1 1 . ENERGY CONSERVING BUILDING DESIGN: Case of a Research Facility in Hyderabad, India

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I have chosen to present this building design because of the unusual requirements put forward by the clients. It is a computer research centre to be located in Hyderabad. The clients—the Computer Maintenance Corporation-chose a rather novel method of selecting the architect for this building. The project brief called for, among other things, an energy conserving building that would make use of natural energies for air-conditioning and one that could at some stage become energy self-sufficient. The building programme required the construction of a computer centre, computer research and development laboratories and workshops, general administrative offices, class-rooms, hostel facilities and some recreational areas for trainees. The original building programme also referred to staff housing on the site but this was not followed up in later discussions. The project site measures 75 acres, a rocky and barren expanse typical of the Hyderabad regions.

In the absence of any specific energy-use information for this building, we analysed it as one might do with an ordinary office building and categorised energy-use as follows:

(1) In construction of building and in site development.
(2) In operation and maintenance of building itself—lifts, pumps, lights, fans, air-conditioners, etc.
(3) In functional processes housed in the building—office equipment like typewriters, computers and copying machines, etc.
(4) Remote consumption-mainly in transportation required to bring workers and supplies to the building.

Of these four types of energy uses, the designer has the greatest control over (b), that is, the energy required for the operation and maintenance of the building and lesser control over (a), the energy consumed in the construction of the building itself. The designer has, however,no control over the energy consumption in functional processes housed in the building and over energy used in transportation.

BUILDING MATERIALS AND CONSTRUCTION TECHNIQUES

One of the unusual aspects of the project brief was the desire of the clients to use local building materials and to avoid the use of manufactured and nationally distributed materials like cement, steel and glass. From the point of viewx)f energy conservation, this was an important requirement, because the production and transportation of cement and steel consumes a great deal of energy as compared to possible replacements like lime and timber. Similarly, use of locally available stone is energy conserving as compared to burnt bricks. The manufacture of glass is also an energy-intensive process but the appropriate use of glass can save much greater amounts of energy during the life-time of the building.

So we took the client's intentions rather seriously and designed with stone and lime masonry block walls and with timber beams and trusses supporting a roof of stone slabs finished with lime concrete. The decision to use or not to use glass was influenced only by the need to provide adequate lighting and views for the work spaces. The chosen materials imposed limitations upon the building design, limitations of permissible structural loading and possible clear spans. To our surprise, we found it possible to resolve all of these problems, only to discover at a later stage that the building owners themselves were not serious about the use of local materials.

ENERGY FOR OPERATION AND MAINTENANCE OF THE BUILDING

Here we divided the energy required into two parts:

(a) Energy for Environmental Control in the work spaces—lighting, air-conditioning and ventilation, etc.
(b) Energy for other building equipment like pumps, lifts, cooking and so on.

These two called for separate strategies. The first one being a greater consumer of energy, required more attention.

Lighting

We set out to design a building where no artificial lights would be needed in the daytime. This is more complex that it sounds because artificial lighting is required even in buildings where window areas for adequate day lighting have been provided. Experience told us that many people prefer to switch on artificial lights after blocking out all natural light by curtains, particularly in summer. The culprit for this seemingly irrational behaviour is glare from window areas, large or small. Glare is not a function of brightness or size of light source but of contrast. Car headlights cause acute glare on a dark road, much less on a properly lit road and are barely perceptible during daytime.

Office spaces, day-lit from one side (Fig.1) will always suffer from glare problems because of the contrast between the window and the window wall. In the absence of supplementary artificial lighting, such spaces will bear a 'gloomy' character. The problem can be rectified by lighting a workspace from two opposite or adjacent walls (Fig. 2). Unless specially designed, skylights can also cause glare.

In real life situations large office spaces also tend to get divided into smaller rooms, the window usually going to the boss. We, therefore, decided to have all work spaces lit from two sides. To achieve better distribution of light and deeper penetration (Fig. 3) on one side the windows were put at a higher level. On the other side the windows would be lower for view. All windows were provided with deep over-hangs to eliminate direct sunlight in the work areas. Furthermore, to cut down glare from the sky and to prevent low altitude western and eastern sun from entering the building, simple but effective roll-up vertical bamboo screens would be provided at appropriate locations.

