity factor	X	X		
Heat/cold source system	• High efficient operation of equipment (by good management) - efficient part load operation - number and division of multiple equipment - use of thermal storage method - setting of chilled and condensing water temperatures	X	X		X
	• Heat recovery from waste heat and exhaust air - utilization of heat sources: exhaust air, transformers, motors, lighting, gas burning, warm discharged water	X	X		
	• Use of heat pumps	X	X		
	• Total (and sensible) heat exchanger	X	X		
	• Waste heat and condensing boilers	X	X		
	• Use of natural energy sources - primary fresh air unit to use night ventilation - solar thermal utilization - use of river or sea water for cooling	X	X		X
	• Thermal storage to cut down peak load and increase efficiency of heat recovery equipment - water or ice thermal storage - use of latent heat - thermal storage by system equipment	X	X		X
	• Cogeneration system				

2. Heating, Ventilating and Air-conditioning (HVAC) (continued)

Item	Key points	P	D	C	M
Load distribution and transmission systems	• Prevent losses during transmission - thermal insulation of piping and ducting - minimize air leakage - decrease local flow resistance	X	X	X	X
	• Reduce space loads - water-cooled lighting fixture (if needed) - reduce energy losses from inappropriate mixing - better control of latent loads	X	X		X
	• Decrease of running power - use variable air volume (VAV) method - use variable water volume flow (VWV) method - use larger temperature difference - use low-temperature air supply system - use of booster fans and pumps - fans and pumps specific to part load operation - straightening and shortening of air ducts - alternate energy transmission method - close loop for water distribution systems - lowering of water or air flow velocities - better thermal insulation for pipes and ducts	X	X	X	
Ventilation systems	• Reduce transmission energy - prevent excessive ventilation - shut down ventilation when not needed - control of ventilation rate at part load conditions - use of localized ventilation method - use of air-conditioning to replace high volume ventilation (e.g. for transformer and plant rooms) - utilization of natural ventilation - use air cleaners - multiple fans to handle a large flow capacity	X	X	X	X
	• Reduce ventilation load - decrease outside air when preheat or pre-cool is needed - control of fresh air (from number of people or use CO_2 analysis) - use of primary fresh air unit - use of night ventilation - use of total heat exchanger - transfer of exhaust air from plant room to car park - use of exhaust air from cooling tower - decrease of ventilation rate during peak load	X	X		X
Control systems	• Control of indoor environment (computer automatic control) - setting of temperature and humidity control (response to outdoor) - control of outdoor fresh air	X	X		X
	• Control of the operation of equipment - optimal start-stop - capacity control on the number of equipment running - control of water and air flow rates - operation forecast control - demand control - peak-cutting control	X	X		X
Use of natural energy	• solar energy	X	X		
	• geothermal energy	X	X		
	• wind energy	X	X		
	• use of energy in soil (temperature and underground water)	X	X		
Use of energy from waste heat and exhaust	• heat recovery from exhaust air	X	X		
	• heat recovery from waste products	X	X		
	• heat recovery from discharged water	X	X		

3. Electrical Services

Item	Key points	P	D	C	M
Overall planning	• Reduce losses in electrical circuits - with a low voltage system, use a supply method with less losses - consider to use high voltage supply - shortening of electrical cable and wiring network	X	X	X	X
	• Improvement of power factor - use power factor correction equipment (demand or supply sides)	X	X		X
	• Correct capacity and power ratings - correct use of multiplying factors - control of a number of equipment	X	X		
	• Reduce power consumption of control equipment - use of instantaneous magnetic contactors	X	X		
	• Consider a total energy approach - cogeneration, photovoltaics, reduction of harmonics	X	X		
Power transformation and distribution	• Location of the installations - entry/connection point and the load centres	X	X		
	• Capacity - relationship between average load factor and transformer efficiency - number of equipment and division	X	X		
	• Transformer planning and design - economic analysis and system zoning - operation and distribution during no-load condition	X	X		
	• Electric voltage and wiring - study of economics and security	X	X		
	• Power distribution - use of tree-type distribution - raising of voltage	X	X		
	• Group management (by computer automatic control) - control of the number of equipment in operation - peak-cutting strategy - demand control	X	X		X
	• Energy efficient equipment - check the economics and security	X	X		X

4. Lighting Installations

Item	Key points	P	D	C	M
Lighting installations	• Design of illumination levels - suitable zoning and appropriate level for each zone	X	X		
	• Lighting system - general lighting and localized (task) lighting - direct and indirect lighting methods - on-off method and circuitry design	X	X	X	X
	• Lighting control (by computer methods) - manual control - occupant-sensing control - lighting level sensing control - time-schedule control	X	X		X
	• Energy-saving equipment (and their cleaning and maintenance) - energy efficient lighting system and luminaires	X	X		X
	• Light-sensing control - daylight-activated lighting control - control system to maintain appropriate illumination level	X	X		X

5. Lifts and Escalators

Item	Key points	P	D	C	M
Lifts and escalators	• Method and capacity suitable to meet the demand	X	X		
	- traffic analysis (number of equipment, waiting time, speed)				
	- reduce the number of equipment by centralized design				
	- correct combination of lifts and escalators				
	- automatic stopping or standby mode of lifts and escalators				
	• Group management of equipment	X	X		
	- "double-deck" lift system				
	- operation control				
	- better braking control				
	- lights automatic turn off when not in use				
	- escalators turn to standby when not in use				

6. Plumbing and Drainage

Item	Key points	P	D	C	M
Cold water supply and drainage	• Necessity of cold water supply	X	X		
	- selection of rooms and locations for cold water supply				
	• Load estimation and equipment capacity sizing	X	X		
	- correct and accurate loads				
	- suitable capacity (with safety and diversity factors)				
	• Reduce pumping energy	X	X	X	
	- shortening of piping network and system				
	- open loop and close loop systems				
	- booster method				
	• Maintenance of appropriate water pressure	X	X		
	• Equipment	X	X	X	
	- energy-saving (water-saving) equipment and system				
	- correct type and size				
	• Water recycling systems	X	X		
	- feasibility of using them, their economics and reliability				
	• Rainwater utilization	X	X		
Hot water supply	• Necessity of hot water supply	X	X		
	- selection of rooms and locations for hot water supply				
	• Conditions of hot water supply	X	X		X
	- flow rate of hot water supply				
	- temperature of the hot water				
	• Hot water supply system	X	X	X	
	- design of storage tank or pond				
	- specific boiler				
	- central supply method and local supply method				
	- thermal insulation properties				
	- use of solar thermal energy				
	- shortening of water piping network				
	- heating method				
	- thermo-siphon for circulation				
	• Heat recovery from waste water	X	X		

7. Building Management

Item	Key points	P	D	C	M
Building management system	• Management of indoor environment	X			X
	• Management of equipment operation	X			X
	• Energy demand and consumption management	X			X
	• Preventive maintenance	X			X
	• Educational and training	X			X

Table. 3.7. Checklist for energy efficiency in buildings (www.hku.hk/teaching.html)

3.3. MATERIALS MANAGEMENT.

The life cycle of any building material should be studied to understand how it affects the ecosystem at large and the indoor environment at the building level. The study of live cycle analyzes the resources used to make it, how it is manufactured, used and discarded Building materials form a large part of the overall environmental burden of buildings:

- Raw materials extraction damages ecosystems, consumes energy and degrades water quality.
- Manufacturing produces waste and pollution, including toxic waste.
- Many materials, once installed, release toxic gases, affecting occupant health.
- Material cleaning and maintenance often causes health risks and toxic waste.
- Eventual disposal wastes recoverable resources, consumes landfill space and often degrades groundwater.

Green materials would have no adverse impact and might even play a restorative role in the planetary ecosystem. A material must be evaluated according to its life cycle. This consists of four general stages.

1. Raw material extraction
2. Manufacturing and transportation
3. Tenure in the building
4. Disposal or reuse.

The following diagram represents all the components to be considered in the material selection process.

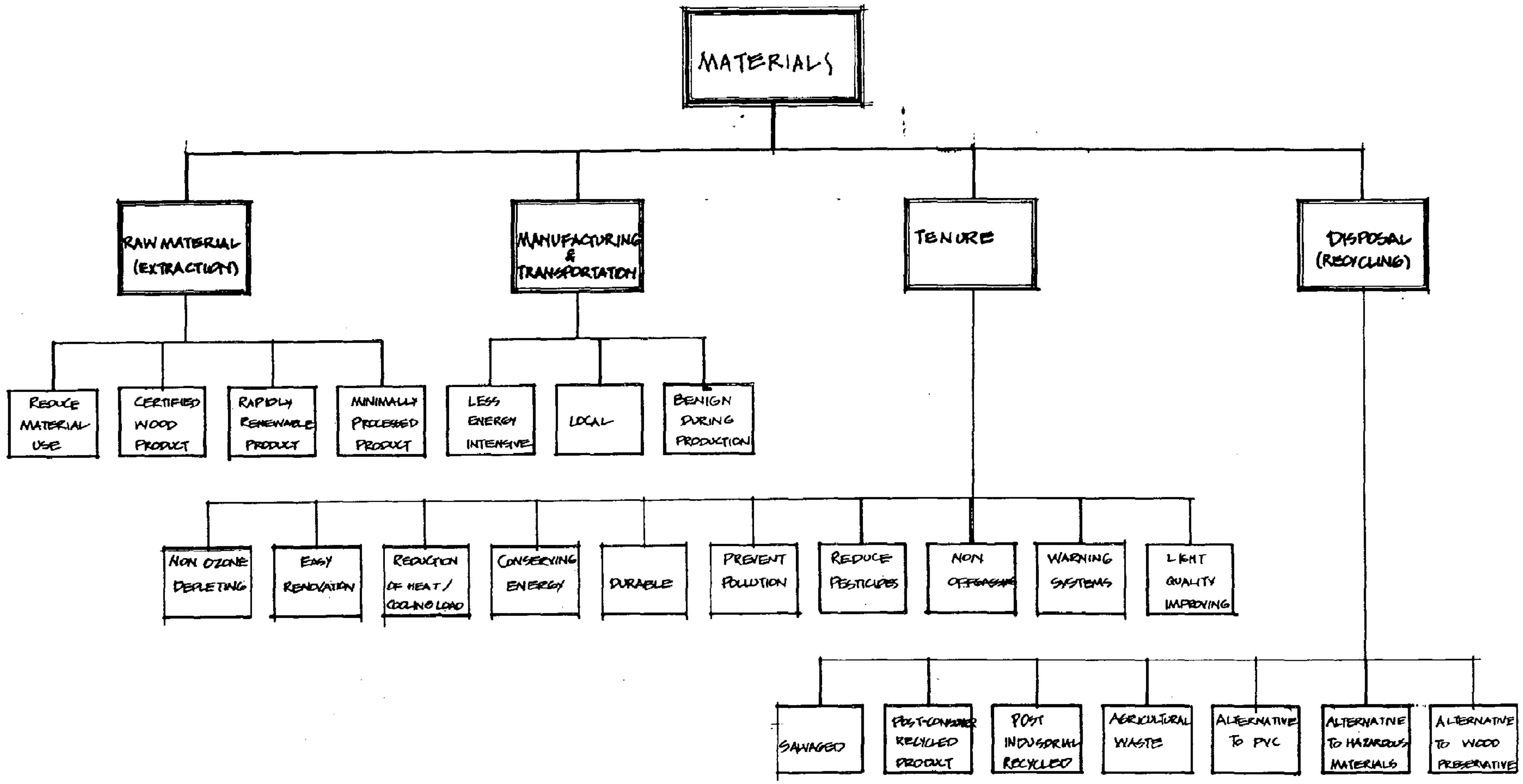


Fig. 3.104. Diagram showing all the considerations in material management

3.3.1. Raw material extraction.

At this stage, the impact of mining, harvesting or extraction practices are concerned. Using recycled materials reduces the amount of raw material extracted from the land, and the amount of waste that reaches landfill.

E.g. flyash and recycled milk jugs and newspapers.

Recycled content is high if it makes up 50% or more of material. Recycling isn't always environmental for some materials. It may take energy to collect and process waste materials than it does to put them in a landfill. Wood for construction purposes must come from sustainably harvested forests.

The following are products that are green at the resource extraction stage

3.3.1.1. Products that reduce material use

E.g. concrete pigments that eliminate the need for conventional floor finish.

3.3.1.2. Certified wood products

E.g. woods from sustainably managed and harvested forest

3.3.1.3. Rapidly renewable products

These are distinguished from wood by the shorter harvest rotation-typically 10 years or less. They are biodegradable, low in VOC emissions and generally produced from agricultural crops.

E.g. linoleum, natural paints, geotextile fabrics from coirs and jute cork, sisal etc.

3.3.1.4. Minimally processed materials.

Low energy use and low chemical release during manufacturing

E.g. natural stone.

3.3.2. Manufacturing and transportation

A product that doesn't harm the environment in its raw material phase may cause ecological destruction during the manufacturing process,

- Petrochemicals used to make plastics, adhesives, and coatings are often toxic at various stages during their manufacture.

Transportation is a factor to consider with any material. Selecting local materials reduces the amount of fuel used in transport. In the developed world 10-30% energy associated with the manufacture of some materials is related to transportation of the raw and finished materials. Trains are eight times more efficient than trucks for moving materials, and ships are twice as efficient as trains.

The following are products that are green at the manufacturing and transportation stage

3.3.2.1. Less energy intensive materials

Materials with less embodied energy are benign to the environment since they don't consume much energy during manufacturing.

3.3.2.2. Local materials

Materials which are around the vicinity of the construction site, reduce the use of fuel energy for transport.

3.3.2.3. Products that do not cause ecological destruction during manufacturing.

E.g. Petrochemical based materials are harmful to the environment during their various stages of manufacture

3.3.3. Operation and maintenance (Tenure)

Materials in the indoor environment are affected by air, lighting, water consumption and have an impact on the building occupants. Green indoor materials have proved to increase occupant productivity due to their little interference with the comfort of the users of the space.

Paints and adhesives that are applied wet have some volatile organic compounds (VOCs) which are harmful if they are applied when the building is occupied. In this case coatings without VOCs should be applied. Carpets with styrene butadiene (SB) latex backing create IAQ problems, due to offgasing. Moreover, at this stage the materials and products must consume the least amount of resources, should be durable and need less maintenance. Materials and products that consume the least amount of resources, that are durable and that need less maintenance.

The following are products that are green at the tenure stage

3.3.3.1. Alternative to ozone depleting substances

E.g. Materials which contain or use HCFCs; rigid foam insulation and compression-cycle HVAC equipment

3.3.3.2. Products that reduce the impacts of renovation

E.g. Access flooring components and demountable partition system

3.3.3.3. Building components that reduce heating and cooling loads.

E.g. Structural insulated panels (SIPs), insulated concrete forms (ICFs), autoclaved aerated concrete (AAC) blocks and high performance windows and glazing.

3.3.3.4. Equipment that conserves energy.

E.g. Energy conserving water heaters, refrigerators. Compact fluorescent lamps and occupancy daylighting controls, microturbines for their potential of co-generation (combined heat and power)

3.3.3.5. Products with exceptional durability or low maintenance requirements

E.g. Fiber cement siding, Fiberglass windows, slate shingles

3.3.3.6. Products that prevent pollution or reduce waste

E.g. Alternative wastewater disposal systems reduce ground water pollution by decomposing organic wastes more effectively.

Porous pavements, vegetated roofing systems

Recycling bins and compost systems reduce waste generation.

3.3.3.7. Products that reduce pesticide treatments

E.g. Physical termite barriers, borate-treated building products, bait systems that eliminate the need for broad-based pesticide application.

3.3.3.8. Products that don't release pollutants into the building

E.g. Zero and low VOC paints, caulks, adhesives, non formaldehyde wood products

3.3.3.9. Products that block the introduction, development, or spread of indoor contaminants

E.g. Duct mastic can block the entry of mold-laden air or insulation fibers into a duct system.

Track off systems for entryways help to remove pollutants from the shoes of people entering.

3.3.3.10. Products that warn occupants of health hazards in the building

E.g. Carbon monoxide detectors.

3.3.3.11. Products that improve light quality

Products that enable us to bring daylight into a building, including tubular skylights, fiber-optic daylighting system, and highly reflective ceiling panels.

3.3.4. Disposal.

How a material is handled once it is removed from the building should be considered when it is specified. Materials that are easily recycled, minimally processed, or biodegradable are best. Wood treated with preservatives, such as chromated copper arsenate, works well during its life in the building but creates problems for recycling since it is impossible to recycle and is not safe to incinerate or deposit in landfills. A better choice would be to use recycled plastic lumber.

The following products are green at the resource extraction stage because the materials are salvaged recycled or are safe to dispose materials.

3.3.4.1. Salvaged products

E.g. Salvaged materials used in buildings like bricks, plumbing fixtures

3.3.4.2. Products with post-consumer recycled content

E.g. Rubber flooring made from recycled automobile tires

3.3.4.3. Products with post-industrial recycled content

This refers to the use of industrial by-products, as distinguished from material that has been in consumer use

E.g. Iron-ore slag used to make mineral wool insulation, fly ash for concrete. PVC scrap from pipe manufacture used to make shingles.

3.3.4.4. Products made from agricultural waste material

E.g. Straw based products, rice hull products.

3.3.4.5. Alternatives to products made from PVC and polycarbonate

Most PVC products are over 40% chlorine by weight, and hazardous. Chlorinated hydrocarbons can be produced during incineration or as by-products.

3.3.4.6. Alternatives to hazardous components

E.g. Fluorescent lamps with low mercury levels. Since mercury which is hazardous to the environment will be released when these lamps are disposed, along with a selective absorber surface for solar collectors made without chromium.

3.3.4.7. Alternatives to conventional preservative treated wood.

E.g. CCA-treated wood poses significant environmental risk during disposal. Pentachlorophenol and creosol which are wood preservatives are considered carcinogens.

GREEN FEATURES		
Manufacturing Process	**Building Operations**	**Waste Management**
Waste Reduction	Energy Efficiency	Biodegradable
Pollution Prevention	Water treatment and conservation	Recyclable
Recycling	Non Toxic	Reusable
Embodied Energy Reduction	Renewable Energy Sources	Others
Natural Materials	Longer Life	

Table. 3. 8. Salient green features of materials (www.hku.hk/teaching.html)

Annual Production of Industrial and Agricultural Wastes (1993) with their Potential

Waste	Industry	Production (MT/year)	Potential Applications
Flyash	Thermal power stations	40.0	Portland Pozzolana Cement, bricks, light weight aggregate, lime pozzolana mixture
Blast furnace slag	Iron & Steel Industry	10.0	Portland blast furnace slag cement, super sulphated cement, production of lightweight concrete
Phospho-gypsum	Fertiliser, phosphoric and hydrofluoric acid industries	11.0	Gypsum plaster, fibrous gypsum boards and blocks, cement clinker, super sulphate cement
Lime sludge	Paper, sugar, fertiliser, acetylene and tannery industries	4.8	Masonry cement, sand-lime bricks and lime pozzolana mixture
Cinder	Thermal power stations and railways using lump coal	3.0	Lime cinder mortar, concrete buildings blocks
Mine tailings	Zinc, copper, gold, iron ores benefidation plants	6.0	Calcium-silicate concrete, bricks and masonry cement
Red mud	Aluminium industry	4.0	Bricks, tiles, and lightweight structural blocks and roofing sheets
Water works silts	Water works	10.0	High strength bricks, cement, and lightweight bloated clay aggregate
Limekiln rejects	Limekilns quantity	3.0	Masonry
Coal washery reject	Coal washeries	3.0	Bricks, lightweight aggregate, fuel substitute in burning bricks
Rice husk	Rice mills	25-30	Particle boards, roofing sheets and pozzolana
Coconut husk	Coir-fibre industry	2.0	Particle boards, insulation boards, building panels and roofing sheets
Cotton stalks	Cotton plantation	10.0	Fibre boards, panels and door shutters
Bagasse	Sugar mills	5.3	Insulation boards and wall panels
Groundnut hulls	Oil mills	5.75	Particle boards, roofing sheets and chip boards
Rice straw wheat straw	Agricultural farms	Large	Roofing units, wall panels and fibre boards
Straw mill waste	Straw mills and wood based industries	2.0	Fibre boards, particle boards and insulation boards, etc.

Table. 3.9. Annual production of industrial and agricultural wastes (1993) with their potential to be used in building materials. The production specified is in India. (Lal, 1995)

EPA RECYCLING GUIDELINES, BUILDING PRODUCTS		
Product	Total Recovered Materials	Notes
Insulation, rock wool	75%	From mineral slag (smelting waste)
Insulation, fiberglass	>20%	From waste glass cullett (consumer containers)
Insulation, cellulose	75%	From newsprint
Insulation, plastic fiber batt	100%	From PET soda bottles
Carpet, polyester face fiber	>25%	From PET soda bottles
Concrete, fly ash	>15%	Coal ash as a proportion of cement in mix
Concrete, ground slag	>25%	Furnace slag as a proportion of cement in mix
Latex paint, reprocessed	20 – 100%	Consolidated or reprocessed. Colors limited.
Gypsum board	>10%	Recycled gypsum and face paper
Rubber or plastic patio block	>90%	Tire rubber and waste plastic
Rubber or plastic floor tiles	>80%	Commercial tile. Tire rubber and waste plastic
Structural fiber board	100%	Wood, paper or agricultural waste fiber
Laminated paper board	100%	Post-consumer paper
Shower or restroom dividers, steel	>20%	
Shower or restroom dividers, plastic	20 – 100%	Post-consumer plastic
Hydraulic landscape mulch	100%	Wood fiber and paper waste
Compost	100%	Leaves, grass, clippings (yard waste only)

Table. 3.10. Recyclable materials and extent of recyclability. (Sheltair, 1994)

3.3.5. Energy intensiveness of materials

Finally, from an energy point of view, the energy intensiveness of a building material will act as a rough guide to its greenness. The more it is refined, the more energy it contains. However to judge the energy content of materials of a building their weight together with their energy content must be carefully calculated. Since low energy materials are used in bulk. And high energy ones like steel are used in carefully sized sections. The following is an attempt to put numerical values to energy intensiveness, so that materials can be ranked.

Material	Energy content: kWh/kg
Low energy materials	
Sand, gravel	0.01
Wood	0.1
Concrete	0.2
Sand-lime brickwork	0.4
Lightweight concrete	0.5
Medium energy materials	
Plasterboard	1.0
Brickwork	1.2
Lime	1.5
Cement	2.2
Mineral fiber insulation	3.9
Glass	6.0
Porcelain (sanitary ware)	6.1
High energy materials	
Plastics	10
Steel	10
Lead	14
Zinc	15
Copper	16
Aluminum	56

Table. 3.11. Energy intensiveness of various materials (Brenda, 1991)

3.4. WATER MANAGEMENT.

Only 3% of the Earth's water is fresh water that could be used for drinking, and 2/3 of this is locked up in the polar ice caps and the glacier. Only 0.0001% of the Earth's water is in rivers, and this is the part on which people depend for their water supply. The total volume of water in the world's rivers at any time is about 130 cubic kilometers, enough to supply a world population of 5 billion people with 26,000 liters of water each.

In domestic accommodation the largest single consumer of water is the WC, which uses in its flushing about one third of the total water used by the domestic sector. This is fresh water; purified and safe to drink which is flushed straight back to the sewers.

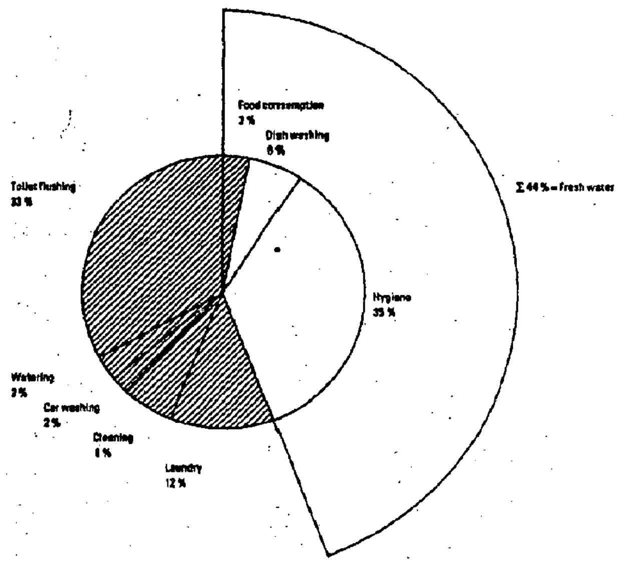


Fig. 3.105. Water requirement in private houses. 56% of potable water consumed in private houses could be replaced with gray water. (Daniels, 1994)

Less than half of these uses need water of drinking quality, yet drinking water is supplied, at increasing cost in resources and land and almost all supply of these demands comes from rivers. Approximately 50% of drinking water could be replaced with rainwater and/or grey water. Only 3% of drinking water is normally used for food preparation or consumed.

The following diagram represents all the components to be considered in the design of water systems.

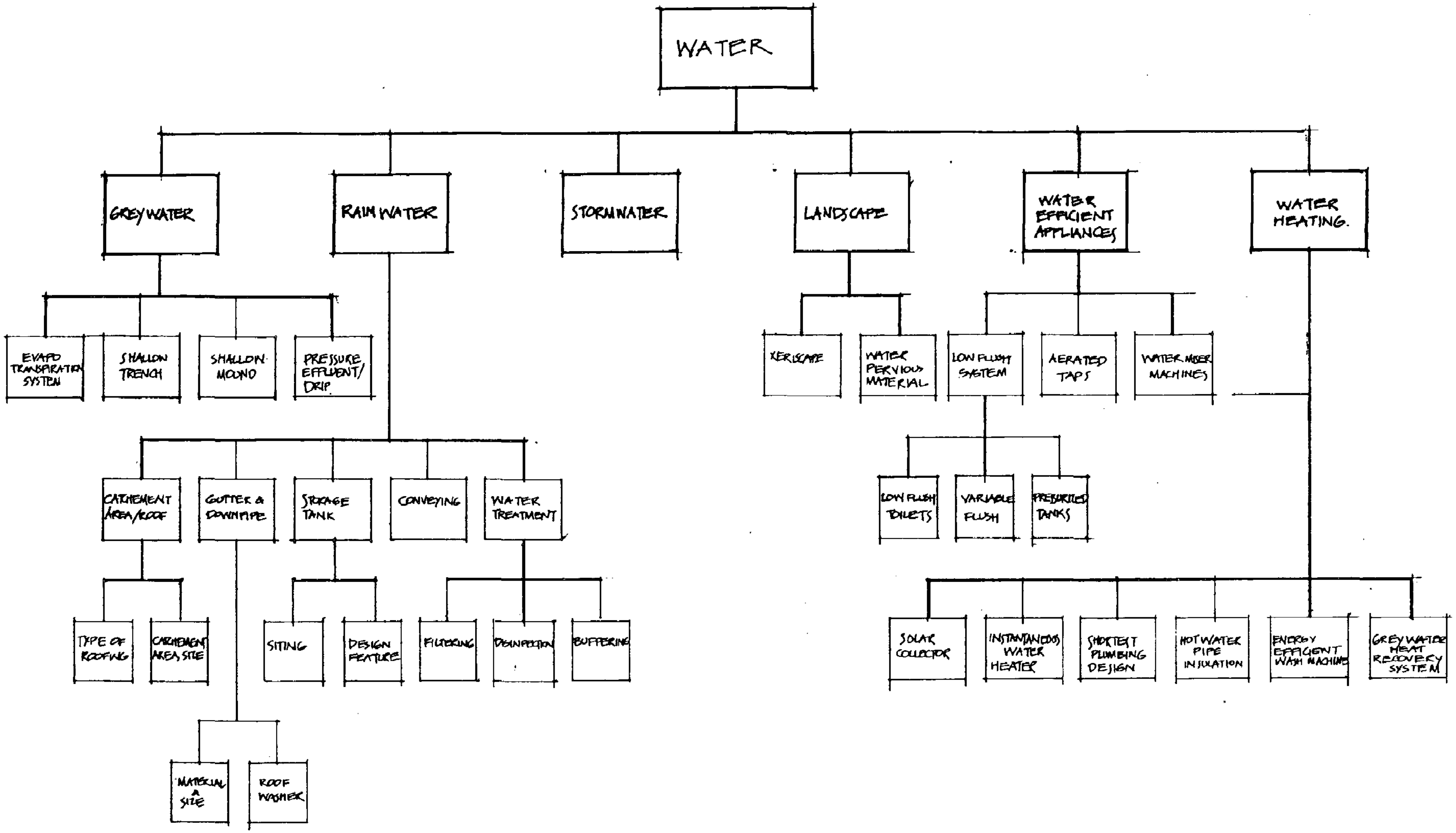


Fig. 3.106. Diagram showing all the considerations in water management

3.4.1. Greywater

Greywater is the wastewater produced from baths and showers, clothes washers, and lavatories. The wastewater generated by toilets, kitchen sinks, and dishwashers is called blackwater. The primary use of greywater is the supply of water to irrigation fields with sub-surface distribution systems. Greywater can also be used for toilet flushing.

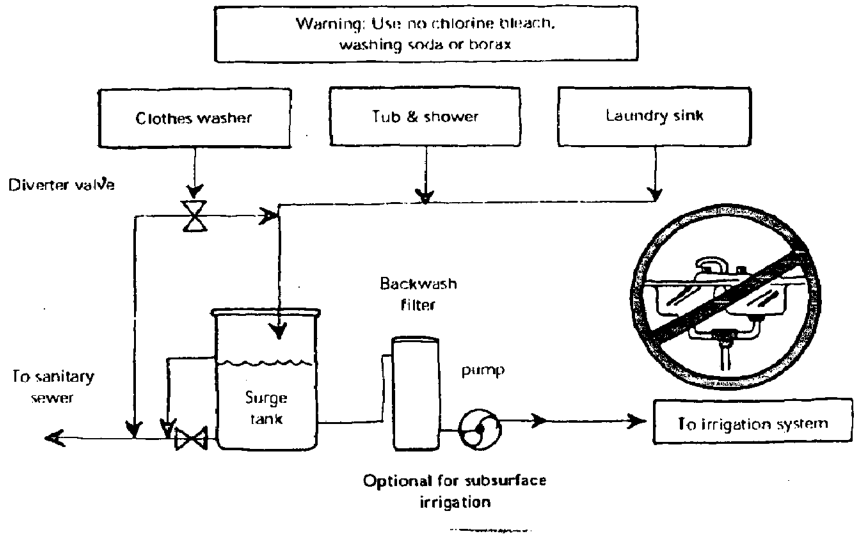


Fig. 3.107. Mechanism for greywater collection (Sheltair, 1994)

3.4.1.1. Considerations

The use of greywater for irrigation requires separate blackwater and greywater waste lines in the building. Some limitations to the simple sub-surface greywater subsystems are steep slopes, poor soil percolation qualities, and close proximity to lakes. The best applications for greywater will be in conjunction with xeriscaped landscapes.

The following are some of the site factors to be analyzed before the greywater system is designed.

- Size of lot and topography (as a general rule of thumb, lot sizes well under one half an acre will need professional engineering. Steeper slopes-beyond 15% need more design)
- Subsoil texture (sand and loamy soils are best)
- Soil depth
- Soil drainage (internal characteristics and external factors such as flooding)

- Soil permeability
- Flooding characteristics

Refer appendix 7 for planning of new greywater systems.

3.4.1.2. Greywater system types

a) Evapotranspiration (ET) Systems

This system combines the process of evaporation and transpiration to utilize and dispose of wastewater. A typical evapotranspiration system consists of a septic tank for pre-treatment (removal of solids) followed by distribution into a shallow sand bed covered with vegetation.