Space Cooling and Thermal Comfort

Thermal comfort for human beings depends upon air temperature, mean radiant temperature, relative humidity and air velocity. Machines, however, are effected mainly by the air temperature and in exceptional circumstances by the mean radiant temperature or relative humidity. The design of the buildings for people is therefore somewhat different from that for machines. Ceiling fans (for example) will affect the comfort level of people but not of machines. Because people can move about from one

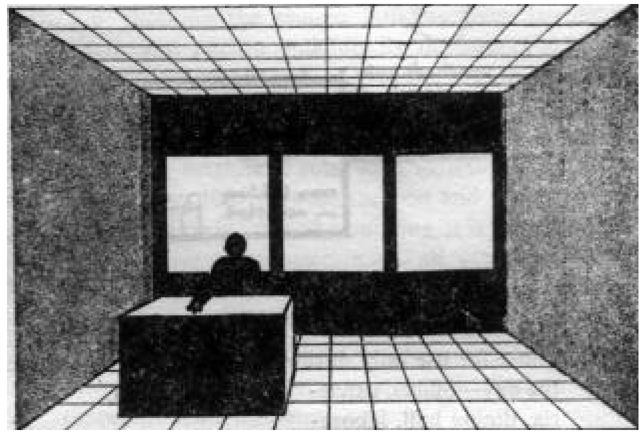

Fig. 1 Glare due to daylighting from one side

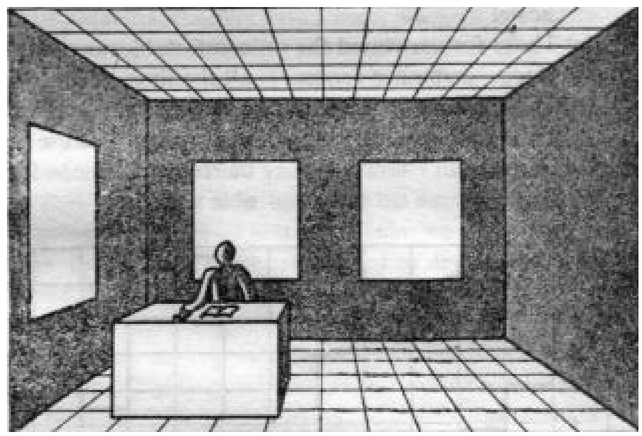

Fig. 2 improved lighting with windows on two walls

space to another and can put on additional clothing or take it off, the comfortable working conditions for machines which are stationary are usually more exacting than for people.

The climatic data of Hyderabad (Fig. 4) shows that the period during which thermal discomfort is likely to occur. The major problem seems to be during the summer months of April, May and June, when the day-time temperature is excessive. At all other times of the year, the outdoor conditions are within comfort limits. Summer evening and night temperatures are not far from the comfort range.

One additional feature of this complex is that not all buildings are to be used simultaneously or continuously. We divided the built up areas according to the time of use as follows:

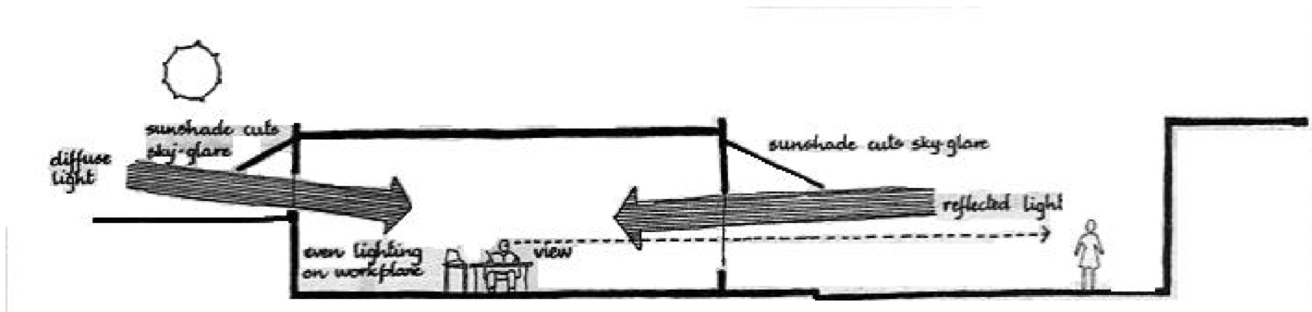

Fig. 3 Section through a typical office space

Spaces	*Comfort Criteria*
(a) Those for use only during the day-offices, cafeteria, dining hall, laboratories, etc.	night-time temperatures do not matter.
(b) Those for use only at night-bedrooms in hostel	day-time temperatures do not matter.
(c) Those for use round the clock-computer rooms	comfortable range needed all the time.
(d) Those for intermittent use only-auditorium, lecture rooms	not very rigid comfort requirements, as use can be restricted to comfortable periods.

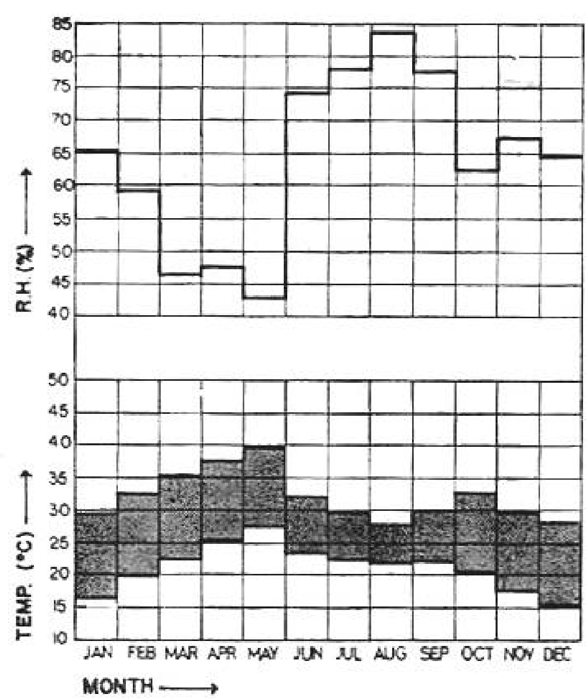

Fig.4 Monthly mean climatic conditions, Hyderabad

The type of building enclosure required for each of these space use types becomes clear from an understanding of the thermal behaviour of light weight and massive construction.

Massive construction results in a lower daytime temperature inside the building, but may become uncomfortable at night when the heat absorbed in the structure finally reaches the inside space. Light weight construction results in high daytime temperatures but cools down quickly in the evening when it will be more comfortable than the massive structure. Buildings for predominant daytime use should, therefore, be of massive construction whereas areas such as hostel bedrooms, used mainly at night, should be built from light weight materials. Spaces for round the clock use present special problems and some form of cooling other than mere arrangement of thermal mass is needed to make them comfortable. Spaces for casual use need no special consideration, as it is possible to restrict their use to the comfortable periods of the day.

All of these buildings, however, should be designed to prevent over-heating of internal spaces. In warm climates the most important factor that causes over-heating of a building is solar radiation. Absorption and inward transmission of solar radiation can be reduced by choosing an appropriate building form and shading devices. Further heat removal from the building can be affected by natural or induced ventilation, evaporation of water and use of heat sinks.