The greywater flows from the house through the septic tank and into the evapotranspiration bed. The greywater is distributed through perforated pipes. Once in the sand, greywater is taken into the plant root system. Underneath the bed is either a plastic lining or very impermeable soil, which prevents the greywater from seeping into the ground. Another variation is the rock/plant system that use living beds of marsh plants combined with gravel to break down wastewater pollutants that become food for the plants. Plant such as cana lilies, iris, ginger lily, elephant ears, and cattails have been used with these types of systems. Trenches are lined with PVC liner and filled with 1 to 1 ½ inches of river gravel and topped with 6 inches of pea gravel. Plants are planted directly in the gravel, so no soil is used.

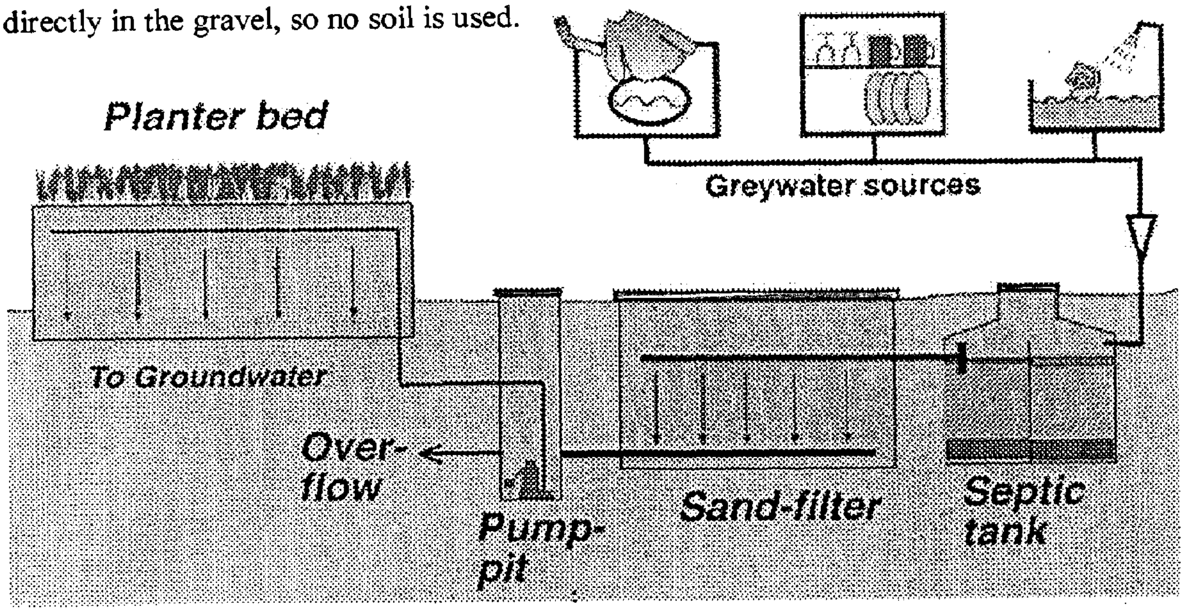


Fig. 3.108. Evapotranspiration system for grey water recycling.

b) Shallow trench

In this system greywater flows from the house through pre-treatment and is piped into shallow trenches (pipe placed 8 inches or 20 cm deep). These pipes are placed close enough to the surface to feed the plant roots. The shallow trench greywater system can provide irrigation via shallow placement of distribution pipes and the optimum spacing of trenches.

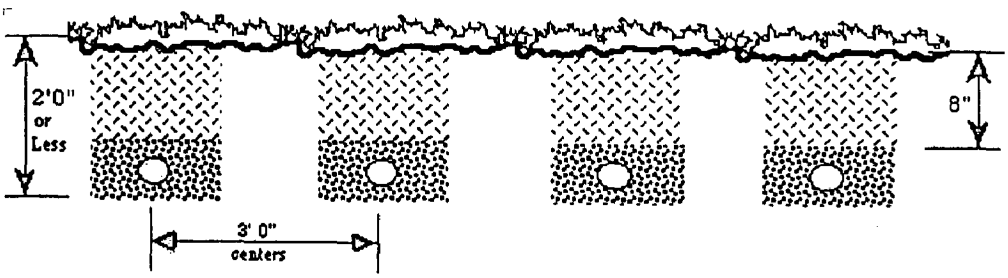


Fig. 3.109. Shallow trench section view (www.greenbuilder.com)

c) Shallow mound

The shallow mound uses an elevated absorption field for disposal of wastewater. For irrigation, a shallow layer of sand fill and topsoil is placed over existing soil. This technique is usually done when existing soil is unsuitable for wastewater disposal. Pipes are placed near the root zone to provide irrigation. The shallow mound system will require pumping of the greywater to function properly.

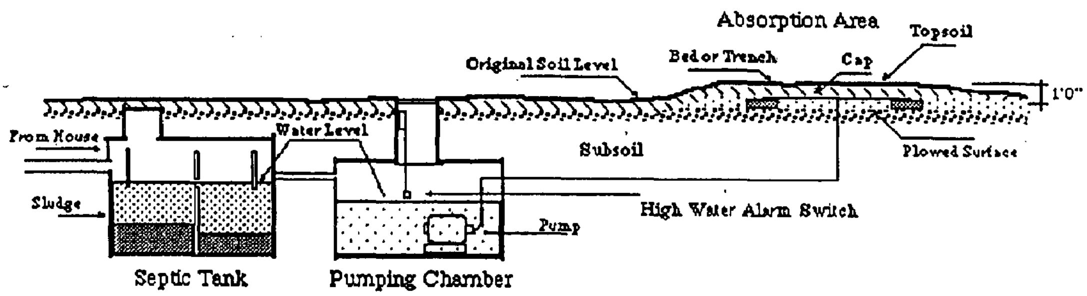


Fig. 3.110. Shallow mound section view (www.greenbuilder.com)

d) Pressure effluent Dosing and Drip irrigation

It is an option to gravity distribution that overcomes many site limitations such as shallow soils, high ground water, excessive slopes, and uphill drain fields. Low pressure dosing uses a pump to distribute greywater through perforated pipes in the absorption bed. This is applicable to all greywater systems. The greywater flows from the house thought pre-treatment and is pumped into absorption alternatives.

The drip system requires a filter in addition to the settling tank (septic tank) to prevent clogging the emitters. Drip irrigation is frequent, low-pressure application of small amounts of water to the soil area directly surrounding the plant roots. A constant level of soil moisture is maintained, even though up to 60% less water than the conventional watering is used by this method. It reduces evaporation, run-off, and deep percolation.

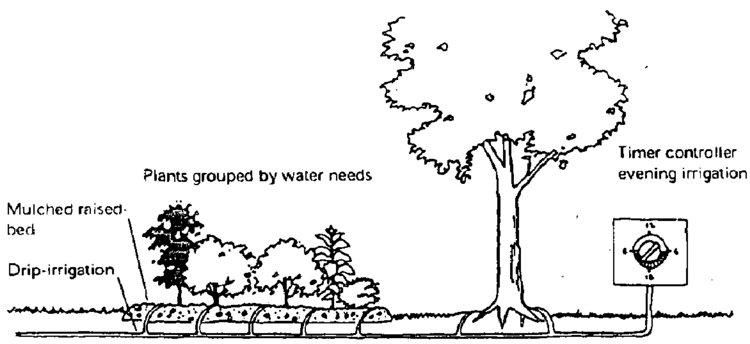


Fig. 3.111. Drip irrigation system. (Sheltair, 1994)

3.4.2. Rainwater

Harvested rainwater is rainwater that is captured from the roofs of buildings. Harvested rainwater can be used for indoor needs, irrigation, or both. Utilization of rainfall has got environmental and qualitative advantages. The environmental advantages are.

i. Energy conservation.

Energy input required to operate a centralized water system designed to treat and pump water over a vast service area is bypassed

ii. Erosion and flood prevention,

Rainwater harvesting lessens erosion and flooding caused by runoff from impervious cover such as pavement and roofs.

The qualitative advantages are

i. Purity. Rainwater is one of the purest sources of water available, exceeding the quality of ground or surface waters: it does not come into contact with soil and rocks where it dissolves salts and minerals, and it is not polluted like rivers.

ii. Softness. Rainwater is soft and can significantly reduce the quantity of detergents and soaps needed for cleaning, as compared to typical municipal tap water.

3.4.2.1. Water quality criteria

a) Primary water quality criteria-aesthetic concerns

The rain washes many types of bacteria, molds, algae, protozoa and other contaminants into the cistern of storage tank. Therefore it should be treated and disinfected if used for household uses, but if used for irrigation purposes, treatment requirements are not required

b) Secondary quality criteria-Aesthetic concerns (Color, taste, smell, hardness)

Proper screening and removal of sedimentation reduces impurities like, sand, clay, and silt. Rainwater is the softest natural occurring water available. Since the pH of rain is below 7, due to carbon dioxide, sulfates or nitrated, small amount of buffering can neutralize the acid.

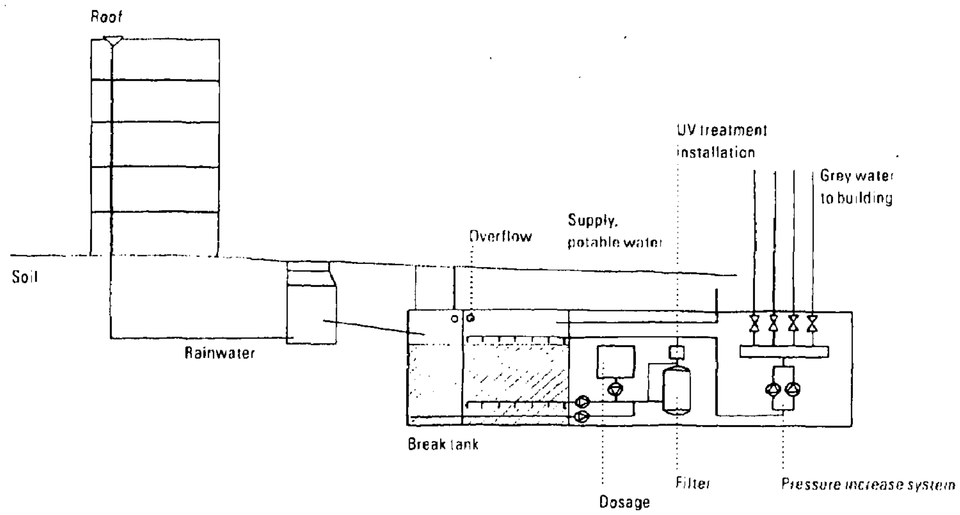


Fig. 3.112. Diagram of a rainwater harvesting system (Daniels, 1994)

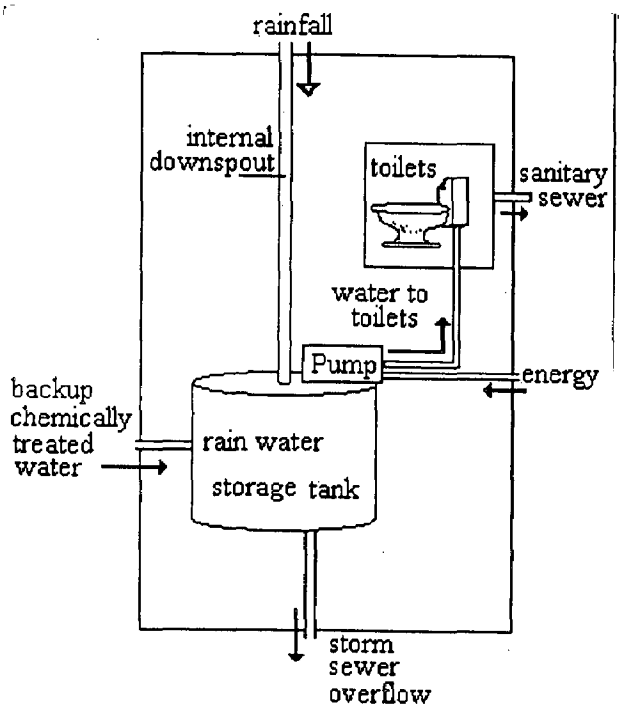


Fig. 3.113. Rainwater system used for flushing toilets. (www.greenbuilder.com)

3.4.2.2. Rainwater system components

All rainwater systems have the following five basic components.

a) Catchement area/roof.

A smoother, cleaner, and more impervious roofing material contributes to better water quality and greater quantity. While loss is negligible for pitched metal roofs, concrete or asphalt roofs average just less than 10% loss, and built up tar and gravel roofs average a maximum of 15% loss. Regardless of roofing material, many designers assume up to a 25% loss on annual rainfall. These losses are due to factors like: the roofing material texture, which slows down the flow and evaporation.

i. Type of roofing material.

Metal roofing is preferred for smoothness and durability. Clay tile or slate are appropriate for rainwater intended for potable use. The surfaces can be treated with special painted coating to discourage bacterial growth on an otherwise porous surface. Since asbestos, composite asphalt, chemically treated wood shingles, roofs with lead flushing, and some painted roofs could leach toxic materials they are used only for non-potable water uses.

ii. Catchement area size.

The size of a roof catchement area is the building's footprint under the roof and is not dependent upon the slope of the roof.

b) Gutters and downspouts.

These are the components, which catch the rain from the roof catchement surface and transport it to the cistern.

i. Materials and sizes.

Galvanized metal and aluminum free of lead elements can be used for gutters and down spouts. To keep leaves and other debris from entering the system, the gutters should have a continuous leaf screen, made of ¼ inch wire mesh in a metal frame, installed along their entire length, and a strainer at the head of the downspout.

ii. Roof washers.

Roof washing, or collection and disposal of the first flush of water from a roof, is needed if it is used for human consumption, since it picks up most of the impurities collected in the dry seasons.

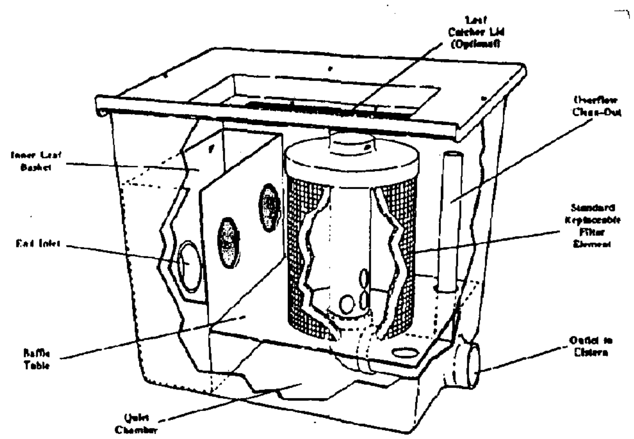


Fig. 3.114. Commercially available roof washer with filter system (Hoffman, 1997)

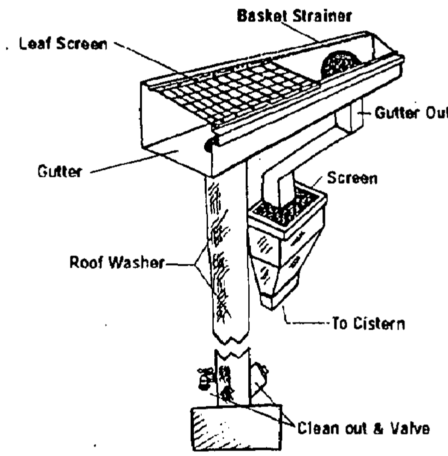
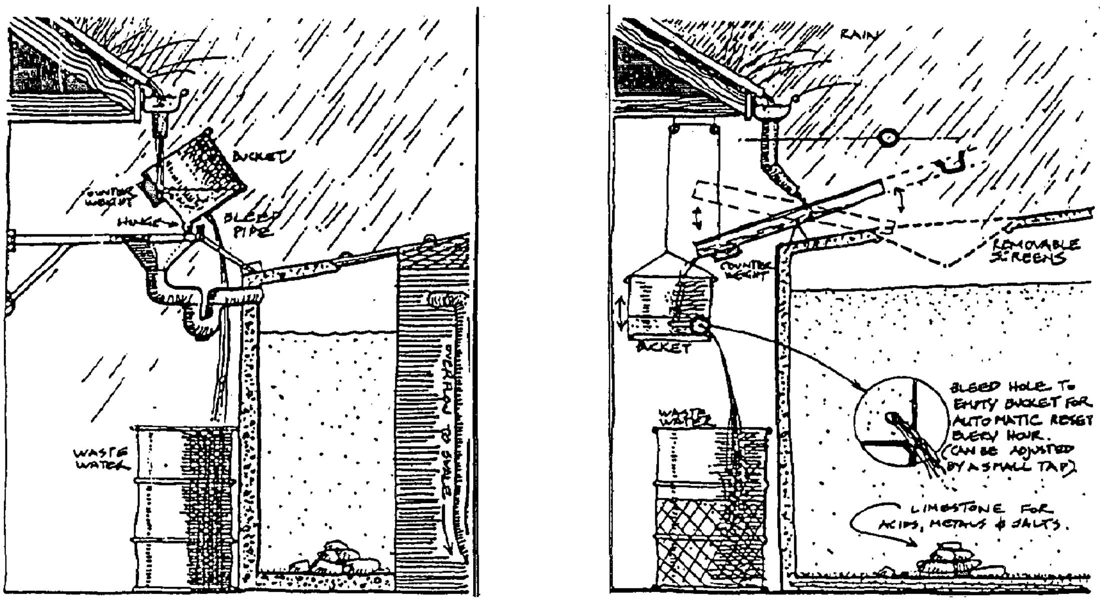


Fig. 3.115. Example of a standpipe type roof washer (Hoffman, 1997)



Methods of rejection of first water flow from a roof. The first rains wash the roof and are rejected; these systems automatically reset when empty.

Fig. 3.116. Simple systems for roof washing. (Woolley, 1997)

c) Storage tanks.

The building plan should reflect decisions about optimal placement, capacity, and material selection for the cistern.

i. Siting.

Cisterns could be placed above or below the ground, at least 50 ft (15m) away from sources of pollution such as animal stables, or septic fields and should be placed on the highest level possible to alleviate stress on the pump. Cisterns below the ground benefit from the cooler year-round ground temperatures.

ii. Design features.

The cistern should have a durable, watertight exterior and a clean, smooth interior, sealed with non-toxic joint sealant. A tight fitting cover prevents evaporation and keep insects and small animals. They should not allow sunlight to penetrate or algae will grow in the cistern.

The following is a summary of cistern types classified according to materials.

CISTERN TYPES		
MATERIAL	FEATURE	CAUTION
PLASTICS		
Garbage Cans (20-50 gallon)	commercially available, inexpensive	use only new cans
Fiberglass	commercially available, alterable and moveable	degradable, requires interior coating
Polyethylene/Polypropylene	commercially available, alterable and moveable	degradable, requires exterior coating
METALS		
Steel Drums (55 gallon)	commercially available, alterable and moveable	verify prior use for toxics, corrodes and rusts, small capacity
Galvanized Steel Tanks	commercially available, alterable and moveable	possible corrosion and rust
CONCRETE AND MASONRY		
Ferrocement	durable, immoveable	potential to crack and fail
Stone, Concrete Block	durable, immoveable	difficult to maintain
Monolithic/Poured in Place	durable, immoveable	potential to crack
WOOD		
Redwood, Douglas Fir, Cypress	attractive, durable	expensive

Table. 3.12. A summary of cistern types (Hoffman, 1997)

d) Conveying.

To achieve a good pressure pumps are used, much in the way they are used to extract well water.

e) Water treatment.

The types of treatments are limited to filtration, disinfection, and buffering for pH control. The types of treatment units are filters that remove sediment, together with either an ultraviolet light or chemical disinfection.

i. Filters.

Once large debris is removed by screens and roof washers, other filters are used to improve rainwater quality. Screening, sedimentation, and prefiltering occur between catchement and storage or within the tank. A cartridge sediment filter could be used to remove particles of five microns or larger. These sediment filters are often used as a prefilter for other treatment techniques such as ultraviolet light or reverse osmosis filter, which can become clogged from large particles. When a disinfectant such as chlorine is added to rainwater, an activated carbon filter at the tap may be used to remove the chlorine prior to use. Chemical disinfectants such as chlorine must be added prior to the activated carbon filter. If ultraviolet light is used for disinfection, the system should be placed after the activated carbon filter.

ii. Disinfection.

- Ultraviolet light (UV) water disinfection, a physical process, kills most microorganisms that pass through them. Since particulates offer a hiding place for microorganisms, prefiltering is necessary for UV systems.
- Ozone readily kills microorganisms and oxidizes organic matter in the water into carbon dioxide and water. It should be used after an activated carbon filter
- Chlorine or iodine can also be used for disinfection

If the rainwater is used to wash clothes, water plants, or other tasks that do not involve direct human consumption, treatment beyond screening and sedimentation is optional.

iii. Buffering.

Controlling the pH of rainwater by buffering can be easily accomplished by adding base materials like baking soda to the storage tank.

Appendix 8 shows the kinds and other aspects of treatment techniques

3.4.2.3. Water budget and amount

The design of rainwater harvesting system should be preceded by the analysis of water demand, local precipitation, available catchement area, and financial budget. Therefore, water budget inside the buildings, the landscape water budget and the expected harvested rainwater volume should first be analyzed.

a) Water budget inside buildings.

The water budget of any building could be determined by calculating the number of shower heads, bath, toilet flush, urinals, dishwashing run, washing machine and the number of persons that will be using them along with the average amount of water these fixtures will consume.

b) Landscape water budget.

To calculate the landscape water budget, the grass type, the area of the lawn and the annual rainfall must be determined. For this case the chart at appendix y is provided.

c) Harvested rainwater amount.

One inch of precipitation (1/12 foot) on one square foot of collection area equals 0.6233 gallons. This could be round off to 600 gallons (2271 litres) collected per inch of rain on 1,000 square feet. From this basic rule of thumb the analysis of the efficiency and reliability of the rainfall could be carried out. After these the amount of rainfall to be collected and the amount of water that will be used will be balanced. From practice it is discovered that even with the strict measures, rainfall collection can only provide a fraction of the amount of water used.

i. Collection efficiency.

Since there are always losses on the system components, and since water collected will overflow in rainy seasons, collection efficiencies of 75% to 90% are used and if it is only for supplemental garden growing only 50% efficiency is applied.

ii. Rainfall reliability. The parameter to consider is average precipitation of the place to determine how much water would be generated from the roof area. The calculation is the roof catchement area times the average rainfall times 600 gallons divided by 1,000.

$$\text{Area (ft}^2\text{) X Average Rainfall (inches) X 600/ 1000}$$

This is sufficient if the water is needed only to plant water

3.4.3. Storm water.

Building sites have a role to play in reducing the amount and contamination of storm water runoff. The most effective approach is to limit the amount of impermeable surfaces on the site, since permeable surfaces both reduce peak storm water runoff, and treat storm water pollutants. Runoff from parking areas and vehicle lanes in particular contains a wide variety of contaminants.

Detention tanks and bioswales could be used to reduce storm water runoff and improve water quality.

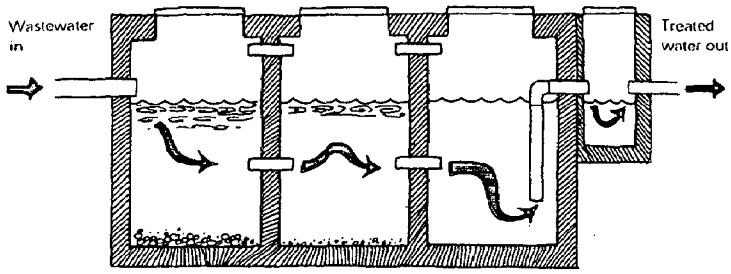


Fig. 3.117. Clarifier or oil/water separator. (Sheltair, 1994)

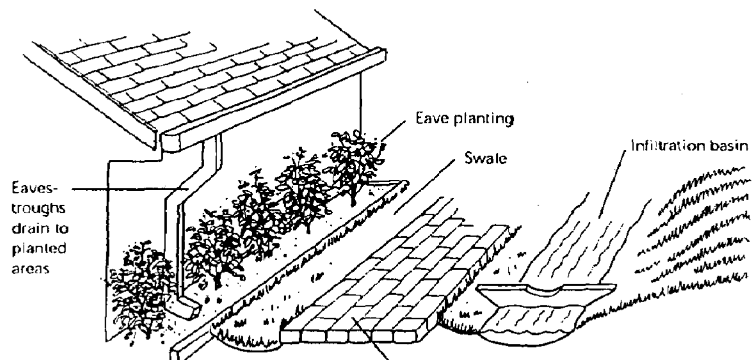


Fig. 3.118. Minimizing storm water runoff to impermeable areas. (Sheltair, 1994)

3.4.4. Landscaping.

Landscaping using native plants with high drought resistance (Xeriscape) is another great way to lower water waste outdoors. Selecting drought resistance grass, and using lawn chemicals and fertilizer sparingly also reduces watering needs. Grass that is heavily fertilized needs two to four times the water to survive, and may wind up with a weak root system.

3.4.5. Water efficient appliances

One of the green design measures to be applied to save precious water is to specify appliances that economically make use of the water available to them.

3.4.5.1. Low flush systems.

a) Low flush toilets

Low flush toilets conserve water since about 33% of potable water is wasted in flushing toilets in domestic house. The other option is a toilet with a variable flush, which uses either half or the full cistern water depending on the choice of the users.

b) Pressurized-Tank toilets.

These are tanks that perform properly at 1.6 gallons (6 litres). In pressure-assisted toilets the porcelain tank contains a metal or plastic tank which holds water under pressure, pressurized by the building's own water pressure. When flushed, the pressurized water provides a rapid and powerful flush. The trapway in a PT toilet is just as large as the trapway in a 3.5 gallons (13 litres) or 5 gallons (19 litres) toilet, eliminating the problem of clogs.

3.4.5.2. Taps

Aerating taps reduce splashing and can reduce flow rates by up to 50% without reducing the effectiveness of the water stream. 5% of water can be saved by using quarter-turn taps as they provide better control. Such taps also avoid drip-leaks by having ceramic seat valves instead of washers

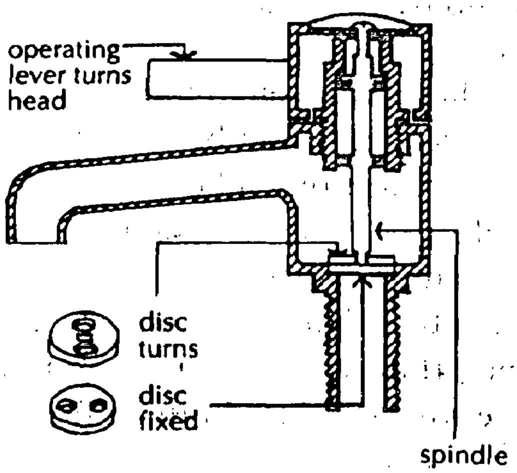


Fig. 3.119. Quarter turn taps with ceramic discs. (Barry, 1998)

3.4.5.3. Water-miser machines

Low-flow showerheads and faucets, dishwashers and clothes washers that have 'water-miser' features are all important to lower water use

3.4.6. Energy conserving water heating.

This is the section that deals with energy spending in buildings while water is being used. The green decision would be to spend as little amount of energy as possible to get the water heated to the desired level.

3.4.6.1. Solar collectors for service hot water heating

Service and space heating water in the 120° F to 160° F (~50-70^0 C) range can be provided by flat- plate solar collectors or evacuated tube systems, which are even better, insulated, with more efficient absorbers. These technologies can offset 50%-70% of the heating load, with simple paybacks of three to fifteen years. The potential to offset peak generation is high when replacing or supplementing electric heat.

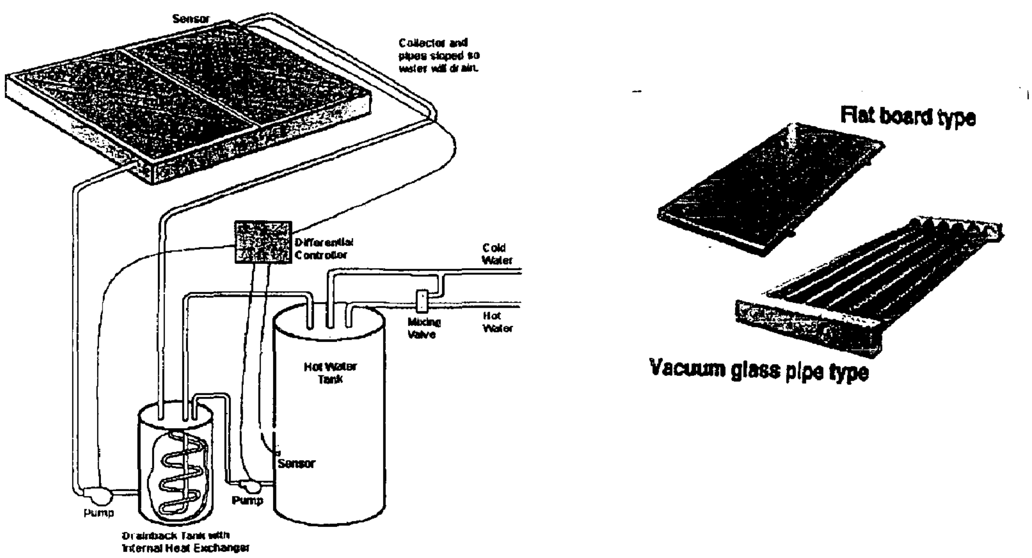


Fig. 3.120. Solar collector for water heating. (www.hku.hk/teaching.html) (Sheltair, 1994)

3.4.6.2. Instantaneous water heater

A good way to cut down running the tap to get hot water is the use of an instantaneous or "tankless" water heater near each point of hot water use.

3.4.6.3. Plumbing design

Another useful option is using plumbing planned so that the shortest possible length of pipe runs from the water heater to each hot water using device or tap.

3.4.6.4. Hot water pipe insulation and heat traps

A lot of water-heating energy is wasted by distribution piping system. Insulation and heat traps are easy ways to greatly reduce these losses. All hot water distribution and recirculating system piping should be insulated. Insulation also reduces the time occupants must wait for hot water at the fixture.

Insulation heat traps on the inlets and outlets of non-circulating hot water heaters and tanks reduces buoyancy-induced flow of hot water through the piping, where it loses heat to the building interior. These simple pipe loops reduce unintended hot water circulation. Apart from the pipes it is wise to wrap storage tanks with foil-faced and taped wrapping.

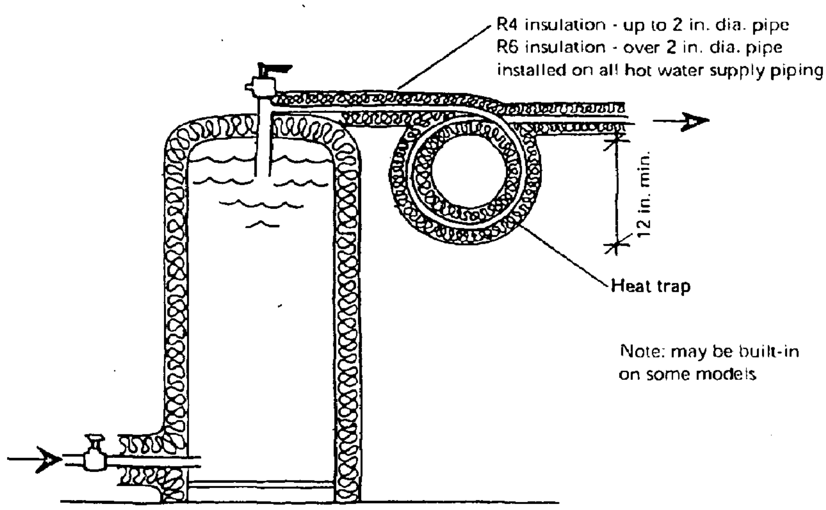


Fig. 3.121. Insulated water heaters and heat traps (Sheltair, 1994)

3.4.6.5. Energy efficient washing machines

Energy star washers are those that make use of optimum amount of energy and water to wash clothes. In doing so they will use 40% less water than the normal ones. Advanced designs automatically sense the condition of the dishes, and adjust water temperature and cycle duration to optimize both cleanliness and water consumption.