Building Form and Orientation

In Hyderabad (17° N latitude), the theoretical direct solar radiation incident on differently oriented surfaces in the month of May, in gm-cal./cm^{2}· dy, is as follows:

Roof	*E or W wall*	*N wall*	*Swall*
599	237	100	I

SEorSW wall	*NE or NW wall*
134	202

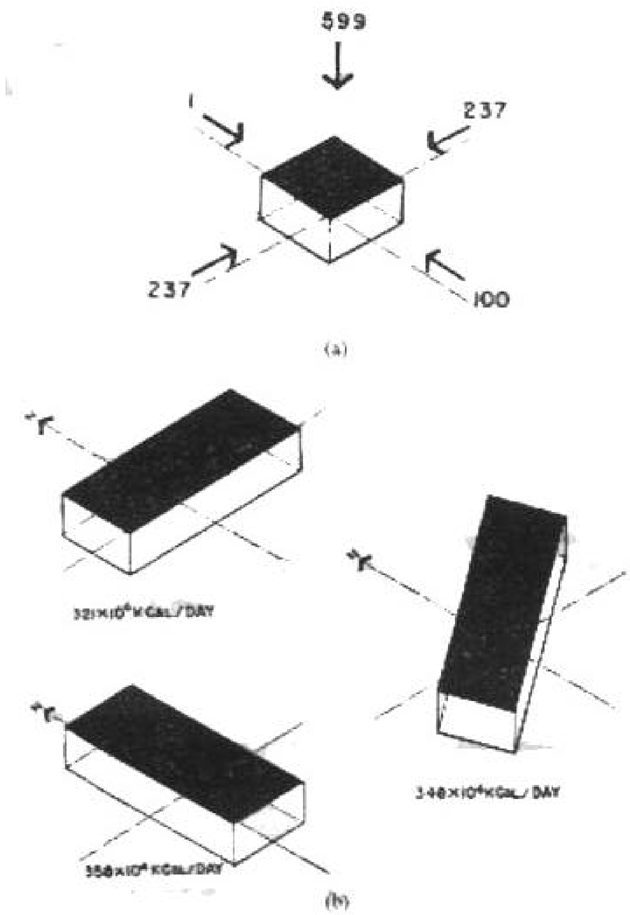

Fig. 5 (a) Relative amounts of direct solar radiation incident on a cube oriented to face the four cardinal directions
(b) Total solar radiation incident on a building 40x10x3.5m high in Hyderabad in June, with different orientations

The ideal orientation for the building is therefore due south. But checking the chosen building form (single storey, long and narrow building) for different orientations we discovered that the heat load on such a block was more or less constant as the major heat gain is from the roof. For a building block of 12 m width 40 m length and 3.5 m height, the solar load variation (Fig. 5) was no more than *l0°/o* between the best and the worst orientation. Obviously for such a building, it is important to provide effective sun protection on all exposed surfaces, particularly the roof.

Roof shading can be achieved by

(a) Fixed shades made of light weight materials.
(b) Movable shades of canvas or openable shutters of timber or some insulating material.
(c) Decidous creepers that shed their leaves in winter.

The fixed shades are less effective because they do not permit radiant cooling at night. Canvas, timber and insulating material shutters have a short life-span and many maintenance problems. Our chosen alternative (Fig. 6) is shading by creepers trained on a wire mesh about I metre above the roof surface. The creepers would not interfere with radiant cooling as leaf tmperatures are lower than the ambient temperature and even under full solar exposure they would not heat up above the ambient.

Having taken care of solar heat gain, we went on to define the building form further and to devise a cooling method. For cooling of the building, the heat sinks available are the night sky, air and earth. **Our** first thought was to build underground and let the landscape cover the building. Lighting and ventilation for the rooms could have been ensured by arranging the buildings around courtyards. But there were difficult structural and waterproofing problems which could have been solved only with large monetary inputs. We, therefore, decided to

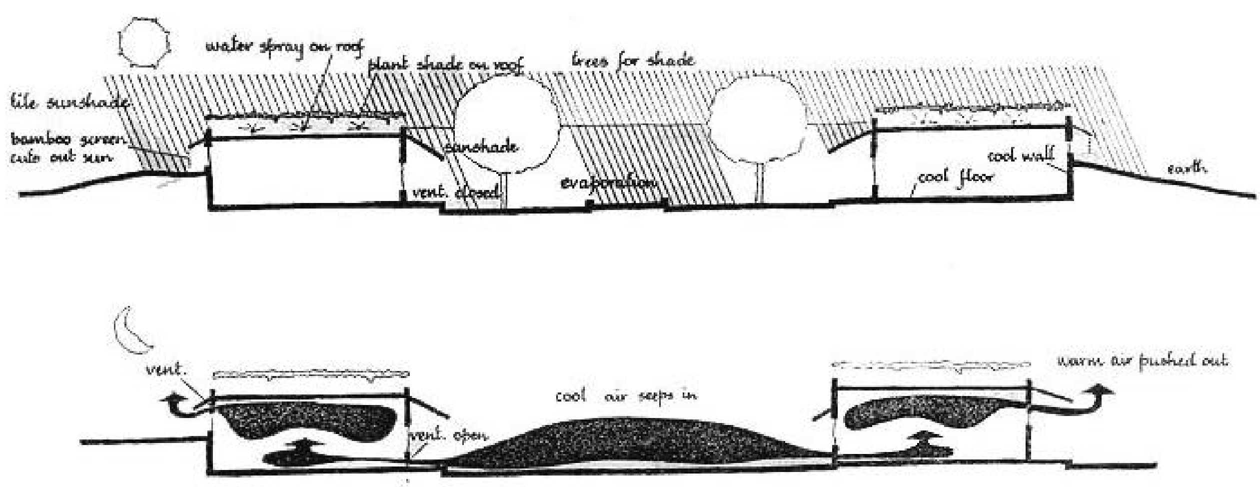

Fig. 6 Sections through the building module. Roofs have been provided with a plant shade

modify this scheme to one where the buildings could be partially sunk into the ground and the roof developed as a garden. While this would have relieved the side thrust on the walls, the roof would still be quite heavy and unless the garden was allowed to wither away in winter, the offices would have been uncomfortably cool in the months of December and January.

The final solution did call for partially building into the slope but did away with the massive garden. Instead we decided to have water spraying over the roof. Theoretically, there would be no need to shade the roof if water was sprayed over it; but we decided to have both shading and water spray mainly to conserve water in summer. With the roof shaded, water spray would not be required all the time. Roof spraying and roof shading with plants are both traditional methods used in different parts of India. The effectiveness of this cooling method is given by Bansal and Sodha (Chapter 8).

Some of the buildings in the complex are two-storeyed and for structural and aesthetic reasons we decided to roof these buildings with terra-cotta tiles. The normal Mangalore roofing tiles that are laid in a single layer tend to overheat. We decided to use a cheaper variety of tiles that can be laid in a double layer (Fig. 7), the upper

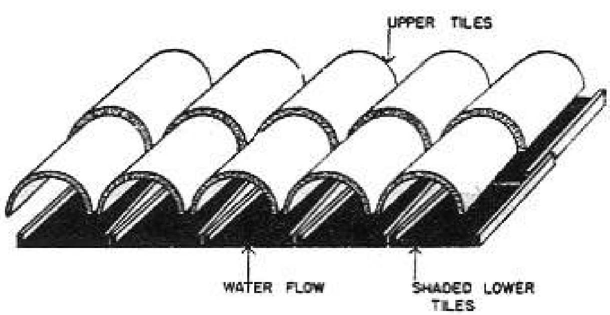

Fig. 7 Double layer of roofing tiles with water flow and shading

layer shading the lower layer. A perforated pipe would be installed at the ridge so that water could flow over the lower layer of tiles and keep the building cool. Again, shading would reduce both heat gain and water loss. Such a system would be more difficult to maintain than the simple flat roofs but it was felt that it would be possible for the owners to operate and maintain it over limited roof areas.

Sun-shading of windows is even more important than roof-shading. Because of the green-house effect, glass permits sunlight to enter the building but does not allow long wave heat radiated by room surfaces to escape out. South windows can be shaded by a simple horizontal over-hang but all other windows (north, south and east) require either complex egg-crate type sun-shades or some form of movable shades. Curtains or internal blinds are not very effective in keeping heat out as the heat absorbed by them enters the building any way. We decided to use the traditional bamboo screens outside the windows because of their effectiveness and flexibility of use. To enable the users to operate them easily, we suggested the use of a simple rope and pulley arrangement that could be operated from within the building. The screens could move in guide rails to resist movement due to wind.