3.4.6.6. Greywater heat recovery system

Installing greywater heat-recovery equipment in residential projects, commercial or institutional buildings with multiple showers, can save up to 60% of water-heating energy where hot water drain flow occurs at the same time as hot water supply flow-such as multiple showers or industrial process water systems.

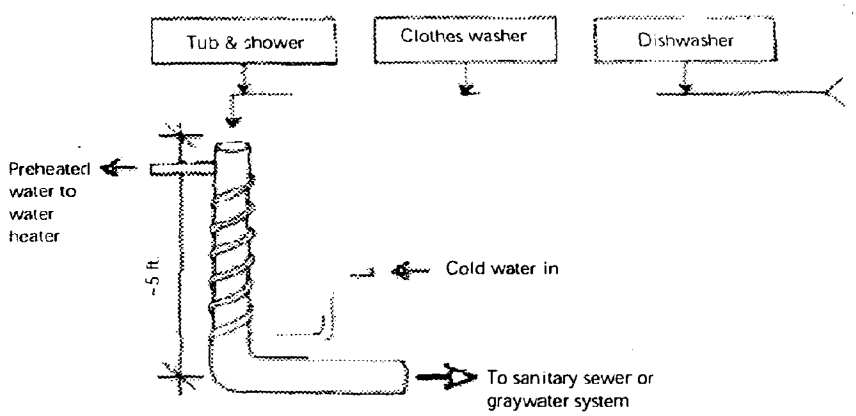


Fig. 3.122. Gray water heat recovery system (Sheltair, 1994)

3.5. Waste Management

Buildings and their systems together with their immediate environments are one of the sources of toxic waste materials that burden the ecosystem and consume huge amount of energy for their processing into relatively harmless matter. The concept of waste as something to be disposed off into landfills and other ecological sinks should be challenged by the green design team.

Direct and indirect wastes such as sewage, construction waste and garden waste should be given due attention to get the most out of them in terms of resource and energy benefits. Waste grey water was discussed separately, in the water management section.

3.5.1. Sewage

Sewage flushed into municipal sewers is rich with nutrients that the earth can make use of. Unfortunately it ends up mixing with other toxic effluents from various sources where it hardly is possible to treat it well, so that it is taken back to the natural ecosystem. Moreover the demand of energy and resources to run such a central sewage disposal and treatment system is colossal. Safe and inexpensive forms of aerobic and anaerobic sewage treatments should be used, to lessen the impacts of such systems and enhance the environment.

3.5.1.1. Aerobic (Composting toilets)

Aerobic composting system utilizes the use of oxygen, in breaking down the wastes to harmless compost. Oxygen helps to naturally break down human waste, but once the waste is engulfed by water, the break down process ceases. Oxygen, chemical and mechanical systems must be used. But this requires an unsustainable energy and material expenditure. The most common kind of composting toilet, the Clivus Multrum, is discussed.

- Clivus Multrum

The composting toilet (waterless or humus) toilet utilizes a starter mix of worms and soil organisms. It is not completely waterless to help it control temperature and circulate oxygen. The great advantage of this system is that no water is needed and the volume of waste is only 5-10% of the original.

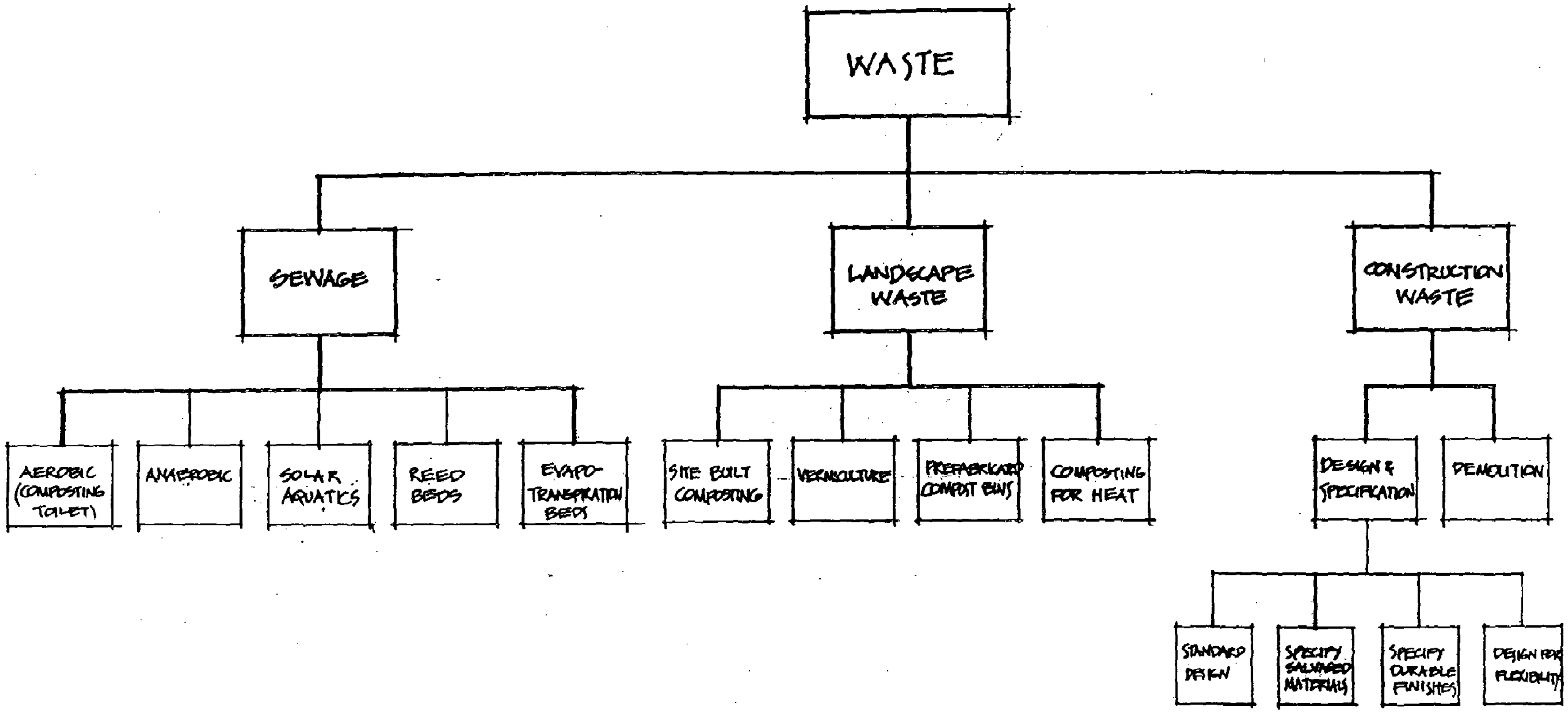
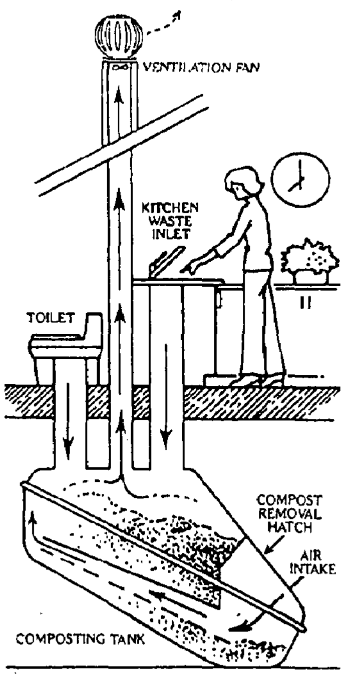


Fig. 3.123. Diagram showing all the considerations in waste management

Aerobic decomposition is achieved by sucking air through the wastes from channels running along the container. A draught is created by a chimney, sometimes equipped with a fan. Since inside pressure is lower than the outside, no odor can escape.
The addition of kitchen waste or other organic material permits the correct carbon-nitrogen ration for composting. Electric heater powered by solar cells may be needed., in case of lower temperature, since decomposition slows at such temperatures.

The sludge contains nitrogen, phosphorous and potassium and other nutrient that are used as fertilizers. Its organic structure enables almost 100% utilization unlike synthetic fertilizers that can be washed away. Moreover, it is odor free and pathogenic microorganisms and other parasites are destroyed. See appendix 9 for comparison of on site waste disposal methods on the grounds of safety.



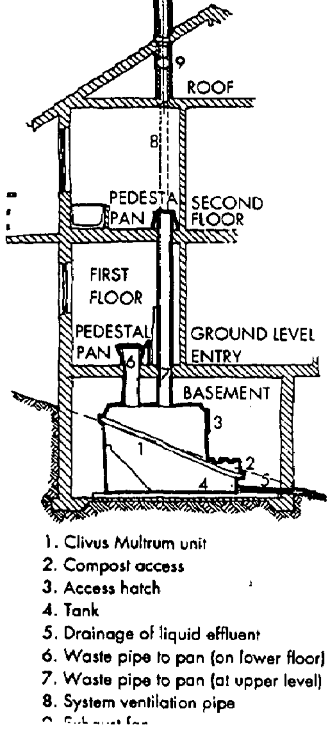


Fig. 3.124. Different kinds of Clivus Multrums (Littler, 1984) (Baggs, 1996)

3.5.1.2. Anaerobic

Anaerobic treatment is the treatment of sewage in the absence of oxygen, due to anaerobic bacteria that thrive in such conditions. Although septic tanks are the most common anaerobic systems, they don't make room for production or collection of methane gas, which is a useful byproduct of anaerobic digestion. To this end only methane digesters are discussed that provide methane gas used for cooking, heating and/or lighting. The other useful end product of anaerobic sewage treatment is sludge, that is used as a soil fertilizer.

Methane production from anaerobic systems is a two-stage biological process performed by two groups of bacteria, namely the acid forming and methane forming bacteria. In an anaerobic digester oxygen is excluded and conditions such as temperature, loading rate, feed type etc are controlled so that the methane former bacteria are in balance with the acid formers.

One of the most important factors affecting the output is temperature and it should be between 20° C-55° C. The other factor influencing the quantity and quality of biogas is pH value. A pH of 7-8.5 is desired. Lower pH is detrimental for methane forming bacteria. However the addition of lime or sodium carbonate can reduce excessive acidity and balance the process.

One other factor is the relationship between carbon and nitrogen. C:N ratio of 25:1 to 30:1 results in optimum biogas production. If the ratio is high, nitrogen rich manure (animal waste) is added, and if it's low (poultry manure) straw or crop residues are added.

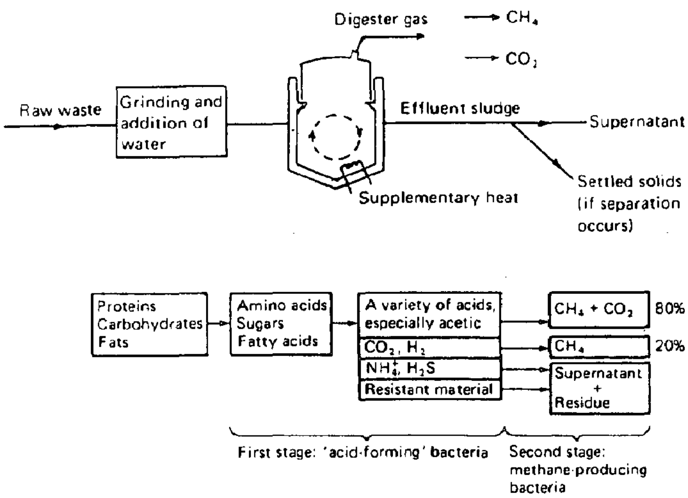


Fig. 3.125. The methane digestion process. (Littler, 1984)

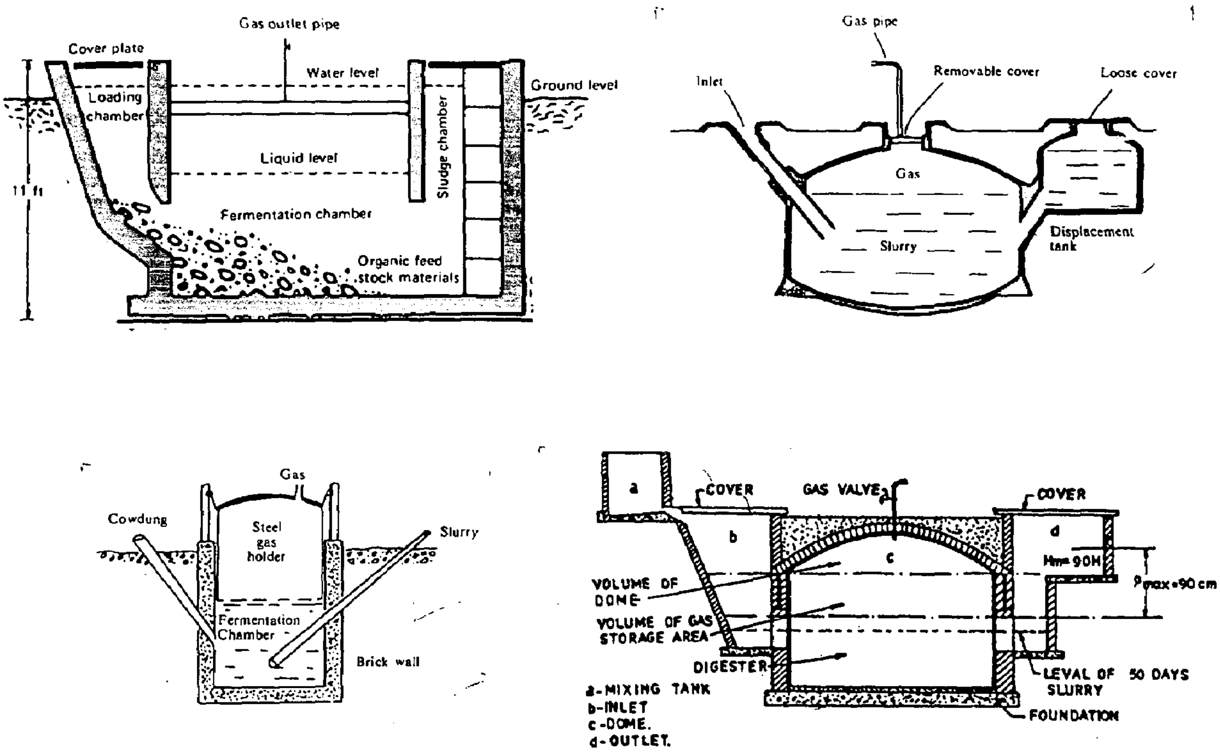


Fig. 3.126. Examples of biogas digesters. (El-Hinnawi, 1981) (Lal, 1995) (Littler, 1994)

Material	Biogas yield (m^3/tonne)
Cattle dung	22– 40
Pig manure	40– 60
Poultry	60–115
Human faeces	20– 28
Crop residues	30– 40
Water hyacinth	40– 50

Table. 3.13. Biogas yield per unit mass of fresh matter completely digested. (El-Hinnawi, 1981)

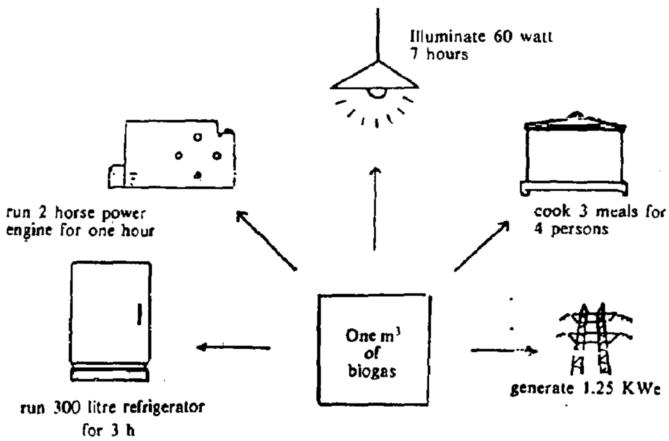


Fig. 3.127. Various applications of biogas. (El-Hinnawi, 1981)

Sulabh international an NGO working in India, has experimented with the gas produced in biogas plants containing human excretas, for street light of a major thoroughfare in Patna (Lal, 1995)

a) By products of anaerobic digestion.

The effluent and sludge after digestion is a rich fertilizer. The major advantage is the conservation of all the nitrogen, present in the material used, in organic or ammonium nitrogen forms. It has no offensive odor and no rodents and flies are attracted to it.

The effluents can be used for growing algae that could be fed to animals and used as input material to the digester.

b) Environmental aspects of biogas production

- Anaerobic digestion eliminates to a large extent pathogenic organisms leading to general public health improvement.
- It reduces the dependency on wood and charcoal, in the developing world, leading to the conservation of forest resource and reduction of soil degradation and desertification.

3.5.1.3. Other water treatment practices.

a) Solar aquatics

This biological system has a series of ponds and tanks contained in a large greenhouse to maintain a warm, solar-powered temperature. Aeration and sand filtration are combined with the culture of floating aquatic plants such as water hyacinth, and with a variety of fish, shellfish and invertebrates. Such systems are better at removing nutrients and toxins than conventional sewerage treatment, and work fine in cooler climates. They are adaptable to smaller scale, community-sized installations and 10,000 people's wastes can be treated with an area of around one acre (4050m^2). Another benefit is the harvest of fish and aquatic plants.

b) Reed beds

Constructed reed beds consist of one or more vessels containing gravel and/or sand or soil, with reeds and other aquatic plants growing on top of this. The reeds absorb oxygen from the air through their pores above ground, and transport the oxygen to the root zone, where it enters the soil, thus it extracts nitrates, hydrocarbons, phenols, phosphates, mineral waste and bacteria that are harmful to health. Dirty water flows through the bed, and comes out cleaned. Large numbers of microorganisms form in the root area of the reeds, digesting the slime, nutrients and other pollutants. Reed beds deal with dirty water (grey water,) only, not with faeces in sewage, and so primary treatment, for example in a septic tank or settlement lagoon, is required of this.

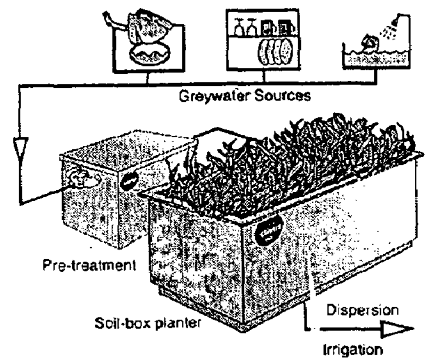


Fig. 3.128. The use of reed beds (www.greywater.com)

c) Evapo-transpiration beds

This type of treatment is already discussed in the grey water treatment section (page 104), and is only suitable for grey water, and not for black water.

3.5.2. Landscape waste

Landscape waste could be made into a very useful compost by the decomposition of organic waste. The compost is a homogenous material that can be part of the soil. Composting is useful, in saving landfill space, saves energy for transporting the material, and it creates a high quality fertilizer at the location where it can be used. It also stops incineration that will affect the environment.

Caution should be taken not to include animal based kitchen products in the compost feed. There are different kinds of composting bins including the site-built compost areas.

3.5.2.1. Site built composting

It can be made from wire, wood slats, discarded pallets or bricks. The base of the compost should be 4 to 5 feet square. The pile will have 4 feet high.

On a level area in a sunny side of the landscape, the grass is first removed exposing the dirt and 3 to 6 inches of coarse materials like branches, leaves, straw are used as the bottom layer. These are high carbon materials, providing air circulation from the bottom. The next layer includes high nitrogen materials such as grass clippings or manure. This will have a depth of 6 inches. The sequence is alternated using carbon materials (browns) with nitrogen materials (greens). The pile is then turned every two weeks and is kept moist. Odor causing acids may be neutralized with wood ashes, or crushed eggshells. The pile should be covered to prevent insect problems.

3.5.2.2. Vermiculture

Vermiculture is composting using worms instead of bacteria. This can be achieved using commercially available kits or produced on the site. The worm composters could be stored inside buildings and even can be placed in closets.

3.5.2.3. Commercial prefabricated compost bins

There are a number of prefabricated compost bins, that can be used to compost the landscape waste. The composters should have a minimum volume of 1 cu. Yd ($0.76m^3$). Except for smaller worm composters.

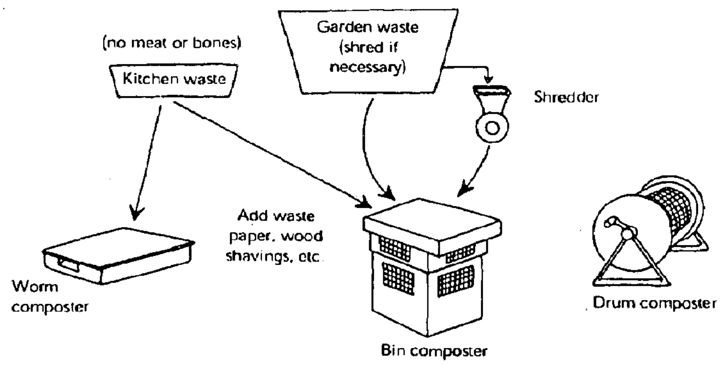


Fig. 3.130. Prefabricated compost bins (Sheltair, 1994)

Compostable materials include, raw kitchen materials, leaves, sawdust, weeds, grass clippings, nut shells, hair, feathers, floor sweepings tobacco, natural clothing, rugs etc. But meat and dairy products, grease, bones fat foods should be avoided.

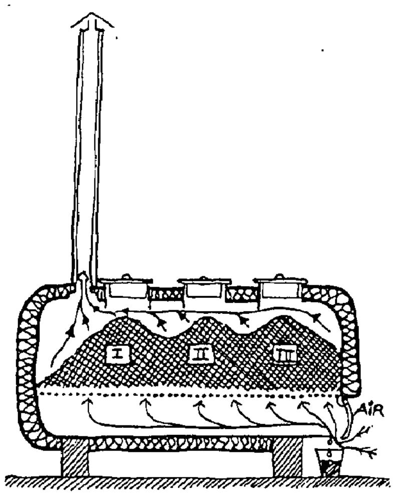


Fig. 3.131. Section of a typical continuous composter, with three sections, where each is removed after 3 weeks and refilled with fresh organic material. (Bansal, 1994)

3.5.2.4. Composting for heat production.

Landscape waste decays in the course of 12 months, giving energy in the form of low-temperature heat emission in the range of 50-70° C. By inserting an heat exchanger into a compost heap it is possible to use the energy for indoor water heating.

A compost container of 30m^3 capacity (corresponding to about 12t brushwood) with a heat exchanger having a circulation rate of 120l/h is shown in Fig. 3.132. This system can heat water to 55° C at the rate of about 50 litres per hour. The 12 tones of brushwood can substitute about 1000 litres of fuel oil.

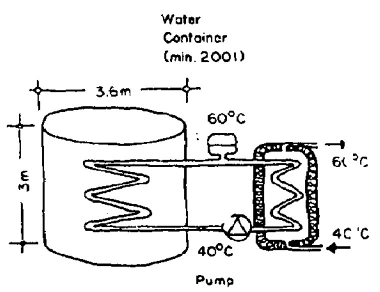


Fig. 3.132. Compost container and water heater (Bansal, 1994)

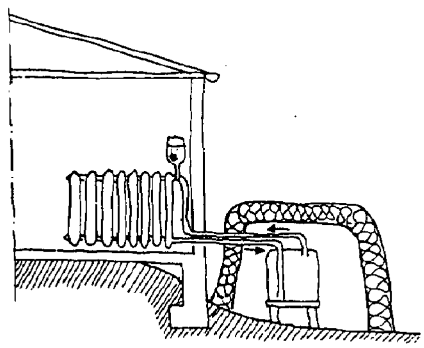


Fig. 3.133. A composter in combination with a radiator to heat a room (Bansal, 1994)

Continuous feed compost heating system is also possible by composting the wastes below the building or as a duct system on the ground floor where the heat is transmitted to the adjacent rooms through the walls and/or the floors.

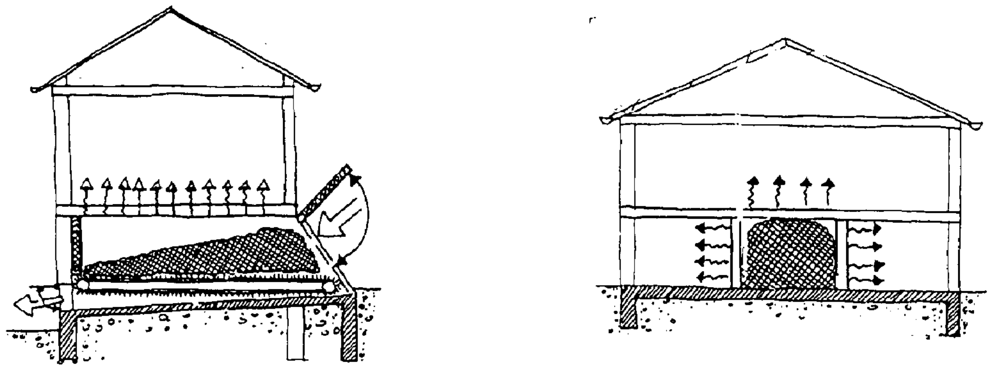


Fig. 3.134. Compost containers under or within a building (Bansal 98)

3.5.3. Construction waste

Construction waste is the waste that is produced when a building is under construction, renovation or demolition. The main purpose here is the reduction of waste materials that go to the landfill, by proper design practice and by recycling the recyclable parts. The other relates to the handling of the waste materials from demolished buildings, so that hazardous materials are handled with care to lessen their impacts to the ecosystem and human beings.

3.5.3.1. Design and specification.

The most important step in a construction waste reduction is a good design practice.

a) Standardized design elements

Design of various elements of buildings must conform to standard sizes and materials should be ordered accurately. It is advisable here, to include the contractors at the design stage, so that they will be able to provide the accurately ordered materials. This method will reduce the amount of material that needs to be recycled.

b) Specify reuse of salvaged material

This is applicable from environmental as well as from heritage point of view, if specially the new building is to be built on the vicinity or on the site of the old building. This could be included in the contract document. Salvaged materials like, bathroom fixtures, bricks and other masonry, doors and windows etc. could be reused.

c) Specify durable finishes

This helps to stop waste due to shorter service lives. Specify durable, ultraviolet and weather resistant cladding and roofing, durable floor finishes and releasable (those installed with removable adhesive) carpet systems, instead of carpets, can substantially reduce long-term waste. The local climate should be considered when specifying the external finishes.

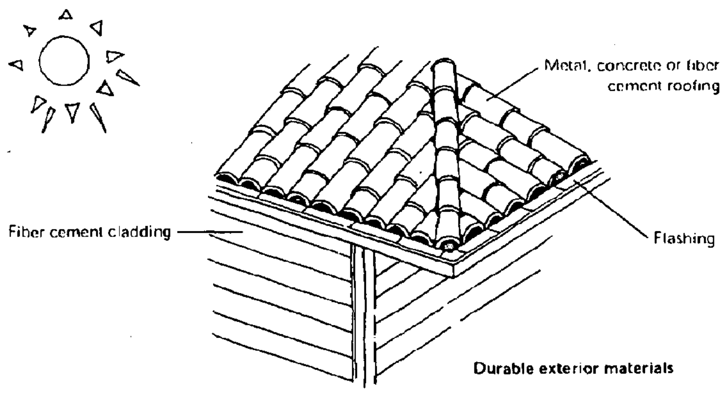


Fig. 3.135. Durable exterior materials (Sheltair 1994).).

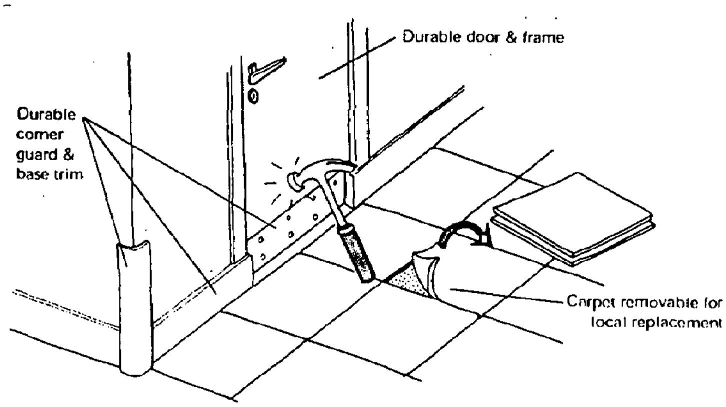


Fig. 3.136. Releasable carpet and durable interior finishes. (Sheltair, 1994)

d) Design interior components for flexibility (Renovation)

Each interior alteration will take its toll on the building materials, therefore it is imperative that flexible detailing should be designed for various parts like the partition walls. For the purpose of flexibility and future disassembly, use bolt and nut fasteners before screws; screws before nails; nails before strippable adhesives, and strippable adhesives before permanent glues.

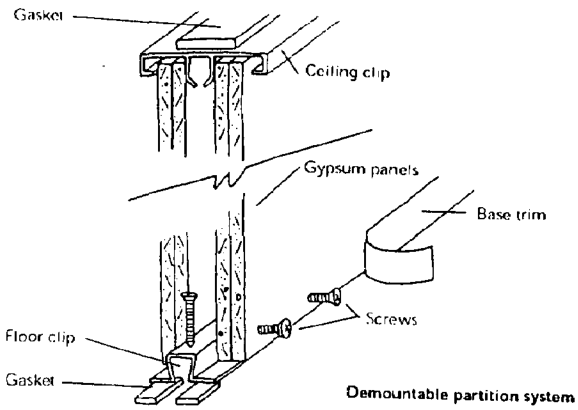


Fig. 3.137. Flexible partition. (Sheltair, 1994)

3.5.3.2. Demolition.

When undertaking renovation or demolition work, care must be taken to handle hazardous materials, like old ceilings, and wall and floor linings that may have been painted with lead primer or contain arsenic-based glues. Roof joints, galvanized piping, sink, bath and basin waste-traps used to contain lead which is a poisonous material that can well leach into the ground water. The other common toxic material is asbestos that was used as a thermal insulation, asbestos-cement roofing, wallboards, water pipe insulation, boiler pipe packing, etc. All types of asbestos are carcinogenic.

3.6. INDOOR ENVIRONMENT

The air within buildings can be more seriously polluted than the outdoor air as people tend to spend most of their times indoors. Indoor air quality (IAQ) is the mixture of the breathe of the occupants, lighting from indoors and outside, off gassing from materials, and pollutants such as radon gas, excess moisture, mold and mildew, formaldehyde, passive tobacco smoke, particle and dust-mite allergen (feces).

A technical definition of IAQ is related to how well indoor air satisfies the three basic requirements for human occupancy.

a) Thermal acceptability
b) Maintenance of normal concentrations of respiratory gases; and
c) Dilution and removal of contaminants to levels below health or odor discomfort thresholds.

Many building products contain chemicals that evaporate or "offgas" for several days or weeks after installation. If large quantities of these products are used inside a building or products with particularly strong emissions are used, they pollute the indoor air. Other products readily trap dust and odors and release them over time. Building materials can also support growth of molds and bacteria, particularly if they become damp, potentially causing allergic reactions, respiratory problems and persistent odors which are symptoms of "sick-building syndrome"

IAQ has factors that have a positive impact on the building and occupants. IAQ problems which affect people fall into three general areas

a) Comfort
b) Acute health effects and
c) Chronic health effects.