Ventilation

Structural ventilation of buildings at night helps to cool down the building and the building mass so cooled warms up slowly the next day. During daytime when the outdoor air temperature is high it is best to minimise ventilation. Natural ventilation of day-use spaces (offices and laboratories) in summer is therefore of no use whatsoever. Improper,ventilation is generally the reason for the poorer thermal performance of office buildings as compared to houses. Offices tend to be ventilated during the daytime and closed up at night for security.

To make use of the cooling effect of night ventilation, it is necessary to organise ventilation apertures so that they could be left open at night without fear of thieves or of wind blowing away papers etc. Special precautions are necessary to prevent birds or animals from entering the building. We decided to put movable louvers (Figs. 6 and 8) below the window sill on one side and high up on the other side of the building. Both openings would be

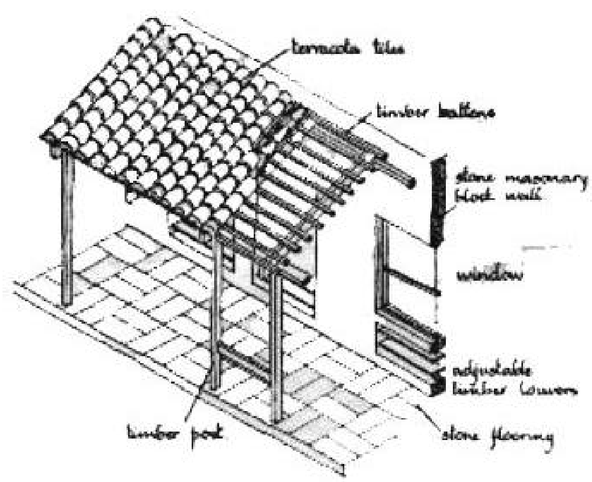

Fig. 8 Cut-away section through a passage roof and office space wall. Adjustable louvers have been provided below the window

screened with fine wire mesh and protected against rain by the deep over-hangs. Ventilation of the building is very useful during the rainy season. At such times the windows at the normal sill height would be opened during the day, providing air movement at the working level.

In the residential buildings (hostels) ventilation has a greater role to play. Such buildings should be oriented to catch the prevailing breezes at night. Cross-ventilation at night will ensure comfortable indoor conditions even in summer. We provided large openings with adjustable louvers (Fig. 9) in each hostel room. These light weight timber slats store little heat during the day and cool down quickly at night.

Air-Conditioning

The computer areas require greater cooling than is possible with natural cooling methods. The ideal situation would be one in which computers could be 'tropicalised' to work at higher temperatures, or if computers could have built-in air-conditioners to cool only the critical heat generating parts. In the absence of such computers, it is necessary to provide cooling of the entire computer work area.

Normal air-conditioning consumes a great deal of energy and to prevent this avoidable energy expense, solar air-conditioning could be installed. Typically a solar air-conditioning unit (Fig. 10) requires flat plate solar collectors for trapping solar energy, and a vapour absorption refrigeration unit to produce cooling. Electricity is required only for blowers and pumps. Such a system is ideally suited for spaces which are in use only during the day-time as very little energy storage is then needed. The solar collectors normally occupy an area one to one and a half times the floor area to be cooled. For twenty-four hour operation of the cooling plant, the solar collector area will be twice as much and even then a stand-by energy source is required for cloudy (but hot) days. The installation costs of such a system become uneconomical and the reliability is also poor. With electricity being used as the stand-by fuel, it is possible that during the two months of rainy weather, an entire year's supply of energy of a conventional air-conditioning plant gets used up in the solar air-conditioning plant.

However, it is possible to use the same absorption refrigeration unit with biogas or fire-wood (Fig. II) as the heat source. With an efficient burner system, such a plant could provide cooling where the installation cost may be no more than that of a conventional air-conditioning plant. If the wood or biogas is produced on site, the cost of running the plant will indeed be much less than that in conventional air-cdhditioning. Instead of using flat plate solar collectors (made of high energy consuming materials like aluminium, copper, steel, glass and synthetic insulation) for collecting solar energy, we could use plants to do the same for us and then the biomass so produced could be pyrolised, composted or otherwise converted into usable gaseous fuel. The technology for doing this exists (Ref. 1) and is far better developed than the technology of solar collectors. Energy storage problems will be totally absent and the entire year's solar collection from a small cultivated area could be used (if needed) in the summer months. Fast growing trees, shrubs and water weeds can be used for producing biomass.

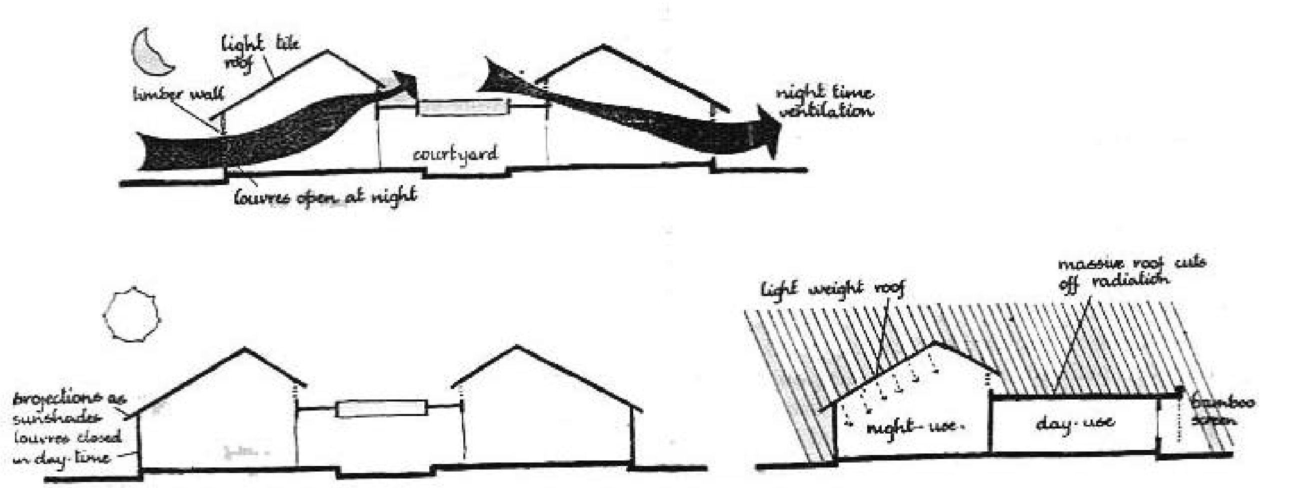

Fig. 9 Sections through a hostel building module. Light-weight construction is used for bed-rooms while day-use space ismassively built