The figure on the paradigms of IAQ will help us understand the different dimensions of problems. The relationship between point sources (contaminants) and susceptible population will determine the risk and effect of indoor air pollution, and this is aggravated by inadequate ventilation

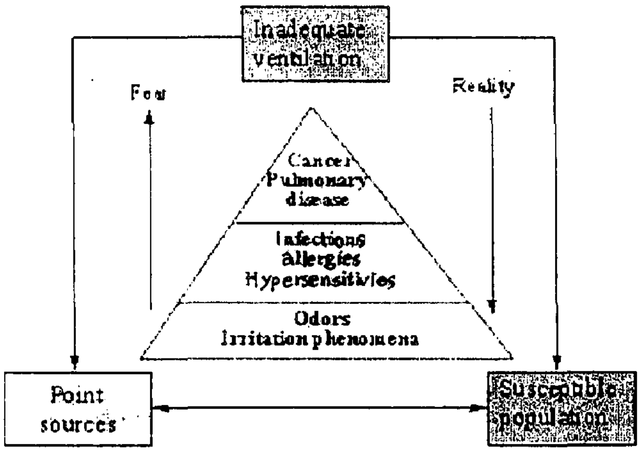


Fig. 3.138. Paradigm of IAQ (www.hku.hk/teaching.html)

Health effects could be divided into six categories (a) respiratory cancer, (b) chronic obstructive pulmonary disease, (c) infectious disease and microbial toxins, (d) immunologic disorders, (e) irritation phenomena, and (f) odors.

Examples of improved occupant performance due to good IAQ, include

- Lower absenteeism in office buildings
- Increased sales in retail stores
- Higher product quality in manufacturing
- Fewer errors in factories

3.6.1. Sick buildings

A group of loosely associated symptoms experienced in the interiors of buildings is known as sick building syndrome (SBS). SBS is a persistent set of symptoms occurring in greater than 20% of those exposed, with causes not recognizable, and symptoms relieved after exiting the building.

The following diagram represents the major contributors to indoor contaminants or poor IAQ.

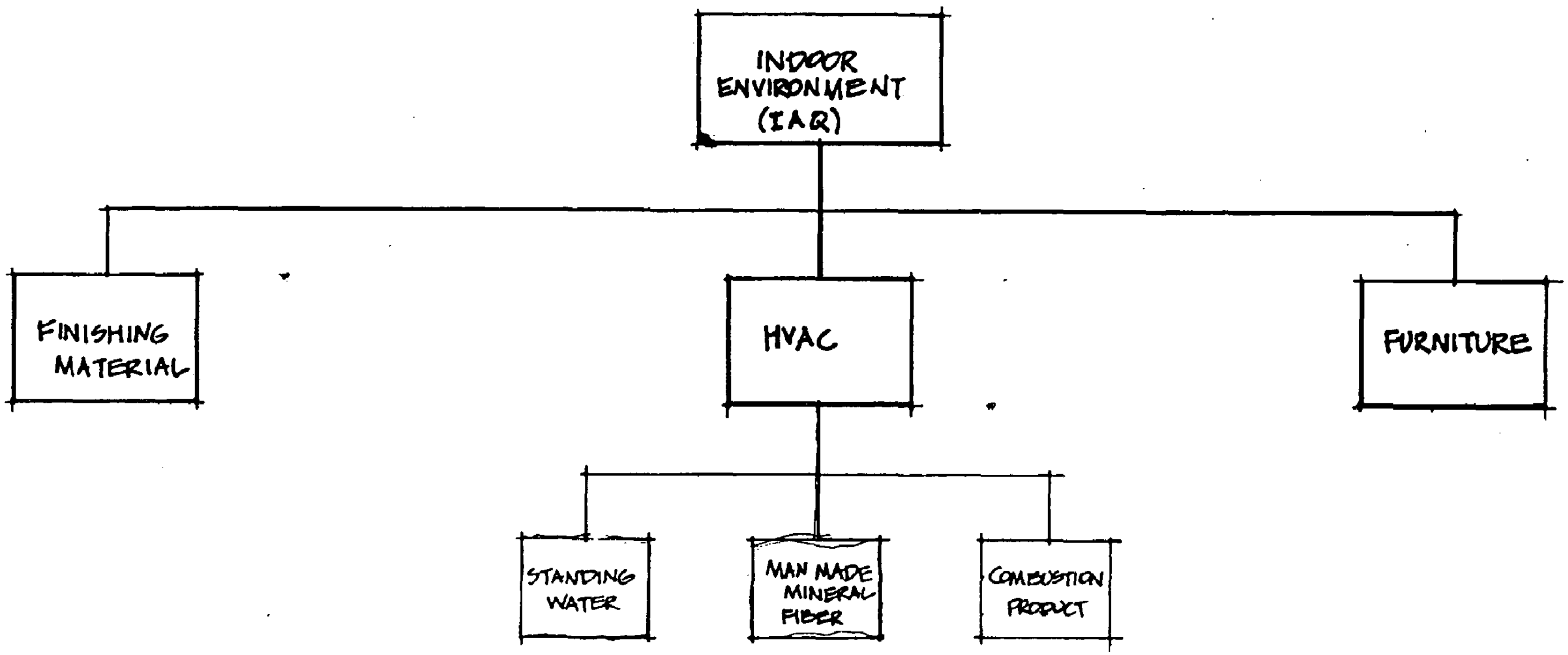


Fig. 3.139. Diagram showing all the considerations in design for indoor air quality

3.6.2. Contaminating agents of IAQ problems

The contaminating agents that account for the poor IAQ problems in buildings can be categorized into seven classes as shown in the following table.

Pollutant class	Typical examples
Combustion products	Carbon monoxide, nitrogen dioxide, sulfur dioxide, carbon dioxide, and tobacco smoke
Volatile organic chemicals	Pesticide and fungicide components, alcohols, benzene, esters, chloroform
Respirable particulates	Asbestos, fibre glass, inorganic and organic dusts, frayed materials, pollen
Respiratory product	Water vapour, carbon dioxide
Biologics and bioaerosols	Molds and fungi, bacteria, viruses, nonviable microbial particulates
Radionuclides	Radon, radon progeny
Odours	Odours associated with any of the above

Table. 3.11. Contaminating agents of indoor environments (www.hku.hk/teaching.html)

3.6.3. Causes of contaminants

Although the contaminating agents are many as classified in the previous tables, the majority of them come from the finishing materials employed, the design and detailing of the HVAC system and the materials used in making the furnishing.

3.6.3.1. Finishing materials

Finishing materials like paints, adhesives, ceiling tiles, wood composite products, acoustic materials, insulation materials and carpets must be studied in detail before they are specified in the interiors of buildings.

Paints or adhesives contain volatile organic compounds (VOCs) which evaporate and pollute indoor air. Low emission paints and adhesives are used to avoid this problem. This is specialty important if a coating needs to be reapplied when the building is occupied.

Carpets are strongly associated with IAQ problems, primarily from the styrene butadiene (SB) latex backing. Healthy floor, ceiling and wall coverings are also those that release the least dust and do not support microbial growth. Hard and resilient floor coverings, such as linoleum and tile, have inherent health advantages over carpet, since they do not trap dust and contaminants.

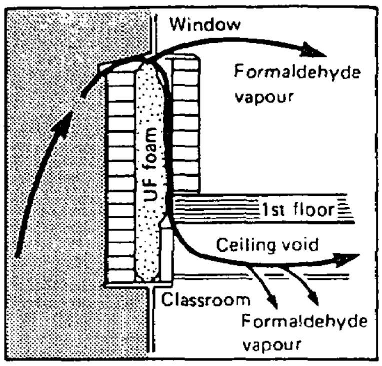


Fig. 3.140. Penetration of formaldehyde vapor into a building from a ureaformaldehyde foam cavity insulation (Littler, 1984)

3.6.3.2. HVAC system

There are three main sources of potential indoor air pollution form heating, ventilating and air conditioning systems:

a) Standing water

Bio-contaminants-microbial diseases, fungi and molds-are some of the most potentially dangerous indoor air pollutants. These typically grow best in warm, dark, moist environments, which have a ready source of nutrients such as dust and dirt. Standing water in contact with ventilation air supplied to occupied spaces can harbor these organisms. Of particular concern is legionella, which can be fatal to exposed occupants. Potential legionella sources include cooling tower drift, direct evaporative coolers, and standing water in coil drain pans or in humidifiers.

As a solution for this the potential for standing water in ducts and HVAC equipment must be eliminated. Particular attention to coils, drain pans, humidifiers and cooling towers must be given. The other thing is that cooling towers should be located distant from outdoor air intakes.

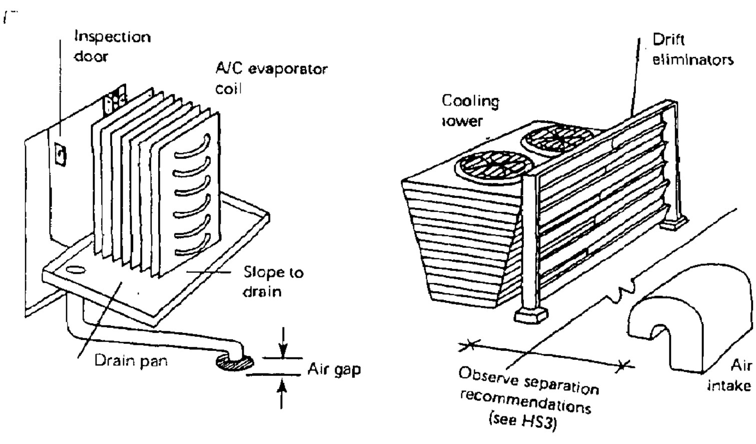


Fig. 3.141. Some methods of avoiding standing water in HVAC equipment (Sheltair, 1994)

b) Man-made mineral fibers (MMMFs)

These are another potential indoor air pollutant from mechanical systems, causing nasal, throat and eye irritation. These typically come from damaged fibrous duct liners used to reduce noise, or from insulation and ceiling tiles exposed in air return plenums. These fibrous materials can become greater hazards if they become damp, as they form an ideal growth medium for biocontaminants.

c) Combustion products

Combustion equipment for heating, such as furnaces and boilers, is another potential source of indoor air pollutants, such as carbon monoxide an nitrogen oxides. Natural gas equipment emit trace pollutants, including sulfur oxides and hydrocarbons which affect health with chronic, low-level exposures. Designers can reduce or eliminate occupant exposure to combustion products by isolating combustion chambers from occupied spaces, and providing excess combustion air under all operating circumstances.

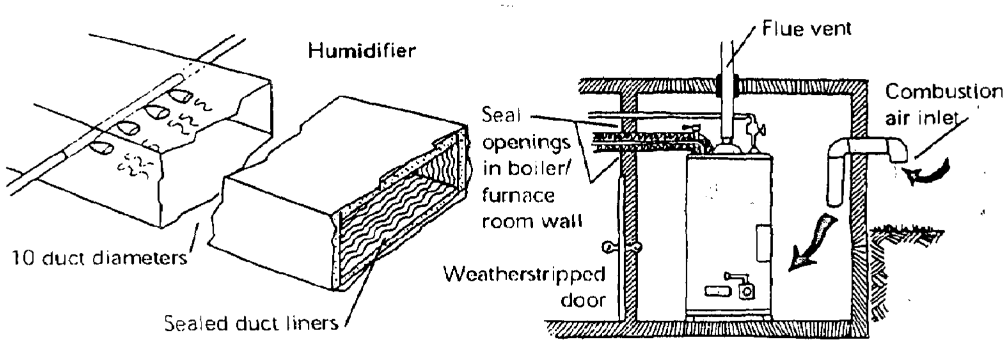


Fig. 3.142. Detailing to avoid spillage of combustion products. (Sheltair, 1994)

Outdoor air intakes located near pollutant sources are also other common causes of indoor air quality problems. Intakes should be located as far as possible from potential pollutant sources. Recommendations for "stretched string" separation distances between pollutant source and outdoor air intakes or the property line are summarized in appendix 11. Stretched string is the distance measured from the closest point of the pollutant source to the closest point of the outdoor air intake, window or door opening, or the property line, along a path as if sting were stretched between them

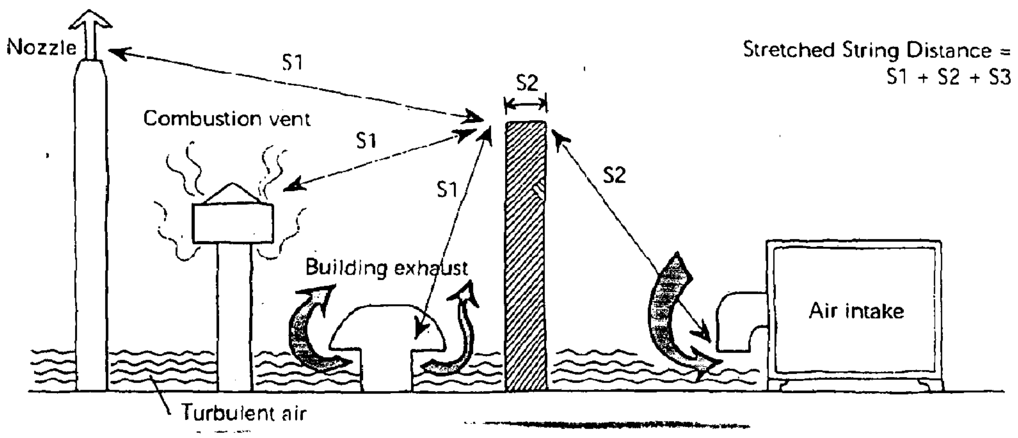


Fig. 3.143. The stretched string distance between air intake and pollutant source (Sheltair, 1994)

<u>*3.6.3.3. Furnishing.*</u>

Engineered wood products and furniture made with fiberboard are made up of glue which contains a lot of formaldehyde which is believed to be a carcinogenic material like asbestos. Furniture made from formaldehyde-free glue fiberboard, and low-odor plastic foams reduce harmful offgassing.

Hard, non-porous and made form metals, glass, ceramics, solid woods, stone and cement, or are designed to release minimal gases and dusts.

Appendix 10 gives all the factors affecting IAQ

CHAPTER 4

HOLISTIC GREEN DESIGN STRATEGIES.

" Architects have learned that green design involves, going back to basics- and inviting more players to the drawing board"
Kira L. Gould

" The age of specialization is dead. We are in the age of integration. The integrated design process for buildings just makes sense. It means avoids reciprocal ignorance"
Bill Reed.

There are various approaches conventionally followed by architects in the design process of projects. Although there are various approaches in the process of deign, the widely adopted standard practice consists of the 6 elements, namely, programming, schematic design, design development, construction documents, bidding and administration of the construction contract.

- The standard, conventional practice follows a linear path through a series of hermetically sealed offices. The architect hands over his portion of the design to the engineer, who does his singular tasks and he hands it to the next in line, perhaps the landscape architect or another distinct engineering group. There the experts will not sit together to design solutions.

- The other aspect of the conventional approach is that it starts with relatively few consultants and design participants and add participants, as the design becomes more complex and detailed.

- Conventional design processes concentrate on the first idea of the architect that will work and develop it into a solution. Typically a designer works as an individual and strives to produce a solution that is unique and original. Holistic integrated approach, by contrast, employs the collective ideas of many individuals and identifies as many ideas as possible, then picks the one that best satisfies the objectives of the project. Multidisciplinary designing group has been shown to yield from 65-93% more ideas than issue from an individual alone (Kirk 1988, 79)

4.1. SALIENT FEATURES OF THE GREEN DESIGN PROCESS.

The green design process is an integrated design approach that recognizes that the building is more than the sum of its parts, it is a set of interrelated systems. It therefore allows for cross-disciplinary decision making regarding all the elements of the building. The following are the salient features of the holistic green approach to design

4.1.1. The holistic green design is Front-loaded.

The largest opportunities to create a more sustainable building come at the early stages of project design. It is at the beginning that there is the opportunity to make the major choices that will have the largest environment and economic impacts. For example the choices made at the outset of design have the largest impact on the mechanical load, the daylighting, the solar absorption, the response to local climate and environment, and the key building elements. Therefore it is crucial to front- load the design process and the best way to do this is to ensure that the whole project team sits down together and creates holistic design solutions.

4.1.2. Multidisciplinary

The integrated green design process involves all the team members sitting down together. Collaboration from the beginning of conceptual design throughout design and construction is needed. Health, resource and ecological issues inherently cross professional boundaries, requiring specialized information and skills. This design integration allows an exchange of ideas from across disciplines. Although the design team will not have too many members, for various reasons, it may consist some of the following, which is a list of the possible decision makers in the multidisciplinary design team.

Client
Owners
Managers
Occupants
Users

Architect
Principal
Project manager
Job captain
Designers
Draftspersons
Specification writers
Job supervisors
Construction manager
Marketing experts

Building Officials
Fire marshal
Zoning board
Building department
Funding agencies
Environmental groups

Builder
General contractor
Subcontractors
Job superintendent
Tradespersons
Unions

Developers
Financiers
Lenders
Legal advisors
Insurance experts
Leasing agents
Realtors

Consultants
Engineering services
Interior designers
Industrial designers
Lighting and acoustic experts
Behavioral scientists
Cost analysis.
Schedulers
Landscape architect
Value engineer
Energy engineer (Simulation)

4.1.3. Extended schematic design phase

The green design process involves deeper analysis than is typical of conventional design practice, and requires more effort from the multi-disciplinary design team. Design fees for this additional work typically reflect the increased work involved, but the investment is small compared to the environmental and cost impacts over the life of a typical building.

The schematic design might occupy roughly 40% of the design rather than the conventional 25% because system and envelope design are so interrelated with massing and siting.

4.1.4. Life cycle costing.

Life cycle costing can be defined as an economic assessment of competing design alternatives, considering all significant costs over the economic life of each alternative, expressed in equivalent money (Kirk, 1988, 104)

In green architectural practice possible study areas for life cycle costs could be

- New building versus retrofit existing structure
- Active/passive solar energy versus conventional HVAC
- Natural versus artificial lighting
- Xeriscape or irrigated landscaping
- Fixed versus demountable partitions.

Life cycle costing is based on several major economic principles like the time value of money, equivalence approaches where it allows moneys spent over time to be brought to a common basis for comparison, and the type of economic decision to be make.

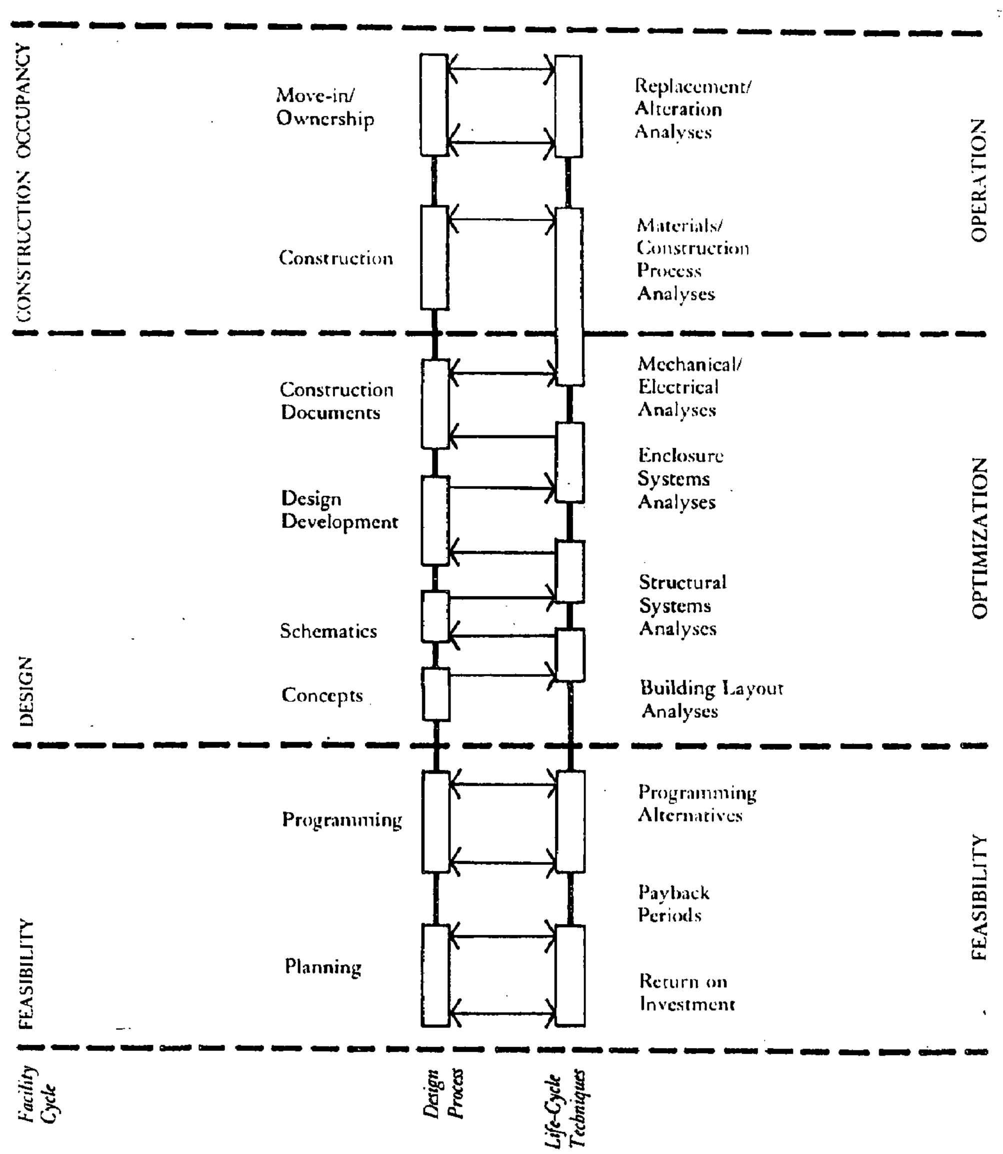


Fig. 4.1. Life cycle costing in the design process. (Kirk, 1988)

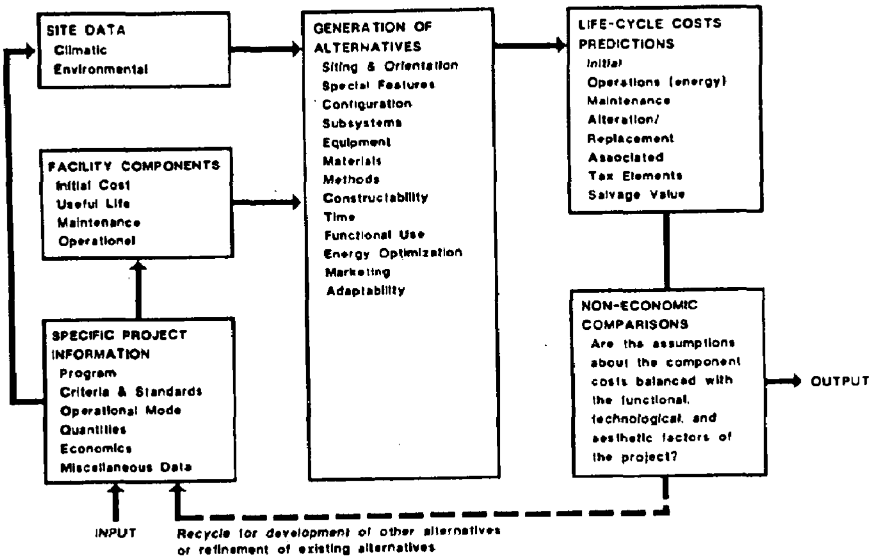


Fig. 4.2. Life-cycle costing logic. (Kirk, 1988)

4.1.5. Integration of construction process

The adversarial, low-bid approach is a disaster and systematically yields poor result. Builders must be brought into the design process and should be selected using the same criterion that is used to select other professional for their skill, experiences and integrity. For instance, early in the design process, the contractor could propose a material for the roof that provides the same level of insulation and can be installed at great savings in time and money.

4.1.6. Commitment to energy modeling

Computerized energy modeling allows important feedback to the design team. Concerning the estimated performance of the proposed design. These assess energy conservation measures early and throughout the design process. They are used to provide constant updates on the projected cost savings of contrasted with other solution. Energy modeling allows feedback so that the design team can find solution that have the lowest life cycle cost. Furthermore, simulations demonstrate compliance with regulatory requirements.

4.2. THE STRATEGIES IN THE DESIGN PROCESS.

4.2.1. Integrated approaches.

In the design of green buildings, the multidisciplinary practice can adopt various approaches for the holistic integrated design process. The following are some of the modes or approaches for multidisciplinary team practices.

4.2.1.1. The charrette process.

The charrette process can be defined as "a brief period of intense activity, if not round the clock/work to accomplish a given task." The charrette is an intense workshop in which all project team members come together to set goals and generate design ideas. This workshop or series of workshops take place in the early phase of the projects design. W.L. Riddich (1971) identifies three essential ingredients for a charrette. (Frederic, 2000)

a) Identification of a specific community problem to study, understand, and hopefully resolve.
b) Participation of interested citizens, particularly those experiencing the problem (or its effects) who are willing to be involved in the decision-making process. This is a fundamental component of the charrette.
c) Involvement of professional experts from within and outside the community. Initially these experts listen and learn as citizens express their concerns. Later, one of the strengths of the charrette process lies in consensus building as citizens and experts brainstorm together to find solutions. Resource material is typically made available to assist in this process.

Charrettes are used during the goal-setting phase of the planning process. They provide an opportunity to bring together expertise to evaluate options and synthesize ideas, which is best done when the focus of the participants is clear.

4.2.1.2. Brainstorming Process

Brainstorming is based on the stimulation of one person's mind by another. A typical brainstorming involves many people spontaneously generating ideas to solve a specific problem. It is an organized way to allow the mind to produce ideas without getting bogged down in trying to judge the value of those ideas at the same time.

A quality solution is expected from greater number of ideas, although criticism is discouraged, the members may suggest how others' ideas can be improved.

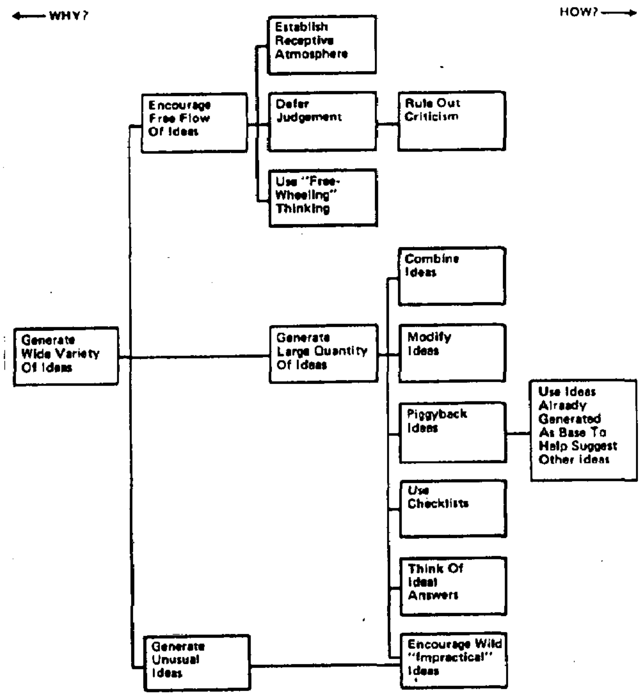


Fig. 4.3. Brainstorming rules (Kirk, 1988)

The group members should represent parallel levels of responsibility because employees might hesitate to suggest ideas in front of their bosses.

All the ideas should be listed on blackboard, however trifling they may look. The final result of this process brings out a number of ideas that with valuation and refinement may generate a solution to the problem presented.

4.2.1.3. Reverse brainstorming process.

It is brainstorming but produces a list of undesirable possibilities, using this permits the team members to be more assured that their recommendations are valid and will satisfy the needs in a better way than any other idea.

4.2.1.4. Delphi process.

Delphi is a method of achieving consensus by identifying design options and speculation on their outcome. It involves individual contributions of information, assessment of the group judgement, an opportunity for individuals to debate and revise their views, and anonymity. Anonymity is achieved as individual responses in a Delphi session are recorded on paper and submitted anonymously, the technique is especially useful in overcoming the emotional blocks often encountered in brainstorming. A major advantage of Delphi is that it minimizes the bias of personality in achieving a group opinion.

The logic of Delphi is that it will gradually converge on a set of design alternatives judged, by consensus, to provide optimum performance for the problem in question. At the first cycle, the members are given a set of inputs about a desired system, for example about a building's floor to floor height. Based on this system, inputs like roofing, interior construction, HVAC system, fire protection etc will be given to the members.

The members will then put in their alternatives together with their resource and environmental implication for the proposal of each input. On the basis of these inputs from the members the team compiles a set of design alternatives and reviews them without their authorship. The group then begins to prioritize or rank the desired system properties.

The second cycle allows each participant to digest the group ranking and focus on the most desirable design options. Empirical confirmation will reinforce the validity of the previous cycle in terms of environmental and resource efficiency.

After the participants have completed the second, individual cycle of Delphi, individual responses are fed into a formal group discussion in order to integrate a priori and a posteriori data. If the resultant design options remain unchanged, it means that they are more desirable ones, in which case the group is ready to make recommendations.

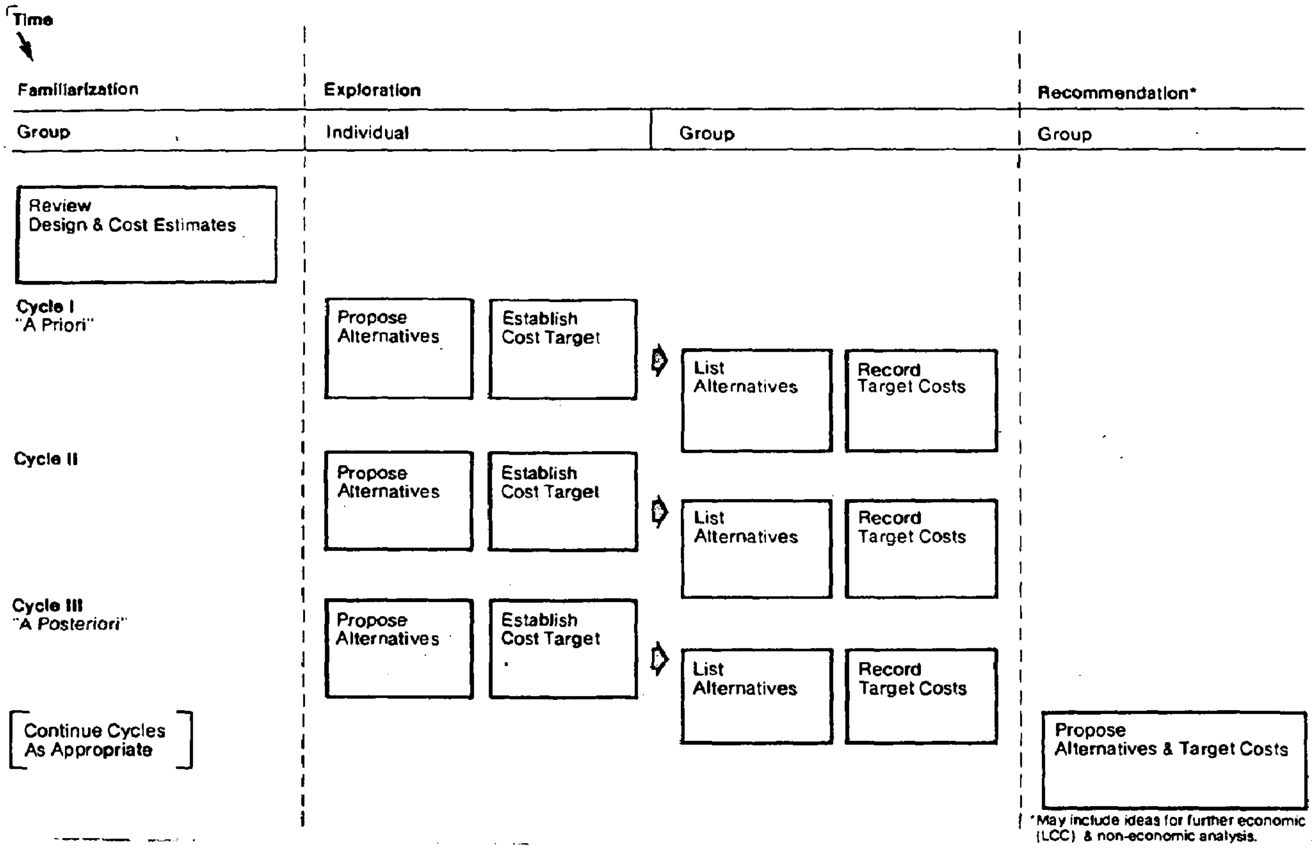


Fig. 4.4. Cycles of the delphi process. (Kirk, 1988)

4.2.2. Design decisions

The multidisciplinary design team makes a number of decisions to achieve the goal of designing green buildings, a number of the practical steps and design decisions are next outlined

4.2.2.1. Identification of project specific problems

The first step is identification of project specific problems. The design team can pick one or more aspects of green design to make the project green. Several factors should be considered in making decisions about the design of buildings that will reduce their environmental impact the most. The following are the four considerations that the group should make.

a) First, the team needs an understanding of what the most significant environmental risks are, globally and locally.

b) Second, the team needs to understand how the buildings contribute to these risks, and how significantly they can reduce them through design.
c) Third, the group should analyze the specific opportunities presented by the project
d) Finally, consideration of the agenda and budget of the client should be made. This is because, group design and a lot of collaboration might incur more money than the conventional linear process. Moreover, some measures might increase the first cost of a building but save money over time.