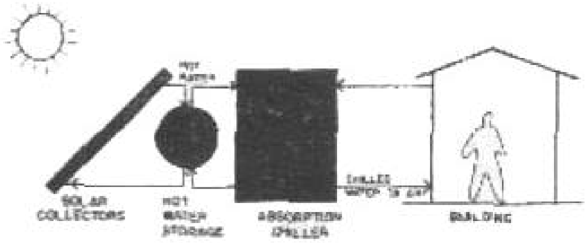

Fig. 10 Conventional solar air-conditioning system

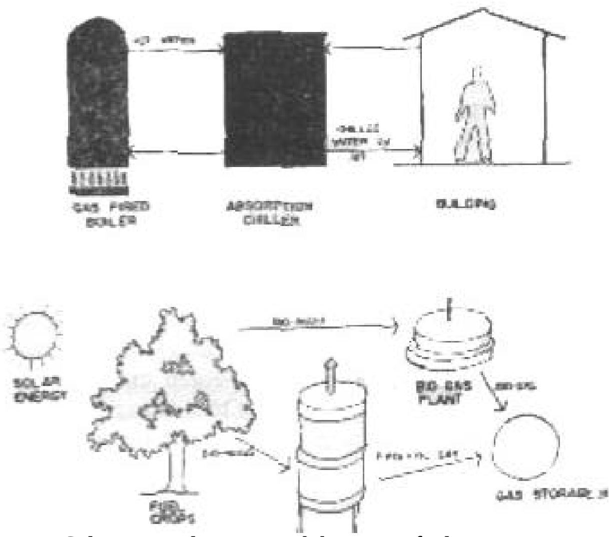

Fig. 11 Solar air-conditioning with bio-mass fuel

If there are water-bodies very close to the building, the unsightly cooling towers can be eliminated by using them for cooling purposes.

We provided sufficient area on the site for cultivation of biomass that could more than meet the fuel requirements of the suggested vapour absorption air-conditioning system.

ENERGY FOR OTHER USES

Some alternative energy sources that we considered using here were direct sunlight-photovoltaic cells for producing electricity; wind, biogas and biomass. The appropriate choice can be made on the basis of end-use energy-form that is required. It needs to be clarified here that this discussion is related to the energy consumed for operation and maintenance of the building only and not to the energy required for operation of office equipment or business machines that are to be housed in the building. We suggested that the building owners should undertake a separate techno-economic survey to find alternative energy sources for powering office equipment.

Solar Energy

Photovoltaic cells are still too expensive for general use and require a further investment in storage batteries. A much better alternative is the use of biomass, plants grown specially for use as fuel. Trees like Ku Babool, Siras, Saru, Nilgiri, Soo Baval, Pardeshi Baval are very useful for this purpose. They require investment only for initial plantation, irrigation and harvesting. Subsequently these plants can be dried and burnt in a furnace which could be used to produce electricity or better still they could be converted into gaseous fuel. Water hyacinth, a water weed that is useful in sewage treatment can be used directly in a biogas digester to produce biogas. The limitation on the production of biomass is the land or water area that is available for this purpose. On the site for this complex, there is plenty of vacant land available and cultivation of biomass is therefore the best method of generating energy from renewable sources. It is important to remember that conversion of fuel to electricity is a low efficiency process and whenever possible the fuel should be used directly as heat energy.

The other advantages of cultivating biomass for fuel are that storage of energy presents no problems and like all other trees, fuel plantations have a beneficial effect on the environment.

Wind

Wind, a highly erratic energy source can be used for the major water pumping requirements of the complex. But windmills are not useful for producing electricity. Storage of energy is not a problem with water pumping as water itself can be stored at the higher level. With electricity produced by wind, storage of energy is very expensive. The technology for water pumping by wind mills is readily available in India. The Allahabad Polytechnic is manufacturing wind-mills for low wind-speed areas.

There are some other methods of generating energy on site, such as solar ponds or solar towers. They are all in experimental stage and not very practical to use here. Any technique of generating energy that is selected must be easy to maintain.

CONCLUSION

Conservation of energy in a building complex is as much the responsibility of the users as it is of the designer. A well designed project may actually consume more energy than a similar conventional project, if the users are not prepared to use the building as it is supposed to be used. We were, however, concerned here mainly with the building design and not with its actual use. Our energy conservation programme for this building complex calls for:

(a) use of low-energy materials for construction.
(b) full use of day-lighting in all areas to eliminate the need for supplementary artificial lighting during daytime.
(c) avoiding air-conditioning in areas where only human comfort is required. This can be provided by fans and natural cooling methods.
(d) supplementing natural cooling methods by biogas operated air-conditioning plant in areas where precise temperature control is needed for machines.
(e) using several smaller air-conditioning plants in place of one large one to provide flexibility of operation and high efficiency.
(f) grouping together of facilities that are used at night, to avoid unnecessary night-time lighting of long corridors and open spaces.
(g) running pumps etc., on wind-power or other natural energies wherever possible.

REFERENCE

1. Report of the Fuelwood Study Committee-Planning Commission, Government of India, New Delhi 1982.