4.2.2.2. Establishing priorities.

After considering all the four factors, the following might act as a rough guideline in prioritization of green features for a particular project. However, it can be modified or customized for specific projects in different climatic regions. In an arid climate, water conservation might come up the suggested sequence, and in cities with smog inversions, transportation might be very much prioritized.

1. Save energy. Design and build energy-efficient buildings
   The ongoing energy use of a building is probably the single greatest environmental impact of a building, so designing buildings for low energy use should be number one priority.
2. Recycle buildings. Utilize existing buildings and infrastructure instead of developing open space.
3. Create community. Design communities to reduce dependence on the automobile and to foster a sense of community. Design communities that provide access to public transit, pedestrian corridors, and bicycle paths.
4. Reduce material use. Optimize design through alternative spatial configuration or other means to make use of smaller spaces and utilize material efficiently.
5. Protect and enhance the site. Preserve or restore local ecosystems and biodiversity
6. Select low impact materials. Specify low environmental impact, resource efficient materials. Impact could be at the manufacturing, operation or disposal stage.
7. Maximize longevity. Design for durability and adaptability.
8. Save water. Design buildings and landscaping that are water-efficient.

9. Make the building healthy. Provide safe and comfortable indoor environment. This is concerned with the indoor materials, furniture and HVAC systems.
10. Minimize C&D waste. Return, reuse and recycle job-site waste.

4.2.2.3. Creation of measurable project specific performance targets.

The establishment of project-specific performance targets at the outset of the design phase creates an important reference for the entire design team. The multidisciplinary team provides a venue for every member of the cross-disciplinary team to respond to the unique aspects of the project's architectural program, site conditions, and skills and resources of the designers and builders.

All the team members including the developers, designers and builders will establish binding health, ecological, and resource use performance targets. These challenge the design and construction team and allow progress to be tracked and managed throughout development and beyond. These project specific performance targets could be revised along the way, when the team discovers that their targets are too challenging for any reason. The targets could also be improved upon as they are reached and surpassed. Constant attention to these targets is crucial to ensure that the project is meeting its objective.

4.2.2.4. Brainstorm potential design solutions.

The multidisciplinary team will brainstorm potential design solutions that are appropriate to the projects' program, its budget, the site and climate.

Review of what is needed for the multidisciplinary design group.

The project team should have

- A project-specific mission statement that reflects the owner's vision.
- Budget for the project
- Site analysis which contains
  - Location
  - Amenities/services(electrical, gas, water, sewer, road)

- Property
- Zoning
- View
- Geotechnical
- Precipitation
- Temperature
- Available daylight
- Prevailing winds
- Planting/vegetation
- Topography
- Drainage/water courses
- Pedestrian, bicycles, and automobile access
- Adjacent development (existing, forthcoming, and historical)

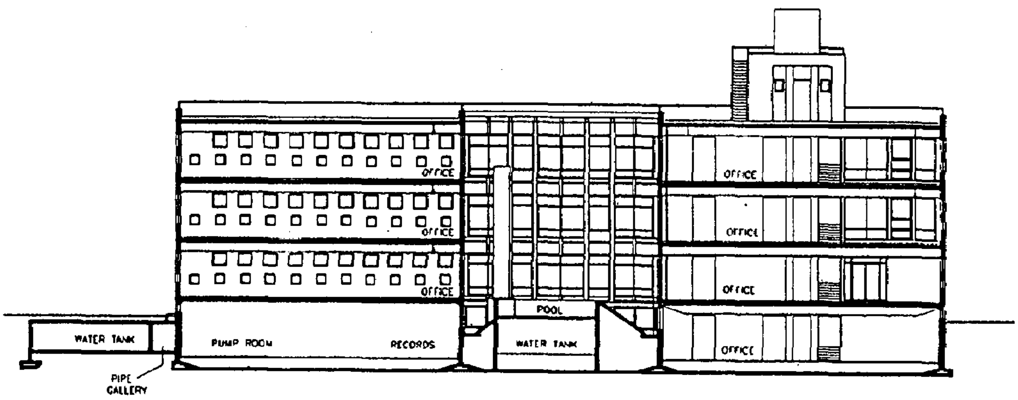
CHAPTER 5

CASE STUDIES

5.1. TRANSPORT CORPORATION OF INDIA LTD., GURGAON.

Although this is an air-conditioned building, it attempts an interactive interface with the external environment to achieve greater energy efficiency. The external skin is treated as a solid insulated wall with peep windows for possible cross-ventilation and higher windows for daylight. Selection of materials and system of environmental control is prioritized in favor of sustainability and efficiency in energy consumption.

The building has three stories of offices and a basement surround the central court. The basement houses building services and some work spaces too.



SECTION

FLEXIBILITY OF THE PLAN.

The entire building plan is based on a planning grid of 1.4m x 1.4m which coordinates the ceilings with air conditioning and light fittings, locations for partitions as well as external windows-to permit a high degree of flexibility in layout for offices

SITE

Landscaping acts as a climate modifier.

ENERGY SAVING FEATURES.

__Exposure:__ The building adopts a compact rectangular form and a minimum height above the ground to limit exposure to the external conditions.

- *Openings*

On the external walls are designed for two separate functions. The small peep windows at seating height provide for possible cross-ventilation and views outside the small peep-windows, due to the deep reveal in which they are set, allow insolation. In winter, cutting out the mid-summer sun by the shade of the reveal onto the glass. The larger windows at ceiling level are designed to distribute glare-free daylight across the office floor. They house adjustable venetian blinds in a double-window sandwich. The blinds are to be adjusted seasonally (three times a year) by the building maintenance staff to control direct insolation and to reflect light towards the ceiling for distribution into the office spaces. Taking the daylighting function into account, the window area is minimized to 18% of the external wall area.

- *Shading devices*

Both the entrance forecourt and the central fountain court, towards which the building envelope opens out with greater transparency, have a structural framework which would provide support for shading screens to be stretched and gathered according to seasonal demands. The structural frameworks enclosing the courts provide the necessary support systems for the screens

- *The planting*

The planting scheme along the edges of the site with tall evergreen (silver oak) trees provides another protective layer for the building.

Heat transfer

- *Wall and roof*

The wall is, a heavy mass construction insulated form the outside. Wall insulation is 25-mm thick polyurethane foam protected by a dry red-stone slab cladding system. The roof insulation is 35 mm thick and has a reflective glazed tile paving cover to minimize sol-air temperature on the roof surface.

- *Windows*

The daylight windows provide insulation by way of tight-sealed two layers of glass with a venetian blind installed between the two layers.

The glazing panels around the inner courtyard, however, are single glazed-it is expected that with the tall water fountain working the courtyard temperatures would shift substantially towards wet bulb temperature. This would considerably reduce heat load for the courtyard side during summers and would act as a heat sink during summers, and would act as a heat sink during spring and autumn.

- *Fountain court (Evaporative cooling)*

The fountain is a re-circulation system in which a large body of water flows over extensive surfaces to maximize evaporation. The tall solid concrete columns of broad diameters over which the water trickles down the height of the courtyard, and the thin sheet that overflows the sides of the pool at ground level, create a large heat sink and a body of air close to wet-bulb temperature. The white marble sides of the tank reflect the courtyard light into the basement work areas.

Absorption technology for air conditioning

After a careful cost-benefit study, an absorption system chilling plant has been installed. Which will not contribute to ozone depletion because of the CFC absence.

Air distribution

Each of the office floors is served with two air handling units on the east and the west to respond to the peak easterly and westerly sun exposures in the morning and the afternoon respectively.

Lighting

- *Daylight Illumination*

Daylight is the primary source of illumination. All workspaces receive adequate daylight, the maximum distance of a workstation from the daylight source being 5m. The high windows on the external walls are designed to throw daylight deep into the office space. Which is varied seasonally by adjusting Venetian blinds installed in the window sandwich to control glare and modulate distribution. On the courtyard side, fabric screens would be stretched over the structural frame to respond to each season.

- *Energy efficient lighting technology*

High efficiency compact fluorescent luminaries at 19 watts per square meter area are used in the interiors.

Height.

Restricting the building height to three storeys was a deliberate choice. With maximum ground coverage, this pattern of planning consumes the total permissible FAR with the least possible building height. The advantages of this are

- The compactness due to reduced height minimizes heat transfer through vertical surfaces of the external skin.
- Energy consumed in vertical transport during construction and occupancy are reduced
- Energy consumed to transport water and diesel to the A/C plant on the roof is minimized.
- A major gain is being able to eliminate the necessity of lifts. Only one six-passenger elevator is provided for disabled or ill people and special guests.

MATERIALS.

Embodied energy.

- Local material

The criteria for choice of materials was that the material should be chosen from the nearest possible source. For office areas, floors are made up of pre-polished granite from Jhansi (the nearest source to Delhi) and for the service areas it is the Kota Stone.

- Less energy intensive

The other criteria was for materials with minimum processing towards converting or installing it. The external cladding is undressed split red Agra sandstone with pre-cast concrete and terrazzo sills and jambs.

- Recycled

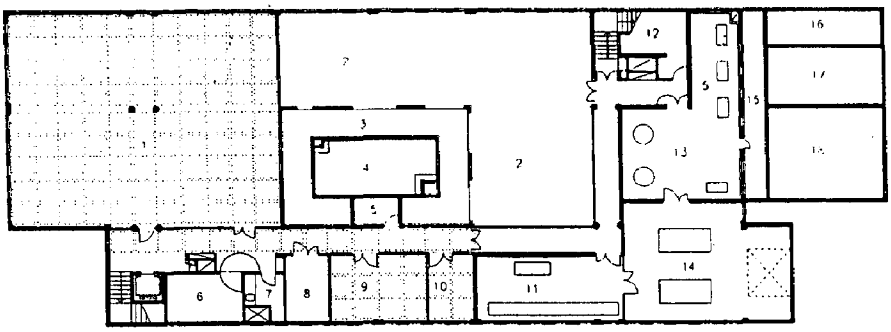
A sound example of how a relatively useless material could be judiciously used is demonstrated in the building, as the roof top is finished with broken white mosaic pieces, that can reflect the solar radiation.

WATER.

A project is underway to construct a bore hole in the compound to return rainwater to the ground water reserve, so that the ground water will be replenished and not depleted.

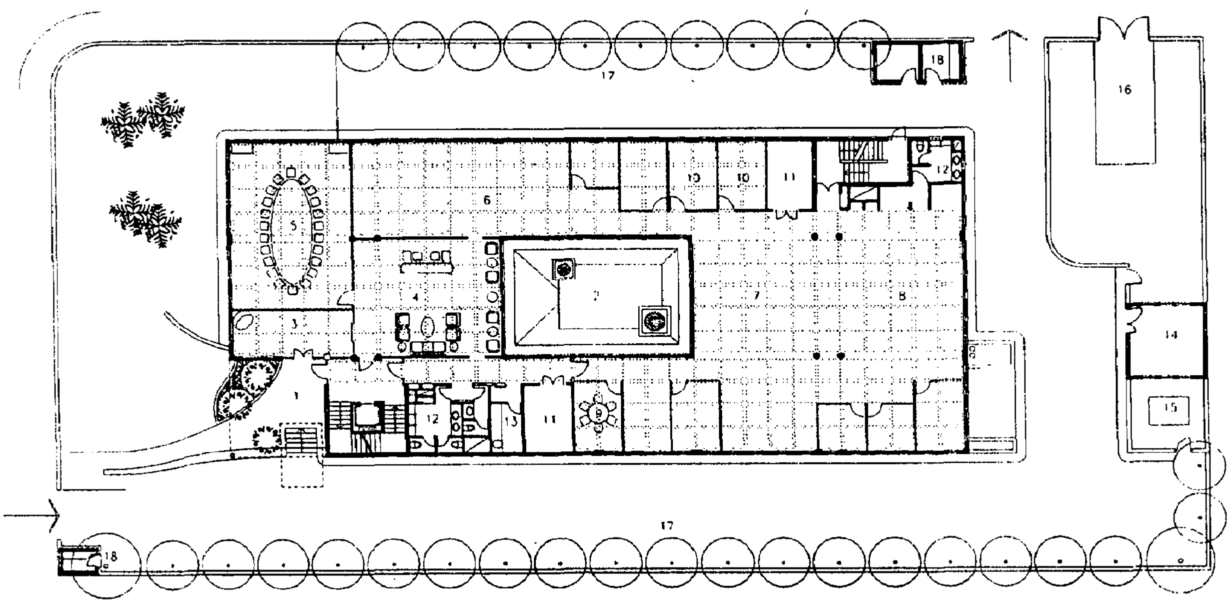
INDOOR AIR QUALITY (IAQ)

The building achieves good indoor air quality due to the complete absence of carpeting that is considered to be one of the main causes for poor indoor quality, as it encourages the growth of microorganisms, that can easily get carried in the air and move from one place to the other.



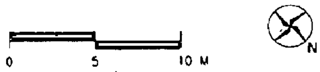
1 OFFICE
2 RECORDS
3 STORE
4 WATER TANK
5 PUMPS
6 STORAGE ROOM
7 PANTRY
8 AHU
9 GYMNASIUM
10 SECURITY
11 ELECTRICAL PANELS
12 UPS
13 SOFTENING PLANT
14 GENERATORS
15 PIPE GALLERY
16 SOFT WATER TANK
17 DOMESTIC WATER TANK
18 FIRE TANK

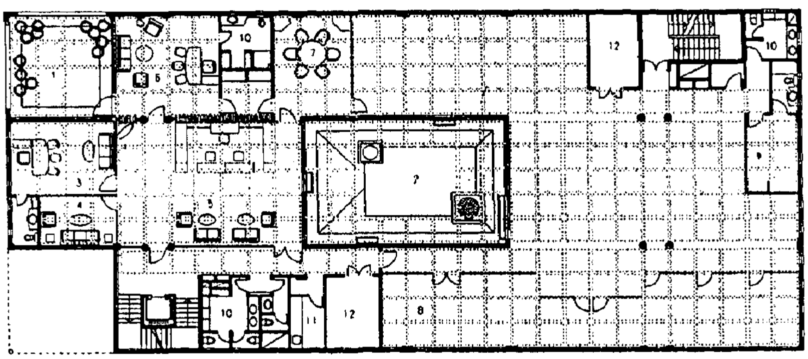
BASEMENT PLAN



1 ENTRANCE COURT
2 FOUNTAIN COURT
3 LOBBY
4 RECEPTION
5 CONFERENCE
6 INFORMATION TECHNOLOGY
7 H.R.D.
8 X.P.S.
9 MEETING
10 SERVER
11 AHU
12 TOILET
13 PANTRY
14 HT PANEL
15 TRANSFORMER
16 FUEL STORAGE YARD
17 PARKING
18 GUARD'S ROOM

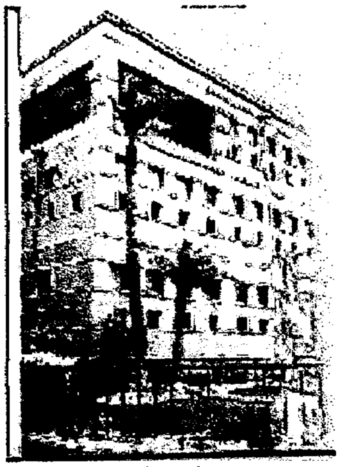
GROUND FLOOR PLAN



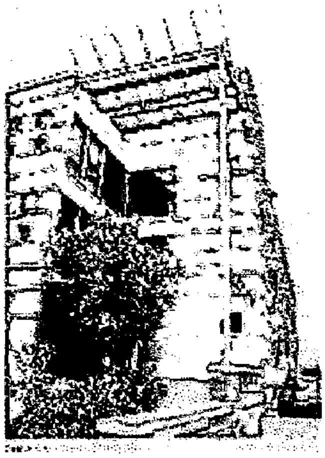


1 TERRACE
2 COURT
3 DIRECTOR
4 LOUNGE
5 SECRETARIAT
6 MD
7 MEETING
8 LIBRARY
9 GUEST ROOM
10 TOILET
11 PANTRY
12 AHU

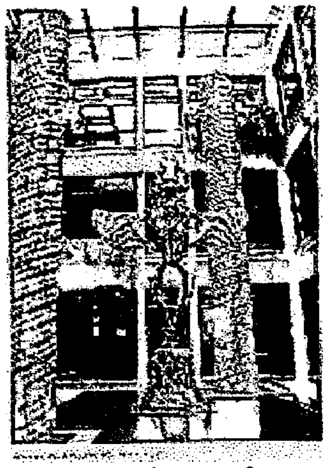
FIRST FLOOR PLAN



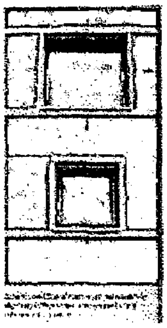
Exterior view



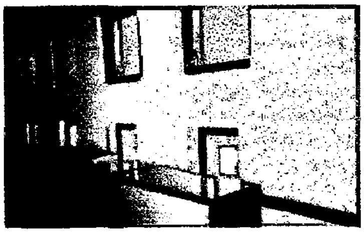
Entrance



Fountain court for evaporative cooling

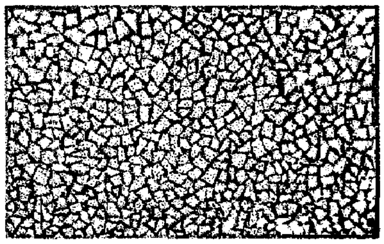


High and low window from Outside

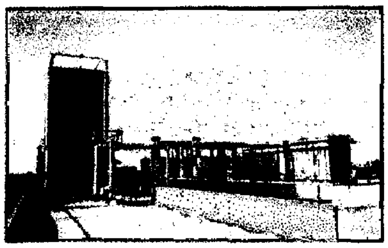


Windows from inside (Office space)

Ample daylighting even in the basement, using sloping ceiling

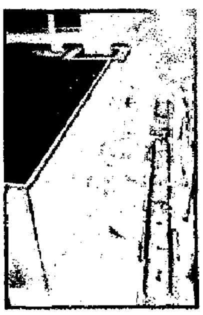


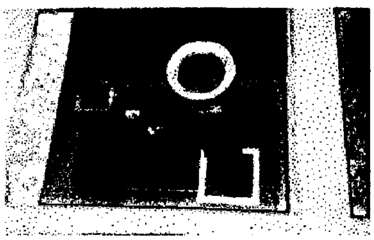
Reuse of salvage material (Broken ceramics, for reflecting material on the roof)



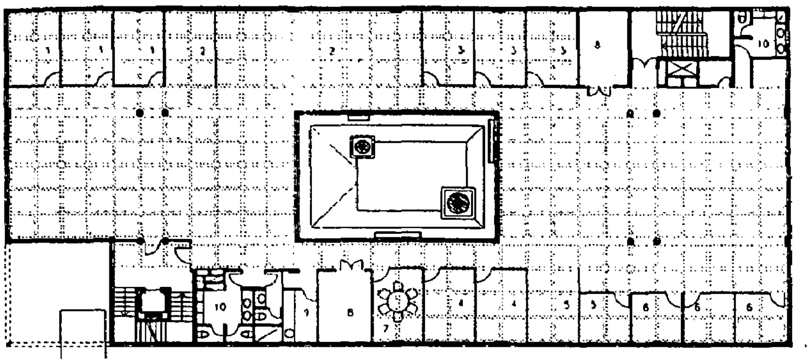
CFC free energy efficient air-conditioning. Placing it on the top gives room for basement use

Climate modifying landscape.





Increasing surface area for evaporative cooling



1 AUDIT
2 ACCOUNTS
3 FINANCE
4 MANAGEMENT
5 LOGISTICS
6 OPERATIONS
7 MEETING
8 AHU
9 PANTRY
10 TOILET

SECOND FLOOR PLAN

5.2. THE RESEARCH INSTITUTE OF INNOVATIVE TECHNOLOGY FOR THE EARTH (RITE) (JAPAN)

1. Basic Data

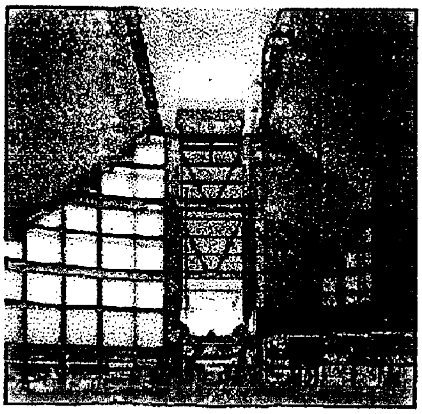
Location	9-2 Kizugawadai, Kizu-cho, Soraku-gun, Kyoto, Japan (at the centre of Kansai Science City)
Site area	40,274 m^2
Building area	3,449 m^2
Total floor area	6,922 m^2
Building height	Highest point 20 m
Major functions	- Research and experiment zone: 4,300 m^2 - Administration and service zone: 1,800 m^2 - Atrium zone: 800 m^2
Structures	Reinforced concrete (partly steel structure)
Finishing	- Roof stainless steel sheet (seamless application) finished by fluorine contained resin coating - External wall ceramic tiles
Construction period	August 1992 to July 1993
Completion	July 1993
Architect/Engineer	Nikken Sekkei Ltd
Construction supervison	Nikken Sekkei Ltd
Construction work	Joint venture of Obayashi Corporation, Taisei Corporation, Takenaka Corporation, Kajima Corporation and the Shimizu Construction Co., Ltd.
Heat source	Air cooled heat pump chiller and gas-burnt absorption type water chiller/heater, heat storage tank, heat storage with building structure
Power supply	Main electric room 700 kVA; sub-electric room 800 kVA
New generating equipment	Solar photovoltaics, fuel cells

2. Design Features

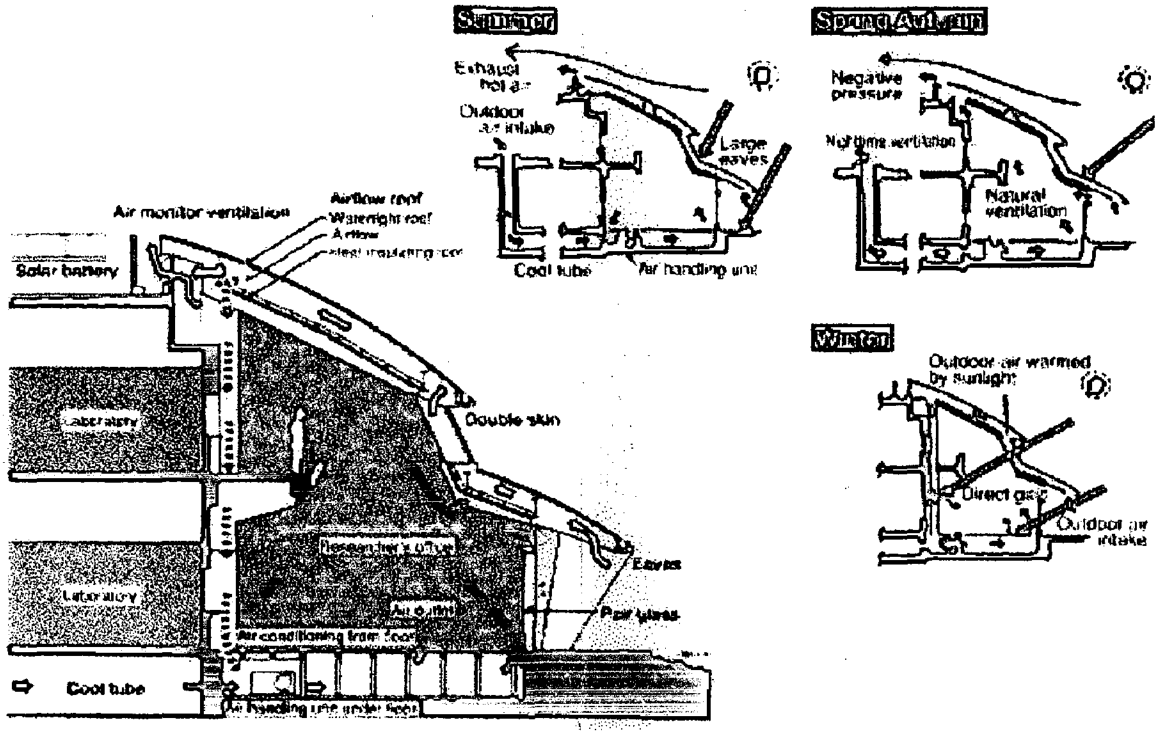
The Research Institute of Innovative Technology for the Earth (RITE) is an international research center for global studies of the environment. Its headquarters building was designed to be as environmentally friendly and efficient as possible to harmonize with RITE's objective of developing technologies to protect and nurture the environment. A number of energy saving methods have been employed.

Control of heat and sublight	Semi-buried structure	To utilize thermal insulation and constant temperature nature of the earth to reduce thermal loads on external walls
	Eaves	Large eaves to block direct solar heat gain in summer
	Double skin	Multi-layer glazing and double roof to ensure high thermal resistance
	Under-floor air-conditioning	Reduced air-conditioning cooling loads for habitable areas
Communication with nature	Air monitor ventilation	Air monitors to enhance ventilation effectiveness (by CO_2 concentration measurement)
	Air flow roof	Outdoor air is warmed in a double roof (which is warmed by sunlight) and then taken into the building for heating in winter
	Cool tube	Outdoor air is cooled in an underground pit (which is cooled by the low temperature of the earth) and then taken into the building for cooling in summer
Efficient use of energy	Heat storage by building structure	Surplus heat is stored in the building structure to reduce air-conditioning starting load
	Utilization of large temperature difference	Hot and chilled water is used in large temperature difference
New energy system	Solar photovoltaics	50 kW solar photovoltaic panels (total area 427 m^2) are installed on the roof of atrium (87 m^2) and laboratory (340 m^2)
	Fuel cells	50 kW town-gas powered fuel cell are installed

2.1. Sunlight



Size and angles of large eaves and window pane materials are selected for optimum thermal efficiency and to enable sunlight to deliver as much of the building's various lighting requirements as possible. Solar photovoltaic panels of total capacity 50 kW are installed to meet 2.5% of total power demand.



2.2. Wind

In summer, large eaves will shade out the strongest sunlight, and the fresh intake air for the air-conditioning system will be taken from a underground pit that remains cool through contact with the earth. In winter, the fresh intake air for the air-conditioning system will be taken from the ceiling space, which is warmed by sunlight. This results in energy savings equivalent to 10% of outdoor air load.

2.3. Water

The building is located on an open hill. Taking advantage of the sloped site, a system was adopted in which rain water collected on site is subsequently recycled and circulated in the springs, brooks, waterfalls and ponds created around the building. The result is a landscape as restful as it is beautiful. The collected rainwater is used as cooling water for the air-conditioning system and then recycled for use in flushing toilets or it is circulated with the within the site for purification by natural filtration. This improves the efficiency of heat pump unit by 20% and reduces city water consumption by 20%.

Exhaust heat from the air conditioning system is transferred to water and discharged into a brook, where it is naturally cooled. This "cooling river" system significantly cuts down the energy consumed for air conditioning. This provides further evidence that running water is valuable not only for creating a cool atmosphere but also for the more practical reason of energy conservation.

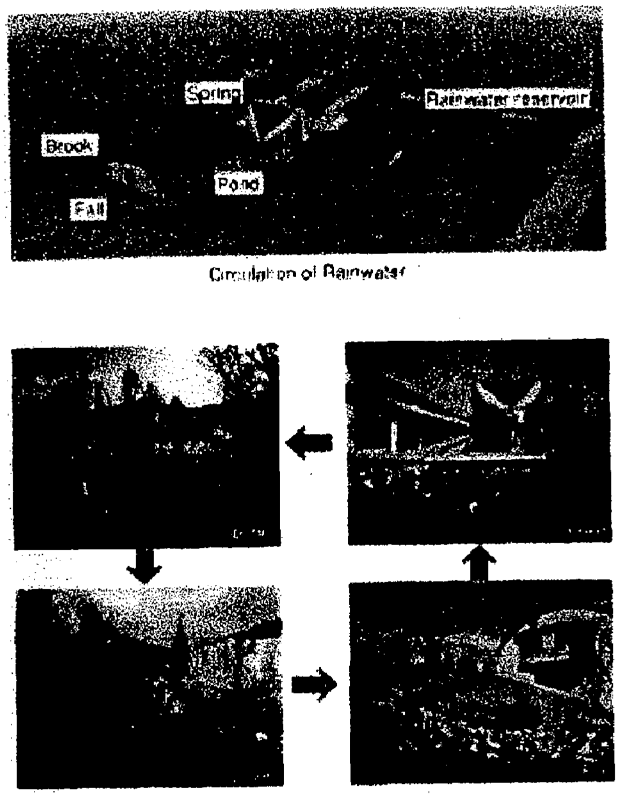


Fig. Circulation of rainwater

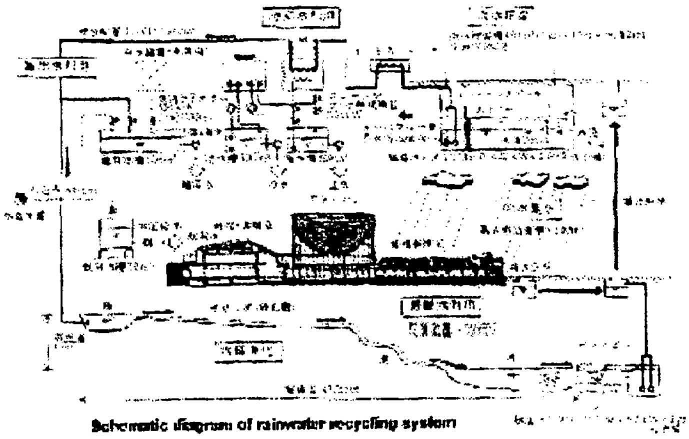


Fig. Schematic diagram of recycling

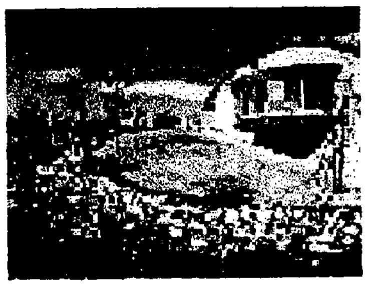


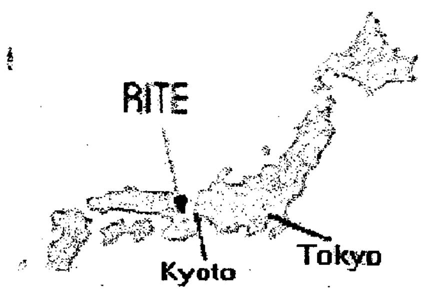
Fig. Water fall.

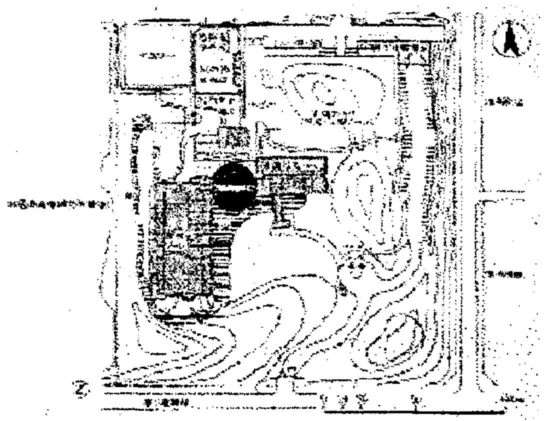
2.4 Fuel Cells

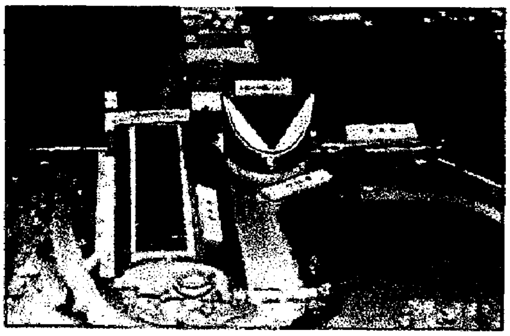
Fuel cells, developed originally for space vehicles, are being explored for their potential in commercial applications as an energy system. They are especially beneficial as urban cogeneration system which supplies both electricity and heat. Fuel cells produce electricity and water by the reaction of hydrogen and oxygen, which is the reverse of water electrolysis. Hydrogen is produced by the natural gas reforming process, while oxygen is obtained from the air. Since electric energy is directly obtained from the chemical reaction of hydrogen and oxygen, electrical efficiency is higher than conventional power generating methods. The specifications of the fuel cell system installed in the RITE headquarters building is given as follows:

Manufacturer	Fuji Electric
Rated power	50 kW AC
Voltage	200/220 V
Electrical efficiency	40% (LHV)
Overall efficiency	80% (LHV)
Heat recovery	90 °C and 55 °C hot water
Fuel	City gas 13A, low pressure
Operation	Grid-connected
Nox	below 5 ppm
Dimensions	1.75 (W) x 3.1 (L) x 2.2 m (H)
Weight	6.5 tons

PICTURES OF THE BUILDING







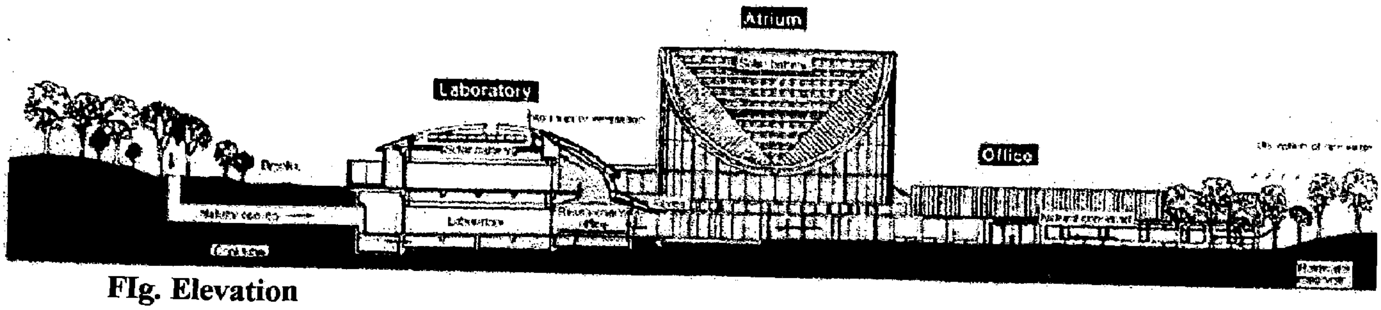


FIg. Elevation

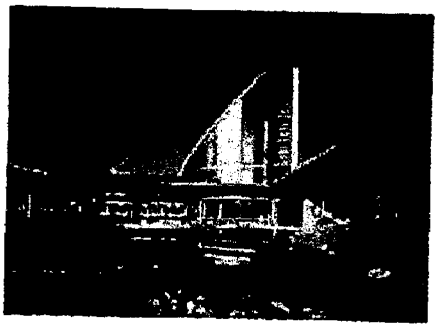
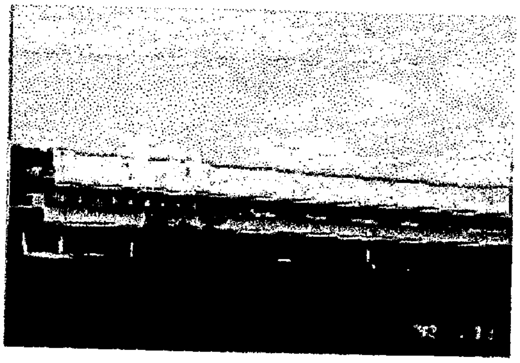
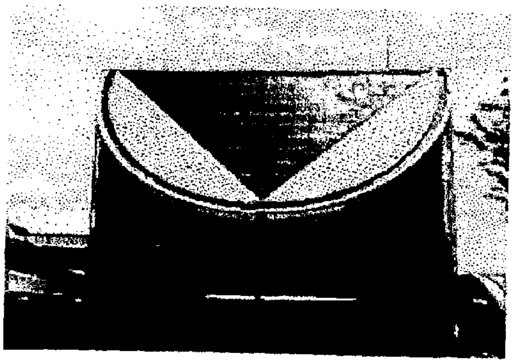
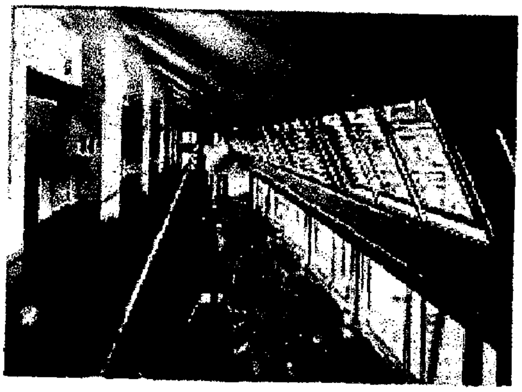


Fig. Building with the water feature.

DESIGN FOR SUNLIGHT (ACTIVE AND PASSIVE).







5.3. THE ENVIRONMENTAL BUILDING, U.K.

Project background

The environmental building at Garston has been built as a demonstration building for the energy efficient office of the future (EOF) performance specification, drawn up by a number of companies representing the manufacturers, designers and installers of building components and the fuel utilities, as part of the EOF projects. A key part of this specification is the need to reduce energy consumption and CO2 emissions by 30% from current best practice. Air conditioning is not used in the new building-the major energy consumer in may office buildings.

Ventilation and cooling.

At the south side there are five ventilation shafts that are acting as solar chimneys for natural ventilation and cooling. They are assisted by low energy fans at the top of the stacks

- Use of thermal mass and water for cooling.

On a windless days the air is taken from the shady north side of the building, coming in through high-level windows. On warmer or windy days, air is drawn in through passages in the curved hollow concrete floor slabs. Because of its bulk-or thermal mass-the concrete cools the incoming air by absorbing heat from it. Additional cooling can be achieved by circulating cools water through the slab. Cold water is drawn from a 70 meter deep bore hole where the temperature is constantly around 10 Celsius. This is passed through heat exchangers to chill water that is circulated through under floor pipe work. The bore hole water is returned to the ground via a second, shallower borehole, so no water is wasted.

The control systems can open ventilation paths right through the concrete slab to cool it further, storing this 'coolness' for the following day. The exposed curved ceiling gives more surface area than a flat ceiling would, acting as a cool 'radiator', again providing summer cooling without energy-consuming air conditioning.

- Use of water and energy efficient boilers for heating.

Hot water heated by an energy efficient boilers is circulated in the slab, during winter seasons.

Solar Control and daylighting.

The building has a large glass area, to receive the maximum use of daylighting, but it is carefully optimized to provide high light levels but low heat losses and solar gain. This is achieved by movable louvers that move with the position of the sun.

Lighting system.

The office is lit using the latest generation fluorescent light that contain much less mercury (just 3 mg per tube compared to 15 mg in the previous cases)

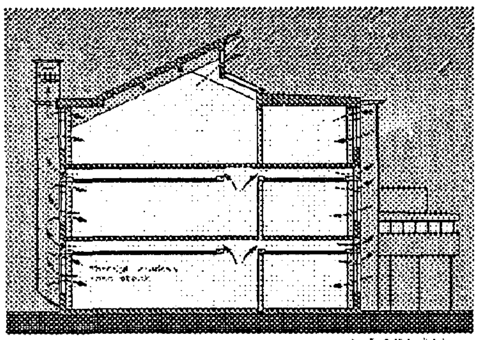
Philips "Helio" sensors fitted into the lighting runs measure the ambient daylighting levels and adjust lamp brightness to suit. Movement detectors in the sensors turn the light off if the local office area is not occupied

Photovoltaics.
A photovoltaic array feeds it's output from the cells into the building's main supply panel via an inverter. It is a building integrated photovoltaic (BPIV) system, that also adds to the aesthetics of the building.

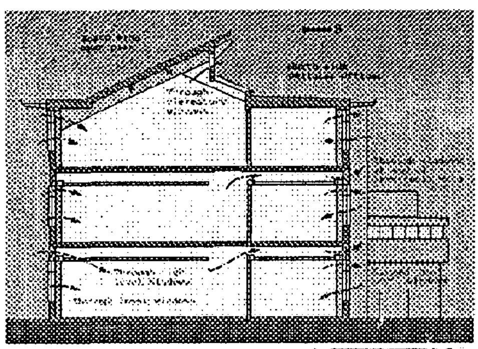
Materials.
The building is the first in the UK to use recycled aggregate in ready-mixed concrete. Recyclers crushed, screened , and graded demolished concrete from a building to supply 20-5mm coarse aggregate for 1,500 cubic meters of concrete.

Other key green features of the BRE building.

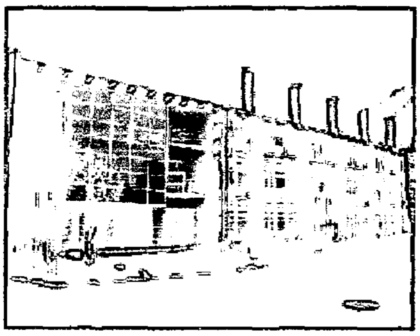
- 80, 000 reclaimed bricks are used.
- 96% of the old building was reclaimed or recycled
- Reclaimed mahogany parquet flooring
- 90% of in-situ concrete used recycled aggregate
- Ground granulated blast furnace slag used in the cement mix
- Timber sourced from sustainable resources are used.
- Low-flush toilets are used.
- Paints and varnishes don't affect the IAQ.



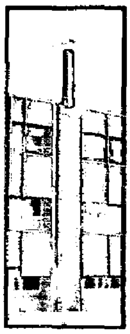
Stack ventilation, hot still summer's day



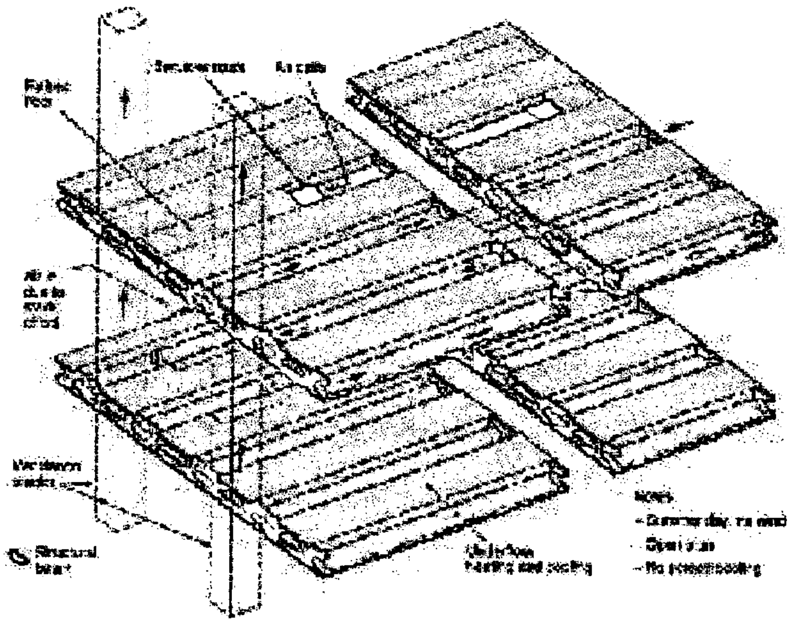
Cross ventilation, windy summer's day



View of the environmental building.

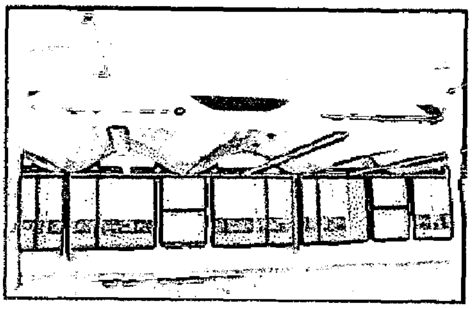


Solar chimney.



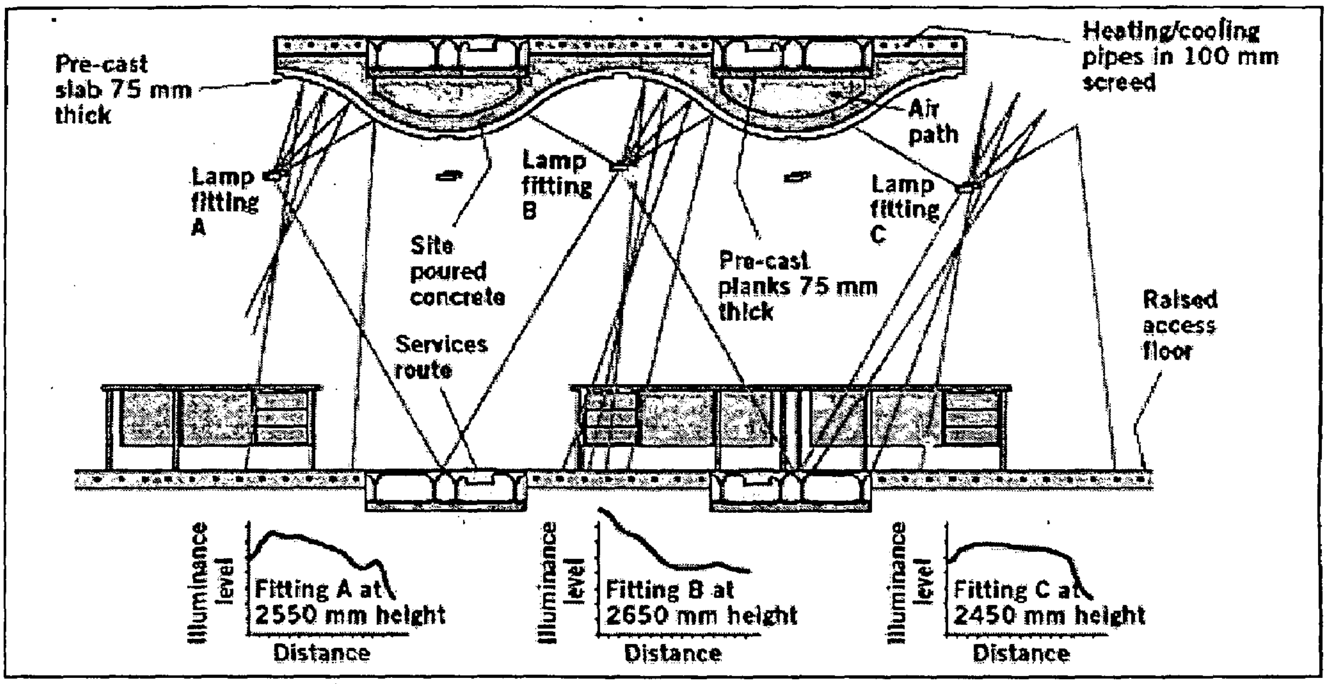
Detail of floors with the incorporated air conditioning systems

Louver detail,



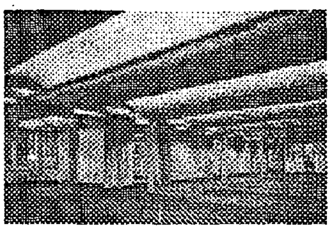
Daylighting and roof construction

THE ENVIRONMENTAL BUILDING LIGHTING

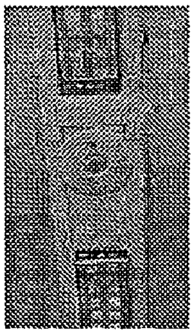


Lighting

A fully integrated, intelligent and efficient lighting system has been installed which automatically compensates for daylight levels and occupancy, controlling each light separately.



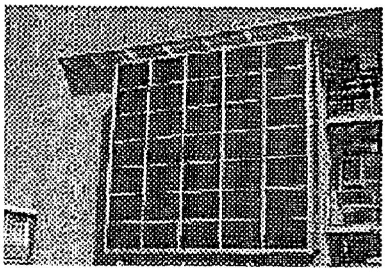
Electric lighting is provided by a highly efficient and fully controllable luminaire system



Three-way sensor for the lighting system provides daylight and occupancy level sensing and a receiver for an infrared controller

Photovoltaic array

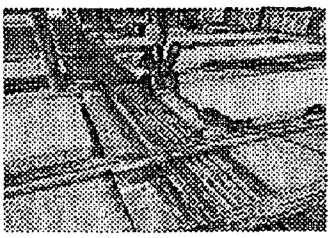
The 47 m² Building Integrated Photovoltaic (BIPV) array incorporated in the Environmental Building provides non-polluting electricity directly to the building. Utilising thin film amorphous silicon cells, the array seeks to explore issues associated with the integration of photovoltaics into vertical walling, building on previous demonstration installations within the UK.



The south-facing photovoltaic façade

Night and groundwater cooling

Air-conditioning has been avoided by exposing the ceiling slab. The slab absorbs heat during the day and is cooled down by ventilation at night. Pipes embedded in the floor can provide additional cooling utilising groundwater.



Low-energy cooling. Underfloor pipework cools the floor slab using groundwater

4. RETREAT: Resource Efficient TERI Retreat for Environmental Awareness and Training, Gurgaon

RETREAT is a part of TERI's Gual Pahari, Campus, about 30 km south of Delhi, in the state of Haryana. Built as a model training complex, RETREAT demonstrates many of the principles of green architecture. It demonstrates efficient utilization of energy, sustainable and integrated use of both natural resources and clean and renewable energy technologies, and efficient waste management.

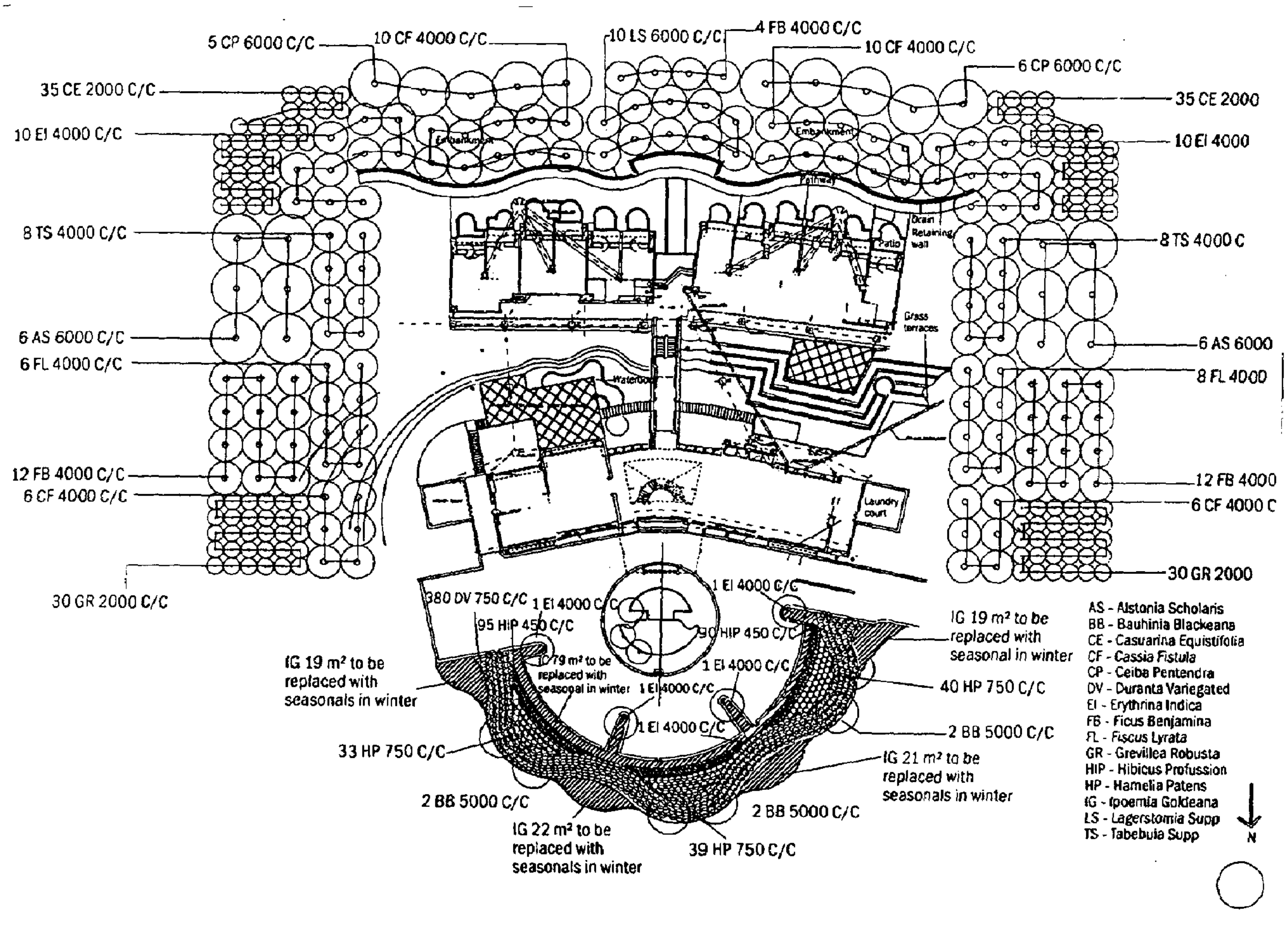


Fig. The RETREAT building has decidious trees on the south side to cut off summer gains. These trees shed leaves during winter so that winter gains are not cut off. Wind breaks are provided in the north and notrh-east to protect from winter winds.

Summary of the RETREAT BUILDING

Design features

Orientation, insulation, and design of the building

- Wall insulation with 40-mm thick expanded polystyrene and roof insulation using vermiculite concrete (vermiculite, a porous material, is mixed with concrete to form a homogenous mix) topped with China mosaic for heat reflection.
- Building oriented to face south for winter gains; summer gains offset using deciduous trees and shading.
- South side partially sunk into the ground to reduce heat gains and losses.
- East and west walls devoid of openings and are shaded.

Earth air tunnel for the south block

- Four tunnels of 70-m length and 70-cm diameter each laid at a depth of 4 m below the ground to supply conditioned air to the rooms.
- At a depth of 4 m below ground, temperature remains 26 °C (in Gurgaon) throughout the year.
- Four fans of 2 hp each force the air in and solar chimneys force the air out of rooms.
- Assisted cooling by air washer in dry summer and a 10 TR dehumidifier in monsoon.

Ammonia absorption chillers for the north block

- Gas-based system with minimal electrical requirement (maximum 9 kW).
- Chloroflurocarbon-free refrigerant (ammonia).

PV-gasifier hybrid system

- 50 kW gasifier and 10.7 kWp solar photovoltaic
- Generates producer gas (containing methane) which runs a diesel generating set with 70% diesel replacement.
- 1 unit of electricity produced needs 1 kg of biomass and 90 ml of diesel.
- 900 amp-hours batteries at 240 V.
- 36 kVA bi-directional inverter.
- Load manager controls and manages loads

Solar hot water system

- 24 solar water heating panels (inclined at 70 degrees instead of 45 degrees) integrated with parapet wall.

Lighting

- Lighting load 9 kW (reduced from a minimum of 28 kW in a conventional building).
- Lighting provided by compact fluorescent lamp, high efficiency fluorescent tubes with electronic chokes.
- Lighting controls to reduce consumption (timers, key-tag systems).
- Innovative daylighting by means of skylights.

Waste water management system by root zone system

- Cleans waste water (5 m^3/day) from toilets, kitchen, etc.
- A bed of reed plants (phragmytes) treat the water and the output is used for irrigation.
- The plants take up nutrients from the water and thrive on the same, in the process cleaning the water.

Building management system

- Monitors building parameters (temperatures, humidity, consumption, etc.)
- Monitors electricity generated from each source
- Decides on load-sharing and load-shedding to optimize energy usage
- Records at regular intervals

Fig. North view of the retreat

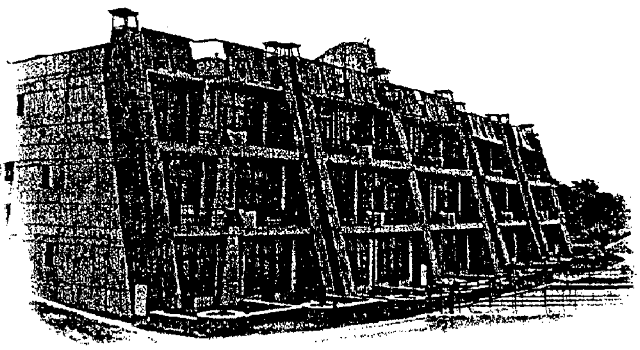


Fig. South view of the building showing solar water heating panels and solar chimney.

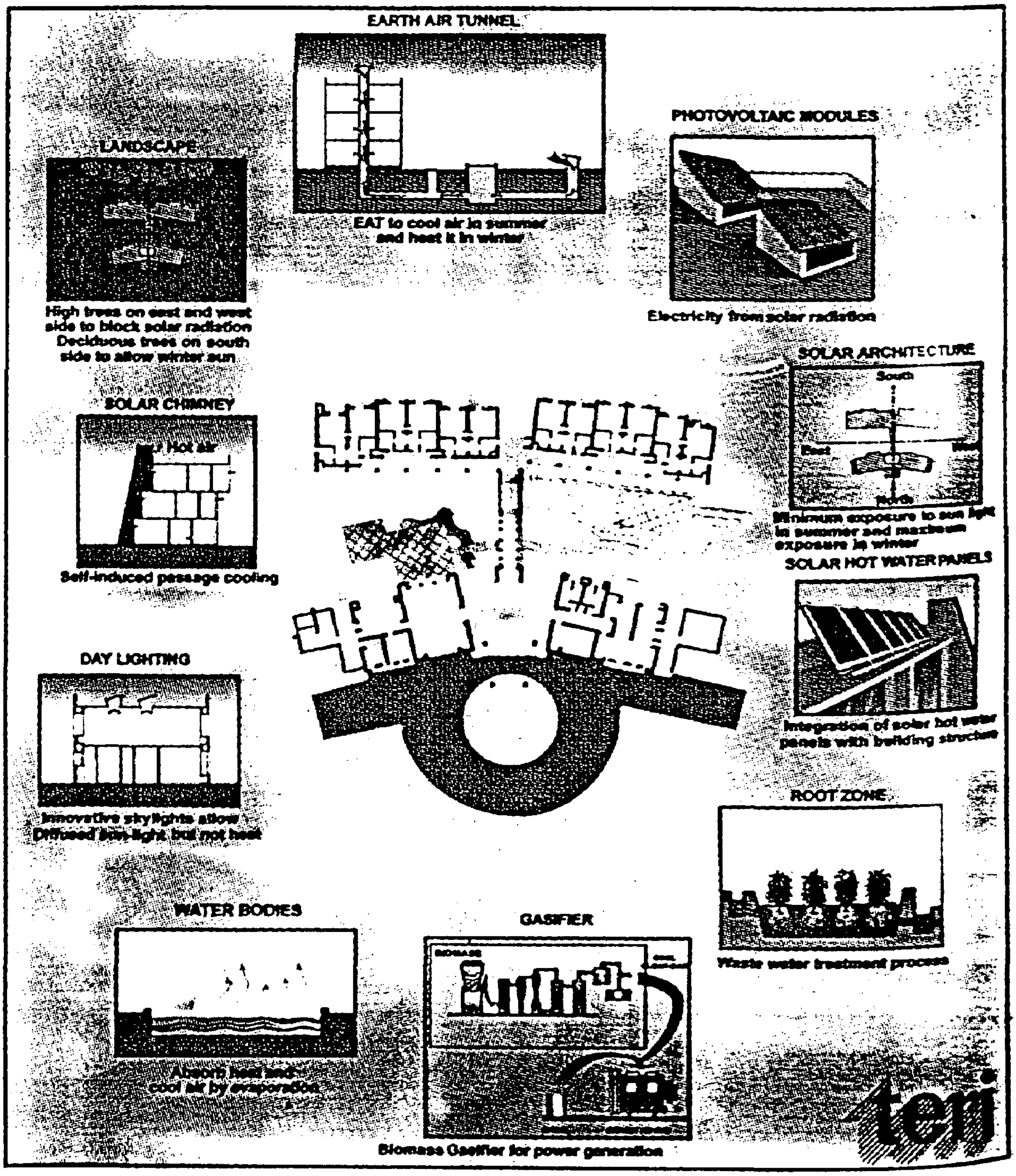


Fig. Schematic diagram showing use of passive solar architectural principles, use of renewable energy resources and waste and water management in RETREAT

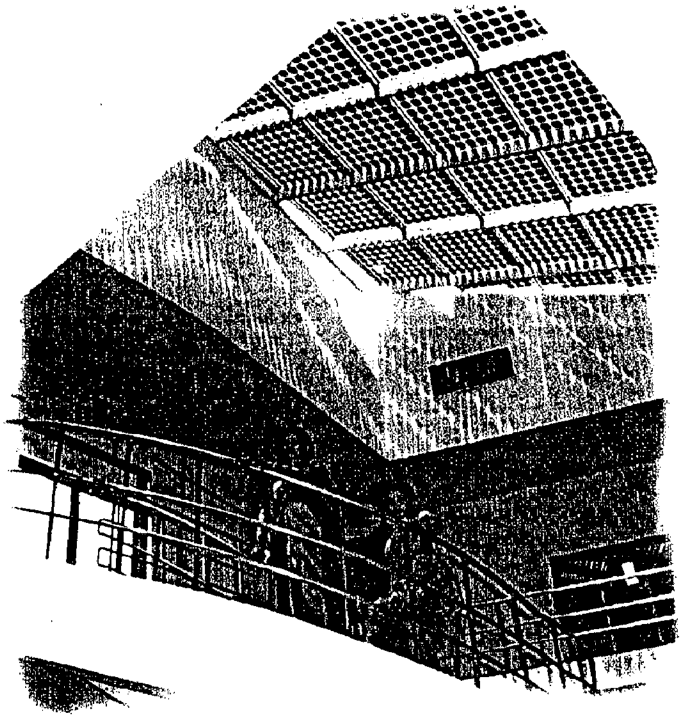


Fig. The sun is the powering force of RETREAT, where solar panels are used to form a 'solar roof'

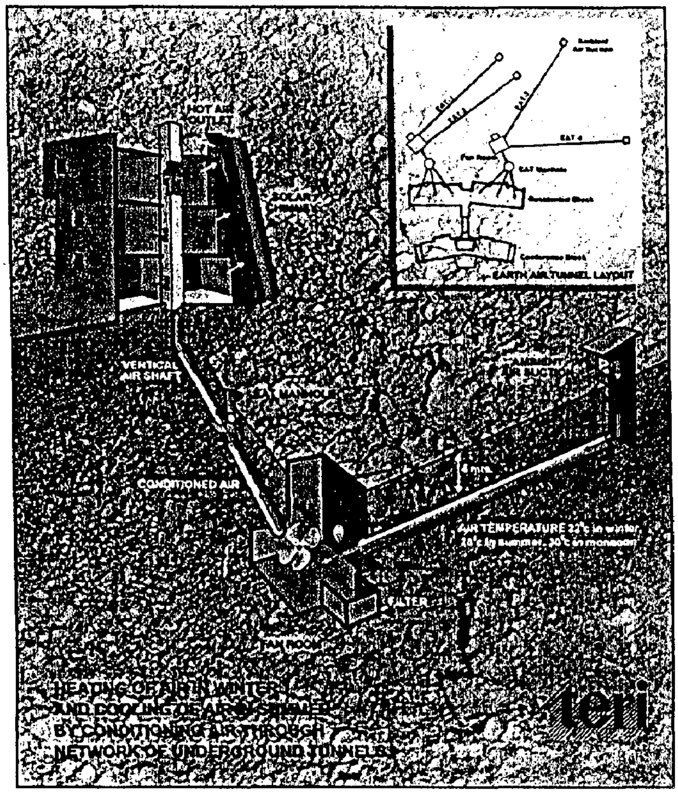


Fig. Passive space-conditioning using earth air tunnel system.

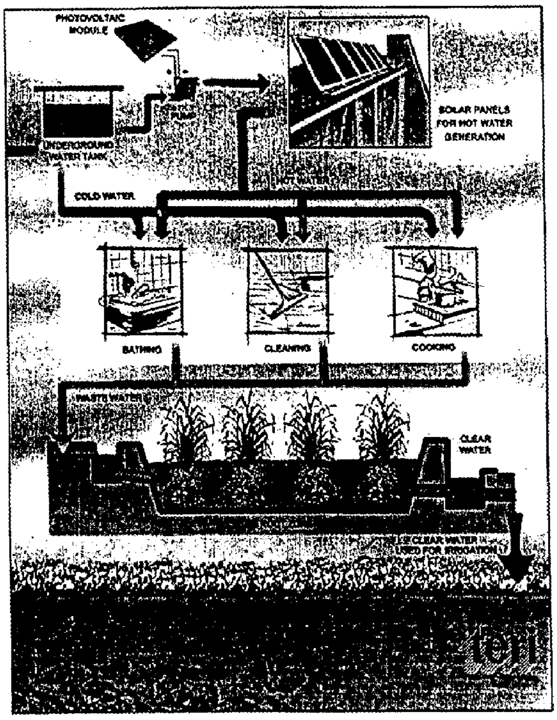


Fig. Water and waste management system

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

CONCLUSION.

Analyzing the different sections of green architecture will arm the designer with a number of profound means' to tackle the problem of designing with the environment. But however knowledgeable the architect is in terms of understanding the elements of green architecture, it will avail him less if he doesn't integrate the parts into a whole and cooperate with other professionals to achieve the integrated approach of designing green buildings which essentially is doing the best with the least impact upon the environment. Less is more is still the paradigm in green architecture.

RECOMMENDATIONS

The following recommendations are first formed on the basis of the specific green features discussed and finally on the way they are supposed to be synergistically integrated to bring about the holistic design.

Siting and orientation (including transportation issues)

- Protect topsoil and trees during sitework. The topsoil is an invaluable natural material therefore it has to be protected by removing it and keeping it in a safe vicinity. Trees must be protected from damage during construction by fencing them off.
- Design foundational construction details that avoid pesticide treatment. Pesticides could leach into the groundwater. Look into less toxic termite treatments, and make use of physical barriers.
- Design a mixed use development with access to mass transit use. Locating complementary occupancies within a project eliminates the need for many automobile trips, encouraging biking and pedestrian movement which avoids the multidimensional menaces created by the automobile.

- Encourage pedestrian and bicycle use. Design streets that are safer and attractive for pedestrians and cyclists.
- Optimize orientation. When feasible, site a building to optimize solar orientation and access prevailing breezes. Locate more of the windows on the south (Northern hemisphere), than other orientations. To minimize cooling loads in buildings, reduce the area of windows on east and west facades.
- Make use of existing vegetation and topography for natural ventilation.
- Design the landscape with minimum impervious paved surfaces. This is extremely important to decrease surface runoff that is polluted specially in parking spaces. Natural and pervious landscape filters storm water that will eventually replenish the ground water.

Energy efficient design

- Specify materials with low embodied energy.
- Consider climate responsive passive building design. Take advantage of the possibilities offered by the microclimate of the project site, to make use of the prevailing wind, the solar radiation, natural and manmade landscape features to come up with a passive building design that extensively cuts dependency on non renewable energy resources.

  Climate responsive design can reduce the size and amount of electrical lighting, heating and cooling equipment.
- Incorporate passive heating/cooling technologies. Passive systems cost little but enhance the efficiency of the building and result in capital saving.
- Install energy efficient HVAC. Capital savings from judicious green design of the building can be applied to purchasing more efficient electrical equipment, such as transformers and motors.
- Enhance the indoor climate with architectural features. Architectural features like windows, shading devices, thermal walls, configuration of interior spaces and color can enhance the indoor climate that will cut energy demands
- Specify energy efficient lighting technology.

- Model the building. During design, model the energy performance of a building so that mechanical systems can be optimized. Conventional practice is to oversize HVAC equipment, which wastes a lot of energy.
- Practice integrated approach for energy efficiency. Analyze all the elements of technical installations, building fabric and climate synergistically to see any interdependence for economy and energy conservation.

Material management

- Choose building materials with low embodied energy. Heavily processed or manufactured products and materials are usually more energy intensive. As long as durability and performance are not sacrificed, choose less energy intensive materials.
- Specify locally produced building materials. Transportation is costly in both energy use and pollution generation. Look for locally produced materials.
- Specify materials made with industrial wastes. Materials like fly ash can be intensively used in concrete and mortar that can reduce energy consumption, and solid waste problems.
- Specify materials from recycled sources. Building materials from recycled sources reduce energy consumption, resource depletion, and reduce solid waste problems.
- Specify materials from agricultural wastes. Building materials like particleboards made from straw contribute to reducing energy and resource depletion.
- Specify certified wood products. Use lumber from sustainably managed forests, and avoid lumber products produced from old-growth timber forest and tropical hardwoods since they can't replenish themselves fast.
- Specify materials that don't release pollutants into the building. Solvent-based finishes, adhesives, carpeting, particleboard, and many other building products release formaldehyde and volatile organic compounds (VOCs) into the air. These chemicals can affect workers' and occupants' health.

Water management

- Look into feasibility of greywater. Water from sinks, showers, or clothes washers can be recycled for irrigation, flushing systems and can be used in any evaporating cooling strategy.
- Design rainwater harvesting system. Rainwater collected from roofs can supplement water for internal or external uses such as irrigation.
- Use xeriscaping practices. In areas with low annual precipitation and areas that are prone to droughts, provide xeriscaping (dry-adapted plantings) to obviate the need for irrigation systems and more expensive plantings.
- Specify water efficient sanitary and other water using machines. Much of the water used in buildings is used to flush toilets. Using low flush toilets and other water miser machines will economize the use of water which is always scarce on the planet.
- Use active solar systems for service water heating.
- Properly insulate hot water pipe and plan the plumbing so that the shortest possible length of pipe runs from the water heater to each hot water using device or tap.

Waste management

- Design aerobic or anaerobic sewage treatment systems. These will lessen the environmental impact of unsustainable centralized sewer systems, and hence decrease the pollution caused by the same. Moreover, the compost and biogas from anaerobic systems can supplement energy demands, specially in developing countries.
- Consider the generation of energy from landscape waste composting. Landscape waste can produce various forms of energy including heat energy. Besides, it replenishes the soil with the compost.
- Avoid construction waste through judicious design of standardized details.
- Specify reuse of salvaged materials, where appropriate.
- Design for flexibility. Flexibility will reduce the amount of waste material that is produced due to the configuration of various functional spaces.
- Handle hazardous materials separately in demolition sites. Hazardous materials like lead based materials and asbestos etc... should be handled with care and should not be considered for recycling.

Indoor environment

- Specify materials that don't release pollutants into the building. Solvent-based finishes, adhesives, carpeting, particleboard, and many other building products release formaldehyde and volatile organic compounds (VOCs) into the air. These chemicals can affect workers' and occupants' health.
- Design the HVAC system to avoid standing water, which are sources of bio contaminants. Detailing of coils, drain pans, humidifiers and cooling towers must be studied to avoid standing water.
- Isolate combustion chambers from occupied spaces. Sealed combustion chambers can be used for this purpose.

Design process

- Integrate the design process. Integrated building design can often result in first cost savings. But strategies that keep first-costs, may not be in the best long-term interest of the client. Therefore integration of inputs from various designers is essential. This is certainly the case with energy design, but savings can also be achieved in other areas of building design through careful integration. For example, including the general contractor in early discussions with the architect and engineer may identify ways to streamline the construction process.
- Perform life cycle cost assessment. Life cycle cost assessment is especially valuable when selecting equipment with large capital costs and long operational lives. New computer software are available that make it easy for designers to optimize equipment choices with life cycle cost assessment, for both initial and long-term savings.

Policy

- Evolve local or national green design rating systems. This helps in promoting awareness about the practice of holistic green design to the various professionals involved in the construction sector and the public so that architecture is practiced in an environmental responsive manner.

GLOSSARY

1. **Biocontaminants:** Biological contaminants like, bacteria, fungi, and molds that are some of the most potentially dangerous indoor air pollutants that typically grow best in warm, dark, moist environments, which have a ready source of nutrients such as dust and dirt.

2. **Biogas.** Methane gas produced from anaerobic digestion of agricultural wastes , cattle dung , human faeces etc. This gas is used in a number of ways, and predominantly for cooking.

3. **Blackwater:** Waste water generated by toilets, kitchen sinks, and dishwashers.

4. **Building energy audit.** Building energy auditing is the measuring and recording of actual energy consumption, at site, of a completed and occupied building (expressed in units of energy, not monetary value); fundamentally for the purposes of reducing and minimizing energy usage."

5. **CFC:** Chlorofluorocarbon, a chemical compound used as aerosol propellants and the coolants in refrigeration and air-conditioning believed to be responsible for depleting the Earth's diminishing ozone layer and the cause for about 14% of the greenhouse effect.

6. **Compost.** Decayed organic matter such as garden waste or kitchen waste (Not animal products), that can be applied to the soil, to increase the fertility of the soil.

7. **Greywater:** Wastewater produced from baths and showers, clothes washers, and lavatories: that can be used for irrigation

8. **Harvested Rainwater:** Water that is captured form the roofs of buildings that can be used for indoors needs, irrigation or both in whole or in part.

9. **HCFC:** Hydrochlorofluorocarbon, a chemical compound used in aerosol cans which is also replacing CFCs in refrigeration and air-conditioning systems .

10. **IAQ:** Indoor air quality.

11. **Katabatic wind:** A cool mass of air descending down a slope.

12. **Lifecycle Cost.** The economic consequence of the building in terms of initial capital investment and long term operating costs.

13. **Outgassing:** The spontaneous release of gases (often toxic) by a material as it dries out or ages.

14. **Passive Solar Design:** An integrated system of building design and materials that utilizes natural climatic conditions to maintain the internal climate of the building without utilizing additional energy. (Active solar design uses purpose-designed and manufactured systems I addition to the design of the building to make use of solar energy.)

15. **PCM.** Phase Change Materials, that change phase-usually from solid to liquid-when they are heated. They store more heat than stone, brick and water, and are available in tubes or as floor tiles. They are used as thermal masses in building walls.

16. **Photovoltaics:** Solar panels used to harness the suns energy, and turn it electricity that can be stored in batteries and used to power a buildings electrical systems.

17. **Stretched string:** Distance measured from the closest point of the pollutant source to the closest point of the outdoor air intake, window or door opening, or the property line, along a path as if sting were stretched between them

18. **Thermal Mass:** High density components of a building (masonry wall, concrete floor near windows) that store heat to later be released. The higher the conductivity of a material, the greater its capacity to store heat.

19. **Thermosiphon.** Thermally driven convection in a closed circuit. Thermosiphoning systems are common in passive solar design.

20. **U-value.** Coefficient of heat transfer or thermal transmittance with a unit of W/m^2K. The more the U value, the more the thermal transmittance, and vice versa.

21. **Vermiculture.** Composting using worms instead of bacteria.

22. **VOC:** Volatile organic compound. A highly evaporative, carbon-based chemical substance, which produces noxious fumes; found in many paints, caulks, stains, and adhesives.

23. **Xeriscape:** Quality, low-maintenance landscaping that conserves water and protects the environment by using mulch, soil analysis, and appropriate plant selection. Especially in drought-ridden areas

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4. http://www.sustainable.doe.gov/buildings/gbintro.shtml
5. http://www.greenconcepts.com
6. http://www.archrecord.com/conteduc/articles/8_99_1.ASP
7. http://www.buildingreen.com/features/4-5/priorities.htm#2
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9. http://www.usgbc.org/progras/leed.htm#refpack
10. http://www.doas.psu.edu/leed.html
11. http://www.greenbuilder.com/sourcebook
12. http://www.termitebites.com
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APPENDICES

1. SAND BARRIERS FOR TERMITE PREVENTION
2. TEMPERATURE AND HUMIDITY INDICATORS
3. CALCULATING THE ALTITUDE OF THE SUN
4. DESIGN OF SHADING DEVICES
5. SOLAR CHARTS FOR ALTITUDE 0°C-16°C (NORTH AND SOUTH)
6. METEOROLOGICAL INFORMATION SHEET
7. PLANNING A NEW GREYWATER SYSTEM
8. WATER TREATMENT TECHNIQUES
9. COMPARISON OF SEWAGE TREATMENT TECHNIQUES
10. FACTORS AFFECTING IAQ
11. SEPARATION DISTANCES OF VENTILATION OUTSIDE-AIR INTAKES AND POLLUTANT SOURCES.

APPENDIX 1
SAND BARRIERS FOR TERMITE PREVENTION

Author	Locality	Termite	Sand Type	Effective Size
Ebeling & Pence 1957	California	*Reticulitermes hesperus*	sand	approx. 1-3 mm
"	"	"	volcanic cinders	Mesh 6-16 tamped
"	"	"	slag (sinter)	same
Ebeling & Forbes 1988	California	*Reticulitermes hesperus*	sand	10-16 Mesh (1.6-2.5 mm)
"	"	"	sand	6-16 Mesh tamped
"	"	"	sandblast sand	12-16 Mesh
"	"	"	volcanic cinders	10-18 Mesh
Smith & Rust 1990	California	*Reticulitermes hesperus*	decomposed granite	0.84-2.36 mm
Tamashiro *et al.* 1987	Hawaii	*Coptotermes formosanus*	basalt gravel	1.7-2.4 mm
"	"	"	sandblast sand	82% btwn 1.4-2.36 mm
"	"	"	gravel substrates	1.4-2.36 mm
"	"	"	sandblast sand	0.07"-0.09"
Ameron HC&D	Hawaii	*Coptotermes formosanus*	Basaltic Termite Barrier	95+% passing 2.36 mm sieve & <10% passing 1.18 mm
French 1989	Australia	*Coptotermes acinaciformis*	basalt or granite	1.6-2.4 mm
"	"	*Coptotermes lacteus*	basalt or granite	1.6-2.4 mm
E.B. Mawson's	Australia	subterranean termites	granite screenings	100% passing 2.4 mm sieve & 0-6% passing 1.7 mm
Pallaske & Igarashi 1991	Germany	*Reticulitermes santonensis*	glass splinters	0.5-3.5 mm
"	"	*Heterotermes indicola*	glass splinters	0.5-3.0 mm
"	"	*Reticulitermes santonensis*	glass globules	0.8-3.0 mm
"	"	*Heterotermes indicola*	glass globules	0.5-3.0 mm
Su *et al.* in press	Florida	*Coptotermes formosanus*	fossilized coral	1.7-2.36 mm
"	"	*Reticulitermes flavipes*	fossilized coral	1.0-2.36 mm
"	"	both species	fossilized coral	mixture 1.18-2.8 mm
Myle & Smith unpub.	Arizona	*Heterotermes aureus*	Horticulture sand	1.18-1.7 mm
"	"	"	Basaltic Termite Barrier	1.18-2.36 mm
"	"	*Paraneotermes simplicicornis*	mortar sand	2.0-4.0 mm
Myles *et al.* unpub.	Canada	*Reticulitermes flavipes*	aquarium sand	1.4-3.35 mm
"	"	"	Pt. Pelee Beach sand	2.0-3.35 or 1-2 mm
"	"	"	Sakreet	2.0-3.35 or 1-2 mm
"	"	"	WP2 sand	whole, 2.0-3.35, 1.0-2.0

APPENDIX 2
TEMPERATURE AND HUMIDITY INDICATORS

Dry-bulb temperature (T_d, DBT) is an indicator of sensible heat, or the heat content of perfectly dry air. It is the temperature measured by an ordinary (dry-bulb) thermometer, and is independent of the moisture content and insensitive to the latent heat of the air.

Wet-bulb temperature (T_w, WBT) is an indicator of the total heat content (or enthalpy) of the air, that is, of its combined sensible and latent heats. It is the temperature measured by a wet-bulb thermometer, a thermometer having a wetted sleeve over the bulb from which water is able to evaporate freely. A wet bulb thermometer is easily made by slipping a sleeve cut from a light cotton shoestring over the bulb of an ordinary outdoor or photo thermometer.

Dew point temperature (T_d, DPT) is an indicator of the moisture content of the air, with specific reference to the temperature of a surface upon which moisture contained in the air will condense. Stated differently, it is the temperature at which a given quantity of air will become saturated (reach 100% relative humidity) if chilled at constant pressure. Dew point temperature is not easily measured directly; it is conveniently found on a psychrometric chart if dry-bulb and wet-bulb temperatures are known.

Humidity refers to the water vapor contained in the air. Like the word "temperature," however, "humidity" must be qualified as to its type for it to have quantitative meaning.

Absolute humidity is defined as the weight of water vapor contained in a unit volume of air; typical units are pounds or grains of water per cubic foot. Absolute humidity is also known as the water vapor density (d_v).

Relative humidity (RH or r) is defined as the (dimensionless) ratio of the amount of moisture contained in the air under specified conditions to the amount of moisture contained in the air at saturation at the same (dry bulb) temperature. Relative humidity can be computed as the ratio of existing vapor pressure to vapor pressure at saturation, or the ratio of absolute humidity to absolute humidity at saturation existing at the same temperature and barometric pressure.

Specific humidity is the weight of water vapor contained in a unit weight of air. It may be expressed as a dimensionless ratio of pounds of water per pounds of (moist) air, or in terms of grains of moisture per pound of (moist) air.

Humidity ratio (W), or *moisture content* or *mixing ratio,* is defined as the (dimensionless) ratio of the weight of the water vapor to the weight of the dry air contained in a given volume of (moist) air.

Water vapor pressure (P_v) is that part of the atmospheric pressure ("partial pressure") which is exerted due to the amount of water vapor present in the air. It is expressed in terms of absolute pressure as inches of mercury (in. Hg) or pounds per square inch (psi). The vapor pressure of ambient air is conventionally associated with the dry bulb temperature at which the air would become saturated if it were chilled to; it is then termed the *water vapor saturation pressure* (analogous to dew point temperature).

Note: One pound contains 7000 grains

Watson. **Climatic design.** McGraw-Hill, 1983

APPENDIX 3
CALCULATING THE ALTITUDE OF THE SUN

CALCULATING THE ALTITUDE OF THE SUN

The following steps will help you to calculate the maximum and minimum angles of sunlight which can be expected on your site. In the southern hemisphere the maximum angle of solar access will occur on 22 December and the minimum angle on 21 June. In the northern hemisphere, the maximum angle will occur on 21 June and the minimum on 22 December.

1. Check in an atlas to find in what latitude (line parallel to the equator) you are located.

2. Face the direction of the sun's zenith, that is, towards the sun's position at noon, when it casts a shadow directly behind you. In the southern hemisphere, this direction is solar north and in the northern hemisphere it is solar south. This direction can also be obtained from a map that shows the angle of deviation of solar north from magnetic north.

3. Find your latitude curve on Figure B.1.

4. Decide for what time of day you wish to calculate the sun's angle and locate it on the bottom horizontal line. In this example, 10:00 am (on the X-axis) in winter, at latitude 40 degrees, has been chosen. A line drawn vertically up from 10:00 am intersects the 40 degree latitude curve at A. Now draw a line horizontally across to B (on the 7-axis). We find that the reading on that axis is about 22 degrees. This means the sun is 22 degrees above the horizon. When it is, for instance, 127 degrees at latitude 5 degrees at 10:00 am, the angle is 37 degrees past 90 degrees.

5. Now we know the altitude of the sun at the 40 degree latitude at 10.00 am, but in which compass direction will the sun lie? Figure B.2 (overleaf) illustrates how the direction of the sun, in relation to the direction of the noonday sun, is different in the northern and southern hemispheres.

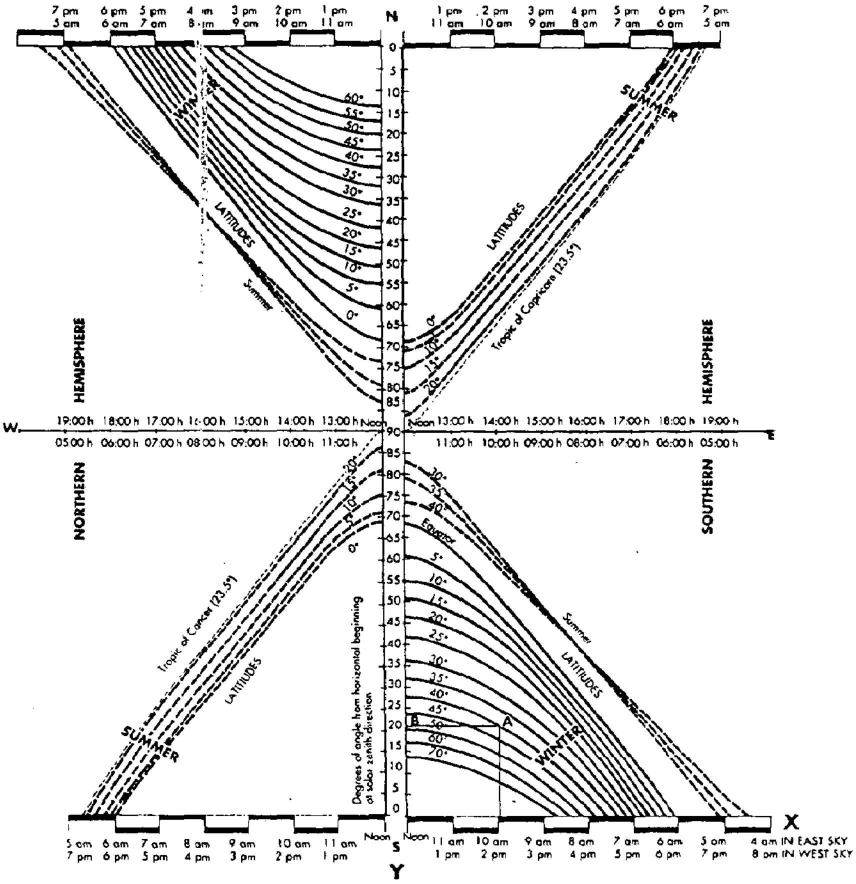
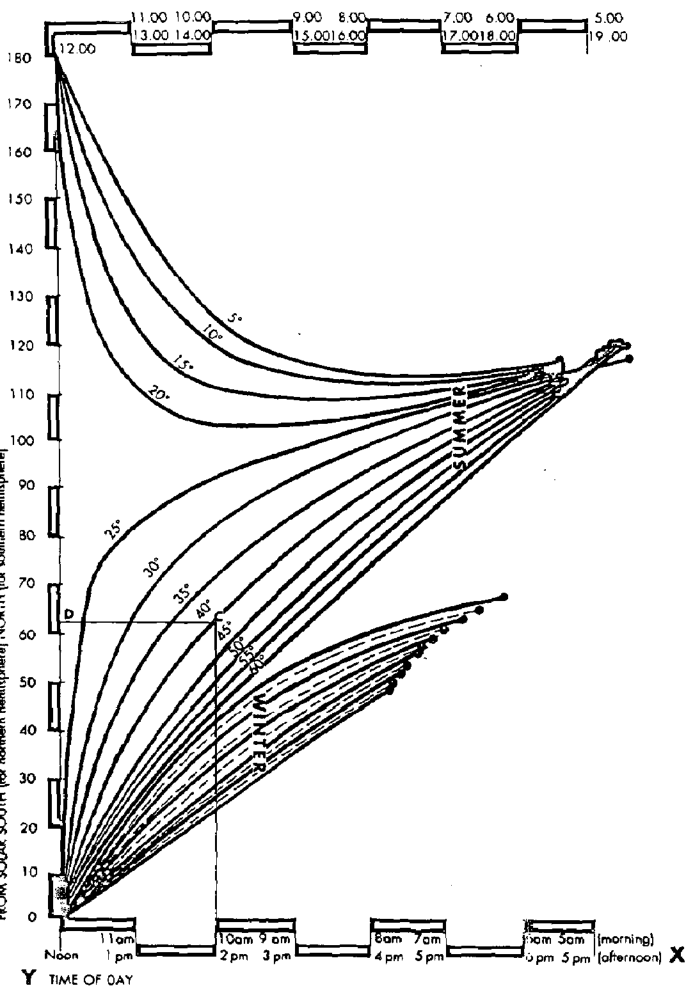


Figure B.1: Solar altitude diagram



re B.2: Solar direction diagram

If you are in the southern hemisphere, the rning sun is on your right as you face the ction of the sun at noon, and in the northern nisphere, the morning sun is on your left. In both es we want to know the angle the sun makes with direction at midday (angle D). Now find 10:00 and follow its line to meet the 40 degrees ude curve at C. Follow the C horizontal across to y-axis to D. The angle the sun makes with its n direction is about 63 degrees. (The angle X ws how other positions of the sun can have an le greater than 90 degrees.)

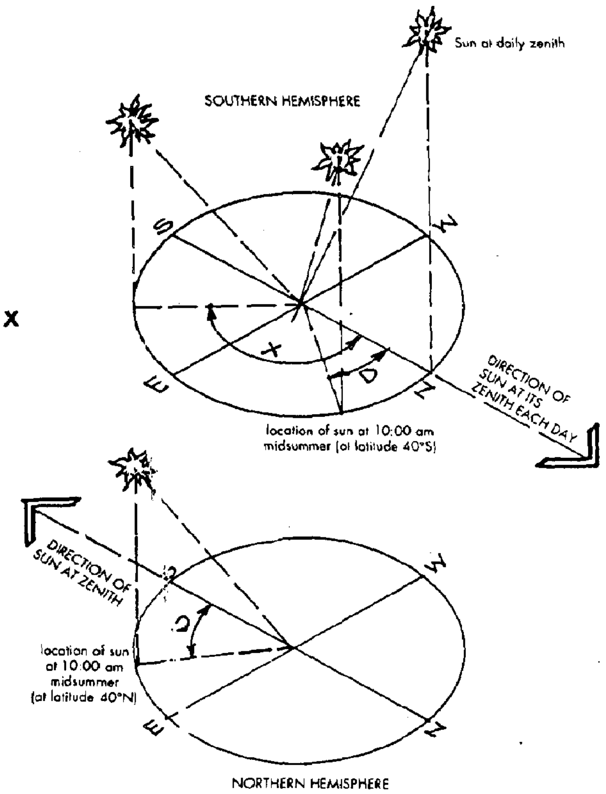


Figure B.3: Horizontal angle of sun's position for any latitude

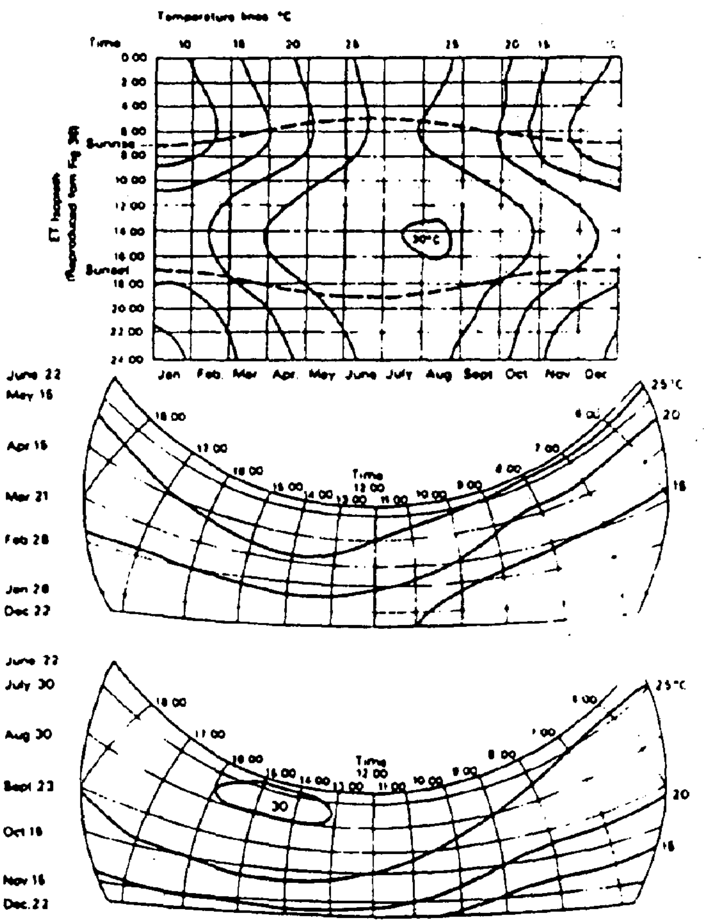
Baggs, Joan and Sydney. **The healthy house.** Thames and Hudson, 1996

APPENDIX 4
DESIGN OF SHADING DEVICES

As a first step, it must be decided when shading is necessary, at what times of the year and between what hours of the day. The best guide to this is the definition of the overheated period. This should be quite easy, if the climatic data has been compiled. Reference can be made to the ET analysis, which shows the daily progress of temperature changes, with separate lines for each season. Alternatively, a temperature isopleth chart can be used.

The latter is a set of coordinates, with month lines horizontally and hour lines vertically, on which time points of equal temperatures are connected by a curve. The solar charts also have month (date) lines horizontally and hour lines vertically; the fact that these are curves and not straight lines should make no difference: the overheated period outlined on the isopleth chart, together with other ET lines can be transferred to the solar chart (Figure 1)

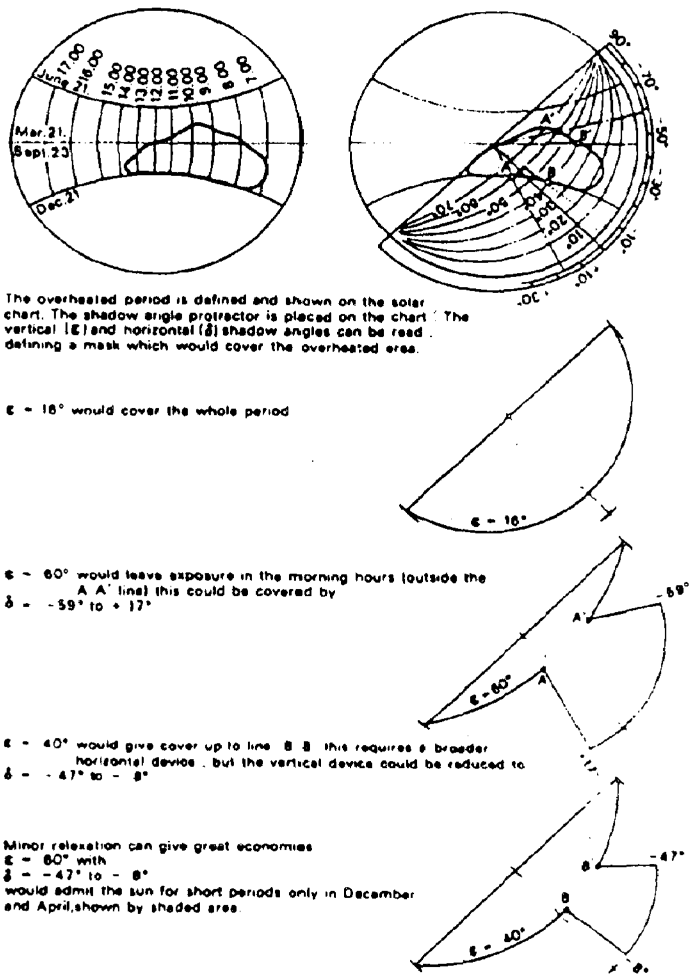
Fig. 1. Transfer of isopleth to the solar chart, to give effective temperature overlays



As on the solar chart each date line represent two different dates, an isopleth chart will be divided into two such diagrams; one for January to June; the other July to December. These can be produced on a transparent medium in the form of an overlay and preserved for further reference.

It should be noted, that radiation heat gain can never be eliminated completely, therefore it is advisable to define the overheated period for the purposes of shading design, by the temperature isopleth corresponding to the lower limit of the comfort zone. When a building elevation is considered from the point of view of shading, it will be represented (in plant) by a line crossing the center point of the solar chart.

Fig.2.
Fitting a shading mask



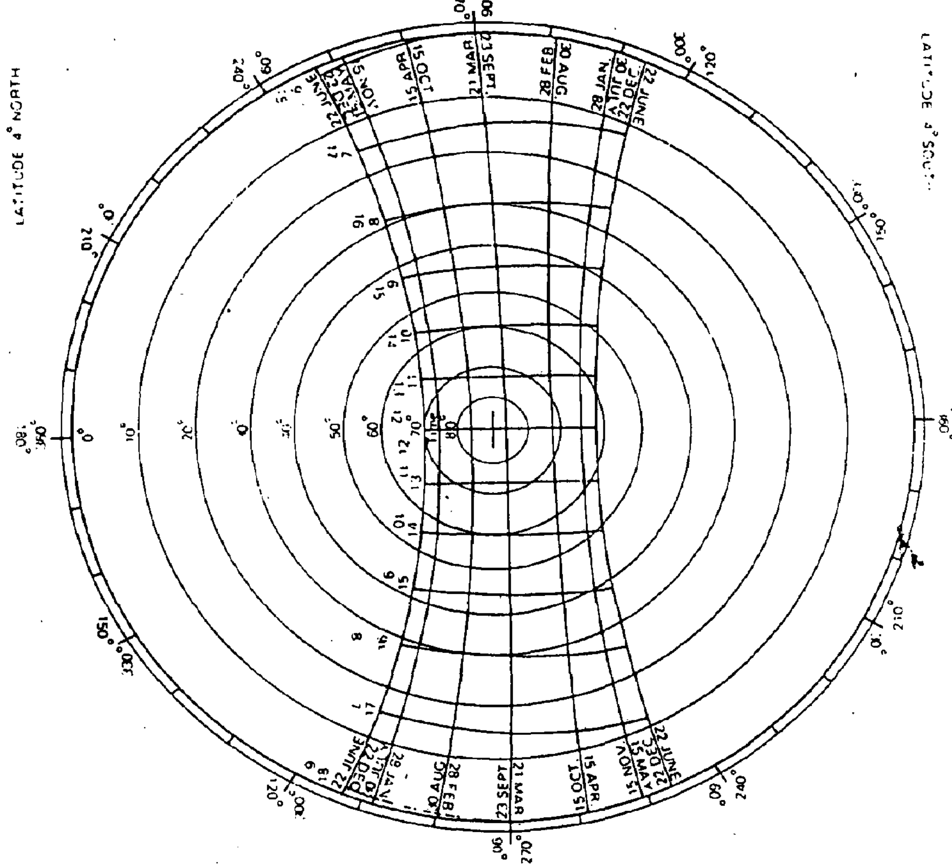
Any part of the overheated period behind this line can be ignored; when the sun is in these position, it will not strike the elevation considered. The design of a suitable shading device is basically the finding of a shading mask which overlaps the overheated period with as close a fit as possible. Many combinations of vertical and horizontal shadow angles may achieve the same purpose. Minor compromises may be acceptable, i.e. for short periods the sun may be permitted to enter, if this results in substantial economies. (Fig. 2). Once the necessary shadow angles have been established, the design of the actual form of the device will be quite a simple task and it can be postponed to a later stage, when it can be handled together with other considerations, structural or aesthetic, daylighting or air movement.

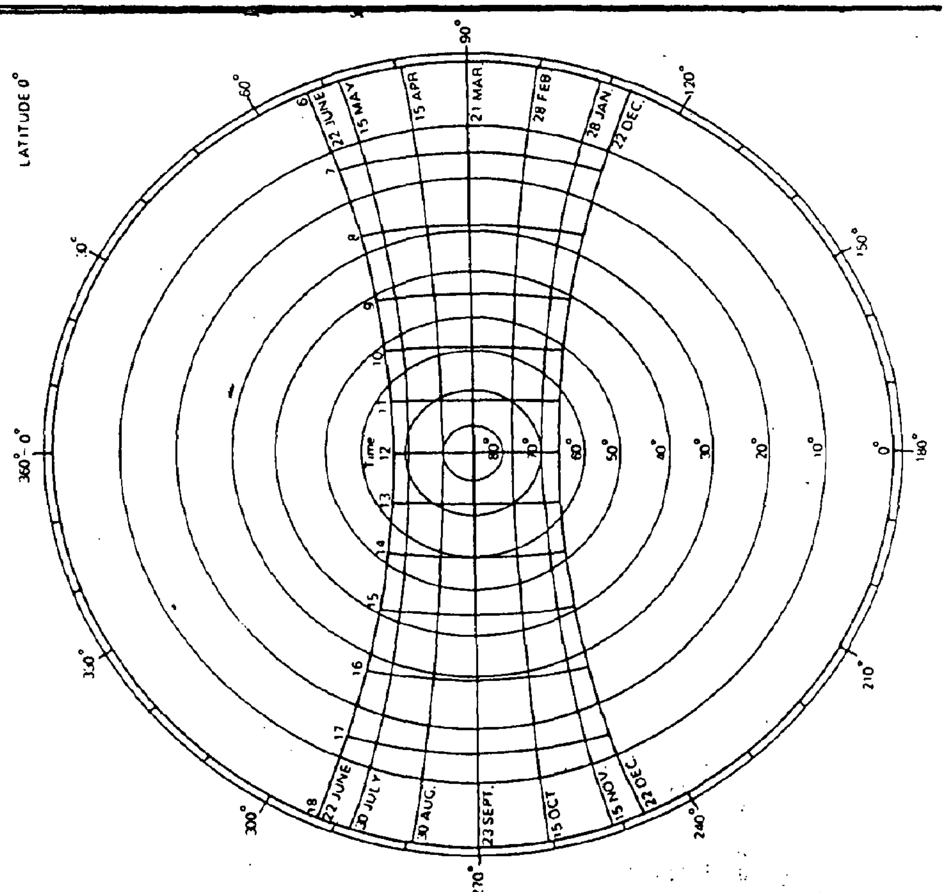
Chernet, Zegeye **Eco-Architecture, a design guideline for housing for Ethiopia**

Master's thesis , University of Roorkee 1998

APPENDIX 5

SOLAR CHARTS FOR ALTITUDE 0°C-16°C (NORTH AND SOUTH)

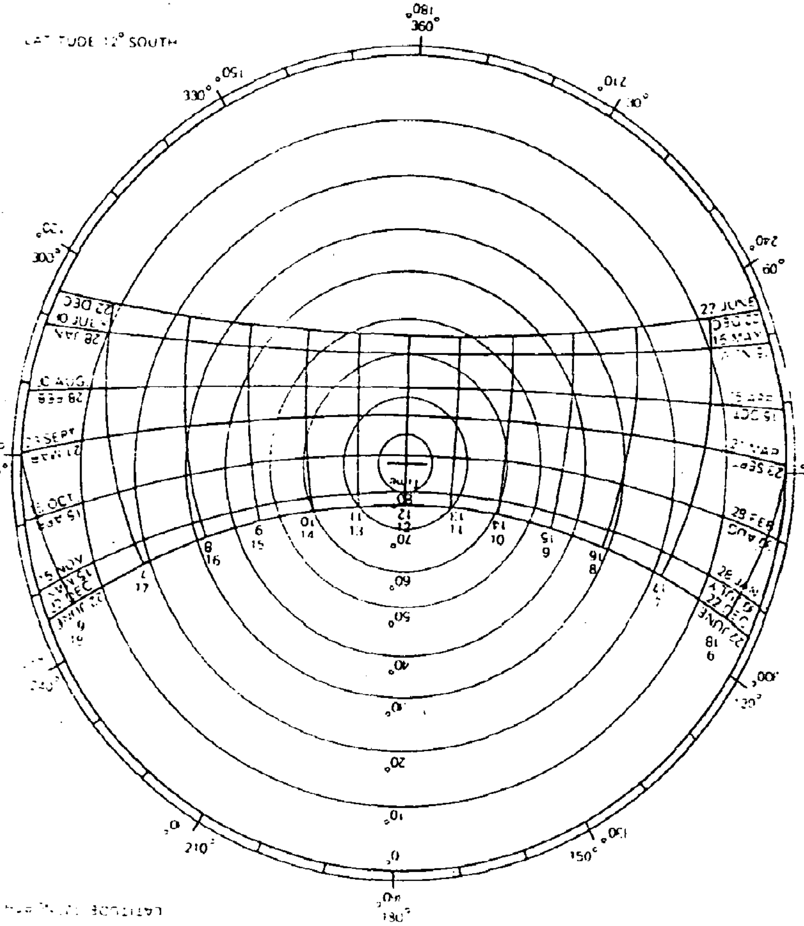




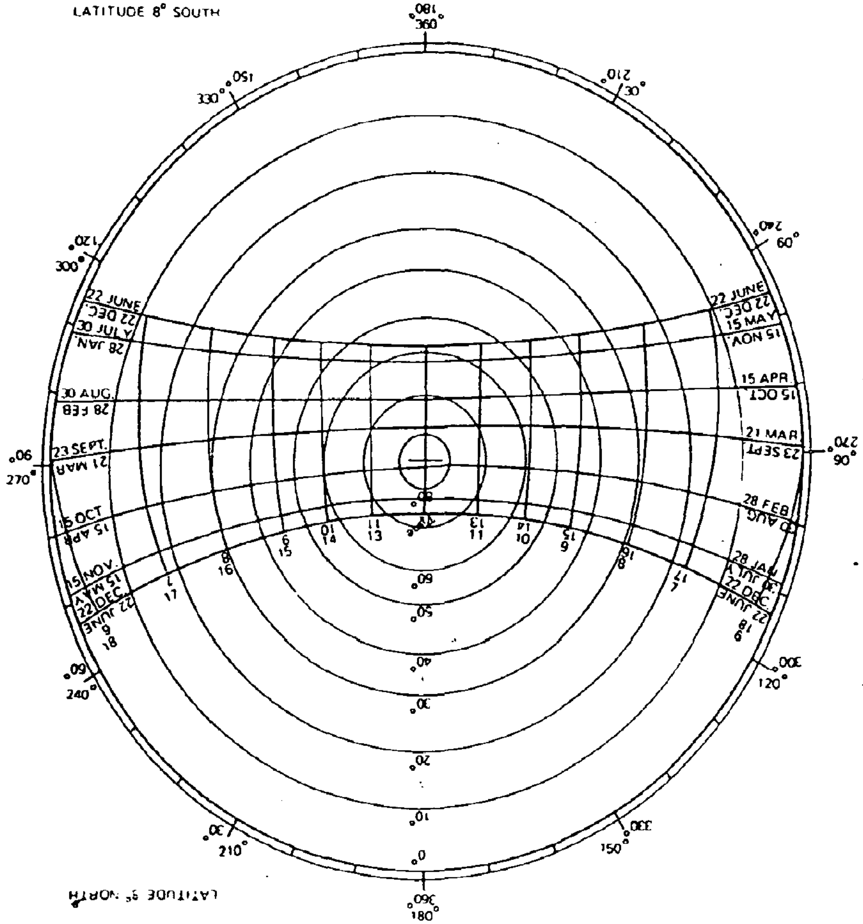
Chernet, Zegeye **Eco-Architecture, a design guideline for housing for Ethiopia**

Master's thesis , University of Roorkee 1998

LATITUDE 12° SOUTH

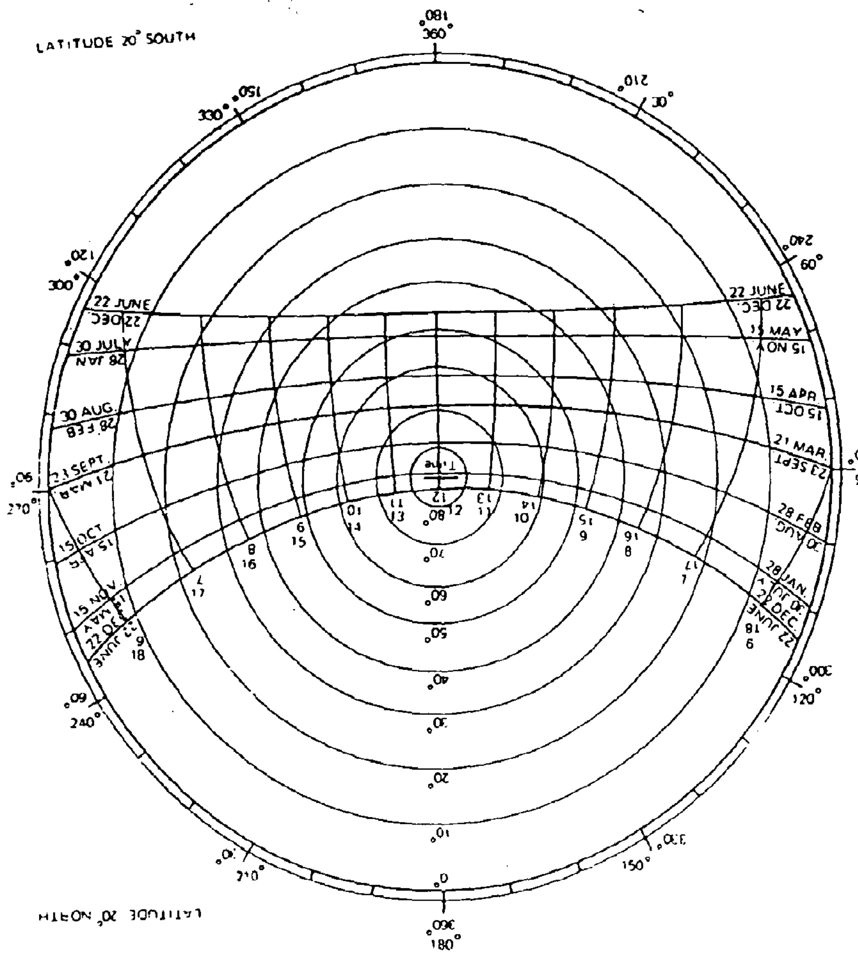


LATITUDE 8° SOUTH



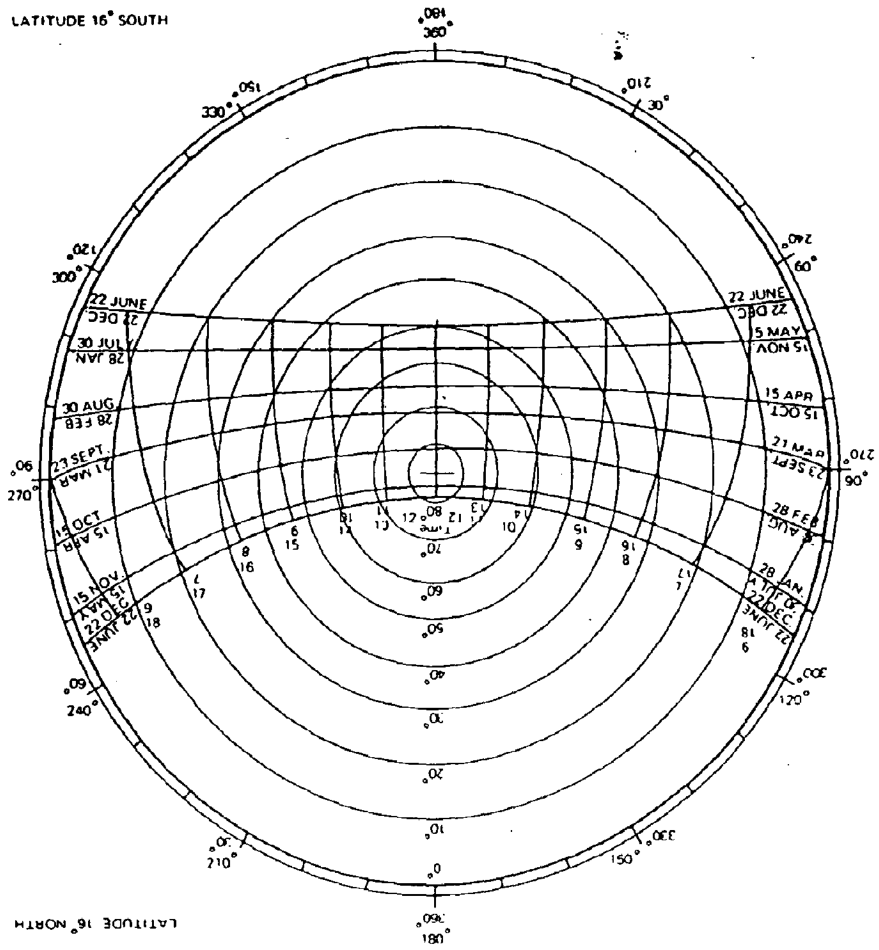
LATITUDE 5° NORTH

LATITUDE 20° SOUTH



LATITUDE 20° NORTH

LATITUDE 16° SOUTH



LATITUDE 16° NORTH

APPENDIX 6
METEOROLOGICAL INFORMATION SHEET

Tab. Meteorological information requirements for design.

		Structural Stability						Serv ices	Weather tightness							
		2/1	2/2	2/3	2/4	2/5	2/6	2/7	2/8	2/9	2/10	2/11	2/12	2/13	2/14	2/15
		Wind loading	Snow loading	Ice loading	Temperature extremes on materials	Foundations - moisture movements	Foundations - frost heave	Freezing of buried pipes	Rain penetration through cracks	Rain absorption by materials	Snow penetration through cracks	Air leakage through cracks	Natural ventilation	Draught in chimneys	Roof drainage	Rain run-off from walls
1	Solar radiance, direct on horizontal				*	*										
2	Solar radiance, diffuse on horizontal				*	*										
3	Illuminance direct on horizontal															
4	Illuminance diffuse on horizontal															
5	Sunshine duration															
6	Sunpaths															
7	UV radiance total on horizontal															
8	Equivalent radiative temperature of sky				*											
9	Temperature of air at standard height			*	*	*	*	*				*				
10	Temperature at vertical variation			*								*				
11	Temperature in ground						*	*								
12	Humidity of air					*										
13	Fog			*												
14	Low cloud			*												
15	Pollution content															
16	Wind speed	*	*	*	*	*			*	*	*	*	*	*		*
17	Wind direction	*	*	*					*	*	*		*	*		*
18	Wind vertical variation	*		*								*	*	*		
19	Rain amount			*		*				*					*	
20	Rain intensity								*	*					*	*
21	Rain duration															
22	Snow amount		*	*							*					
23	Evaporation					*										

Meteorological information requirements for design (cont).

		Heating/cooling				Daylighting				
		2/16	2/17	2/18	2/19	2/20	2/21	2/22	2/23	2/24
		Heating	Cooling	Thermal insulation	Warm nights	Illuminance in rooms	Sky luminance distribution	Daylight quality - spectral distribution	Luminous efficacy	Sunshine in buildings
1	Solar radiance, direct on horizontal	*	*						*	
2	Solar radiance, diffuse on horizontal	*	*							
3	Illuminance direct on horizontal					*			*	
4	Illuminance diffuse on horizontal					*	*	*		
5	Sunshine duration					*				*
6	Sunpaths					*				*
7	UV radiance total on horizontal									
8	Equivalent radiative temperature of sky	*	*							
9	Temperature of air at standard height	*	*	*	*					
10	Temperature of air at vertical variation	*	*							
11	Temperature in ground									
12	Humidity of air		*	*						
13	Fog									
14	Low cloud									
15	Pollution content									
16	Wind speed	*	*		*					
17	Wind direction				*					
18	Wind vertical variation									
19	Rain amount									
20	Rain intensity									
21	Rain duration									
22	Snow amount									
23	Evaporation									

APPENDIX 7
PLANNING A NEW GREYWATER SYSTEM

Steps to follow:

1. **Take a brief inventory** of the house's greywater sources and the number of uses that they get or could get.

Laundry	gal / person . day
Dishwasher	gal / person . day
Bath	gal / person . day
Other sources	gal / person . day
Total greywater	gal / person . day

Try to determine how many gals. per cycle your appliances use--or use the short-form sizing estimator below.

Approximate water use of standard appliances

US clotheswashing machine (top-loading)	30 gallons per cycle
European (front-loading) clotheswasher	10 gallons per cycle
Dishwasher	3 - 5 gallons per cycle
Low-flow shower head (per shower)	3 - 7 gallons per average use
Other sink use (shaving, handwashing, etc.)	1 - 5 gallons per average use

2. **Use the General Site Data and Design Considerations below** to determine what steps are relevant for your situation. Give special consideration to the final dispersion of the effluent, making sure that the soil can accept the amount of water that will be generated, treated and discharged (your local sanitation engineer can do a percolation test to determine the ability of the ground to accept water). If water shortage happens to be a particular restriction where you're located, note that greywater filtered through a soilbed of the sort described in this text will not become anaerobic and thus can be saved for [lawn] irrigation.

3. **Check with your local authorities** regarding any special/local concerns and regulations. Submit your application to the local board of health or consult your local professional engineer (P.E.) for plans and documents needed for your application (usually a topo-graphic site drawing with pertinent information about your site and the proposed solution). If your local P.E. is unfamiliar with alternative greywater pollution prevention systems (e.g., soilbed treatment), provide her/him with the name of this website or send a copy of this manual.

A. Overall Site Plan	**B. Regulatory Requirements**

• Topography
• Slope
• Soil Conditions
• Ledge
• Groundwater
• Buildings
• Utilities
• Property lines
• Vegetation
• Wetlands
	• Plumbing Code
	• State Regulations
	• Reuse Regulations
	• Effluent Discharge Limitations:
	  o BOD
	  o NO3
	  o E-coli
	  o other.
	• Land Application Regulations
	• Permit Question
	  o Local Board of Health
	  o State Environmental Regulations
	  o Building Code Requirements
	  o Monitoring Requirements
	  o Test Data for Approvals

C. Design Information	**D. New System Specifications**

• Existing Treatment Facilities
  o Septic Tank
  o Leach-field
  o Cesspool
  o Other
• Influent Quality and Quantity
  o Number of Bedrooms
  o Number of Persons regulary in residence
  o Occupancy (i.e.,on a year-round or seasonal basis)
• Type of Appliances and fittings
  o Flow-Rates:
  o Dishwashers
  o Washing machines
  o Bathtubs, showers
• Evaporation Rates
• Temperature Data
• Rainfall Data
• Effluent Reuse Goals
	• Propose Treatment Train
	• Technical Specifications
	• Effluent Treatment Character -Typical Transformation
	• Reduction in Pollution
	• Production of Fertilizer
	• Reuse Opportunities
	• Optimum Use of Existing Facilities
	  o Existing Pipes
	  o Dispersion Beds
	  o New Use of Existing Equipment
	• Potential for Savings
	  o Water
	  o Fees - Water and Sewage
	• Overall Improvement Evaluation

http://www.greywater.com

APPENDIX 8
WATER TREATMENT TECHNIQUES

TREATMENT TECHNIQUES

METHOD	LOCATION	RESULT
SCREENING		
Strainers and Leaf Screens	Gutters and Leaders	Prevent leaves and other debris from entering tank
SETTLING		
Sedimentation	Within Tank	Settles particulate matter
FILTERING		
In-Line/Multi Cartridge	After Pump	Sieves sediment
Activated Charcoal	At Tap	Removes chlorine*
Reverse Osmosis	At Tap	Removes contaminants
Mixed Media	Separate Tank	Traps particulate matter
Slow Sand	Separate Tank	Traps particulate matter
DISINFECTING		
Boiling/Distilling	Before use	Kills microorganisms
Chemical Treatments		
(Chlorine or Iodine)	Within Tank or At Pump (liquid, tablet or granule)	Kills microorganisms
Ultraviolet Light	Ultraviolet light systems should be located after the activated carbon filter before trap	Kills microorganisms
Ozonation	Before Tap	Kills microorganisms

* Should only be used after chlorine or iodine has been used as a disinfectant. Ultraviolet light and ozone systems should be located after the activated carbon filter but before the tap.

Hoffman, Bill. **Texas guide to rainwater harvesting.** Texas water development board, 1997

C: From the building interior:

Factor	Control	Options
Interior design (1)	Pollutant sources, ventilation flow	Material selection, design
Interior materials (2)	Odorous or toxic emissions, sinks and reservoirs for pollutants	Material selection
Plywood/LVL	Formaldehyde and volatile organic emissions	Select low emission products
Reconstituted wood-based panels	Formaldehyde and volatile organic emissions	Select low emission products and overlay adhesives
Plastic laminates	Volatile organic emissions	Select low emission adhesives
Plaster/gypsumboard	Few emissions but sinks for pollutants	–
Ceramic tile	Emissions from adhesives/grout	Select low-emission materials
Interior surface finishes (2.1)		
Wallpaper	Formaldehyde and volatile organic emissions	Low emission products, delay occupancy
Paints	Solvent & additive vapours during and after application	Low emission products
Floor coverings (2.2)		
Carpet	Odour and volatile organic emissions, accumulation of contaminants	Low emission adhesives, cleaning methods, walk-off mats
Linoleum	Volatile organic emissions from adhesives	Low emission products
Vinyl	Long-term emission of volatiles and plasticisers	Low emission products
Furnishings & furniture (3)	Formaldehyde and volatile organic emissions from components and surface treatments	Low emission products
Equipment & appliances (4)	Volatile organics and ozone from photocopiers and printers, combustion products from gas and fuel appliances	Low emission products, exhaust flues
Occupant bioeffluence (5)	Odours, skin flakes	Ventilation to Standards
Occupant activities (6).	Smoking, cooking, hobbies, cleaning	Smoking prohibition, rangehoods, cleaning practice
Consumer products (7)	Volatile organics from 'wet' products, dry-cleaned clothing, printed material	Quantity of products
Pest management (8)	Pesticide residues, indoor & outdoor	Product usage
Cleaning (9)	Volatile organic emissions from products, dust disturbance	Low emission products, high efficiency vacuum cleaners
Interior renovation (10)	Volatile organic emissions from new products, pollutant transfer through building	Low emission products, isolation of area

http://www.ipmvp.org/committee/ipmvp-ieq-arc/doc00010.doc

APPENDIX 11
SEPARATION DISTANCES OF VENTILATION OUTSIDE-AIR INTAKES AND POLLUTANT SOURCES.

Recommended Separation Distances of Ventilation Outside-Air Intakes & Pollutant Sources

Pollutant Source	Distance from Outdoor air Intake (ft)	Distance from Property line (ft)	Notes
Property Line	3	-	
Garage entry, loading areas, or drive-in queue	25	-	Note 1
Driveway or street	10	-	Note 1
Limited access highway	25	-	Note 1
Mantles or ledges (sloped less than 1:1 and more than 6 inches wide)	3	-	
Landscaped grade	6 (8)	-	Note 2
Roof or grade	1.5	-	
Air exhausted or vented from spaces without unusual contaminants: e.g. offices, conference rooms, class-rooms, lobbies, retails paces, coffee stations, storage & air handling or elevator machine equipment rooms, individual dwelling units including hotel rooms, and electrical.telephone closets	5	0	Note 1 Note 3
Air exhausted or vented from spaces that may have mild contaminant intensity: eg: copy or printer rooms, dining areas and break rooms, kitchenettes or dining areas with ovens or other cooking of floor dispensing capability such as steam tables, cafeterias, laundry rooms, locker rooms, residential kitchens, limited access toilet rooms, and residential bathrooms.	9	5	Note 3 Note 4
Air exhausted or vented from locations with significant contaminant intensity: Public toilet rooms, health care facility bathrooms, janitor's closets, commercial kitchens, laboratories general exhaust, dry-cleaning establishments general exhaust, indoor swimming pools, diazo printing rooms, etc.	13	10	Note 3 Note 4
Gravity and plumbing vents	19	10	
Air drawn or vented from locations with noxious or toxic fumes or gases: Natural gas and propane appliance vents, paint spray booths, garages, tunnels, kitchen hood exhaust, laboratory filtered fume hood exhaust, chemical storage rooms, refrigerating machinery rooms and soiled laundry storage, etc.	18	10	Note 5
Effluent or exhaust air having a high concentration of dangerous particles, bio-aerosols, or gases: eg fuel-burning appliance vents (other than natural gas and propane), uncleaned fume hood exhaust, evaporative condenser and cooling tower outlets.	26	15	Note 6

Note 1: Per UMC 317.6 minimm separation of ventilation outside air for heating from exhaust outlets, appliance vents, plumbing vents is 10 feet unless outlet is 3 feet above outside air inlet; and for horizontal intakes abutting sidewalk, streets, alleys or driveways. Larger distances may be necessary if intake is above likely location of vehicles.

Note 2: Soil, lawn or plants within 1.5 ft horizontally from intack. UMC 405.2 requires 8 feet above grade for health facilities.

Note 3: Assumes 500 fpm exhaust velocity directed away from outdoor air intake.

Note 4: 0 ft separation from property line if property line abuts a street or public way and outlet is at least 10 ft above grade.

Note 5: Assumes 500 fpm vent exit velocity directed vertically up.

Note 6: Assumes 750 fpm exhaust velocity directed vertically up, and that exhaust is located above or at same level as intake.

Sheltair Scientific Ltd., **Green building design and construction guidelines for the city of Santa Monica. California.** http://greenbuildings.santa-monica.org.