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"THE NATURAL HOUSE" – CONCEPT, DESIGN & CONSTRUCTION

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Abstract

The city of Hyderabad, an explosively growing metropolis located in the south central region of India, experiences hot and dry summers and generally warm day temperatures most of the year. The building construction approaches and techniques currently in use involve excessive use of cement, brick and reinforced concrete with no insulation, resulting in considerable thermal discomfort to occupants several months in a year. To meet the objectives of "climate responsive building design & construction", an initiative at Muffakham Jah College of Engineering & Technology (MJCET), entitled Centre for Environment Studies & Socioresponsive Engineering, has conceived and developed the design of "The Natural House". This has been set up as an undergraduate R&D project, supervised by two faculty members (the two authors of this paper). It is expected that following the R&D phase the students – a group of twenty-three mechanical engineering juniors, including eight female students, will construct a small "Natural House".

The House is being designed for maximum compatibility with the natural surroundings and uses a wide spectrum of principles modeled on the homeostatic and self-regulating behavior of biological and ecological systems. The overall design objective is to ensure maximum energy efficiency, low construction and maintenance cost, thermal comfort without air-conditioning, high aesthetic quality and intimate contact with the natural elements.

The paper describes the architectural and engineering principles used and our attempt to provide an inspired student group an opportunity to fully exercise their creative imagination and "learn by doing".

Keywords: appropriate technology, energy conservation, climate responsive architecture, environmental education

I. Introduction

We teach at a small, primarily undergraduate college located in a large city, Hyderabad, in the south-central region of India. Except for the winter months of December and January, when the average maximum temperature is 28 ^{0}C and the average minimum, 14 ^{0}C, the day temperatures in the remaining months are usually uncomfortably high. The monsoon season runs from June to August, with spells of rain every three or four days. The rest of the months are very dry. Summer highs are over 40 ^{0}C and remain so for two to three months, between March and June. In the monsoon season, on days of no rain, day and night temperatures are usually uncomfortably high, and again in September and October, following the end of monsoon, the weather is very warm.

The prevalent approach to building construction in this densely populated urban environment pays little heed to making the buildings, especially residential homes, which are occupied nights as well as days, climate responsive. The more traditional architecture, prevalent until thirty or forty years ago, tended to rely on availability of verandah or yard space for occupants to sleep outside on hot summer nights. Even roofs were used for this purpose. But rapid urbanization and explosive growth, resulting in very close spacing of adjacent houses, with little or no verandah and yard space, have made this either impossible or unpractical.

We have noticed that the indoor temperature in most homes tends to remain above 30 ^{0}C all day and night for much of the year, even when evening and night temperatures outside are well below that level. As a result, air conditioners are used extensively by those who have them, while others, a very large majority, experience almost continuous discomfort. Evaporative "desert" coolers are used by some people, but they are inconvenient, noisy, introduce excessive humidity and effective only for about two to three months in a year.

These observations have led us to evolve a radically different approach to housing design and construction for our particular region, breaking from existing convention and looking to nature as a designer, innovator and problem solver that has been performing ingenious engineering feats for billions of years. In the process of attempting to teach ourselves the basics of nature's engineering as they apply to ensuring thermal comfort, we believe we have also stumbled upon a fascinating new paradigm for engineering education. "The Natural House Project" is an exciting adventure in teaching and learning – an enjoyable opportunity for students, and also the teachers, to use art, science and engineering principles in almost equal measure to imagine, conceptualize, design and build a home that reflects the beauty and ingenuity of nature. That being an important motivation, we are less concerned with measuring the success of the project in purely engineering terms than in terms of its educational and experiential value. The rewards, as far as we are concerned, are as much existential as tangible [1].

II. “The Natural House” philosophy

Every living organism, including each plant and tree, is an engineering marvel. It survives by maintaining homeostasis – a stable set of internal conditions necessary for healthy biological functioning, in the midst of environmental fluctuations of temperature, light intensity, humidity levels, air currents and so on. A tree can not only survive harsh winter and summer, wet and dry weather, but is able to maintain its own temperature fairly constant throughout while doing so. While successfully achieving this it uses energy and essential materials with amazing efficiency, automatically conserving its own energy and avoiding waste. The secret behind nature’s engineering seems to be that, in addition to the intricate information pool contained in the genes of each organism, each biological and ecological unit has intimate contact and intercommunication with its neighbors. The units work in harmony, preserving mutual balances and providing checks and channels that enable continuous flow of information and energy and overall ecological stability.

In most cases the homes that human beings live in, especially urban homes in densely populated towns, are an inefficient and unviable counterpoint to nature’s living design. They enclose people in rectangular boxes of cement and brick, cut off from nature and isolated from human surroundings. They are, for all practical purposes, “dumb” – incapable of responding intelligently and naturally to environmental rhythms and fluctuations. They are generally wasteful in the use of energy. As we have observed in our own region, most houses soak up excessive heat from solar heating in summer and release it into the house at night, keeping the temperature uncomfortably high at night, even when the air temperature outside is relatively cool.

To develop a radically different approach to house design and to maintain nearly constant thermal comfort diurnally and seasonally while minimizing cooling/heating energy expenditure, we have used some of the most elementary principles and concepts observed in nature.

To illustrate, consider how refreshingly cool it is under a green, nicely leafed tree on a hot summer day. The roots draw up groundwater through capillary action. This cool nutrient-rich water is distributed throughout the branches and leaves, where controlled evaporation of water ensures effective heat dissipation and cooling. This, and the continuous release of oxygen, is what makes standing under a tree canopy such a pleasant experience.

We have conceived “The Natural House” as a paradigm in which a house is considered to be an ecological unit, whose fitness may be evaluated in terms of its ability to integrate with the natural surroundings and “survive” on its own. Ideally, this means the ability to support itself through energy and materials drawn from nature, while providing for its occupants an environment that is comfortable, enjoyable and healthy.

As a work in progress, our Natural House is still very much at a conceptual stage, where various processes and principles observed in nature are being progressively integrated into the design in a trial-and-error type of approach. What follows is both an overview of the entire project as it is expected to unfold, as well as a statement and discussion of our experience of involving an undergraduate mechanical and civil engineering student group in a "real life" engineering project with exciting creative possibilities.

III. How the project is expected to unfold

Step I: Conceptualization of philosophy and definition of overall design objectives.
Step II (Present phase): Study of principles to be used for achieving thermal comfort, conservation of energy, air ventilation and oxygen generation, enhancing aesthetic features and contact with nature and its elements.
Step III: (Partly begun): Preliminary attempt at qualitative design, generation of drawings and plans illustrating the basic processes of nature-based cooling/heating and arrangement of essential components.
Step IV: Tentative selection of insulation and building materials, data collection on properties and market costs.
Step V: Preliminary modeling and quantitative analysis, cooling load calculations, development of methodology for optimization of parameters affecting cost and overall thermal behavior.
Step VI: Preliminary design of solar collector and concentrators, water flow and storage system.
Step VII: Preliminary structural analysis and design, load calculations, design of load bearing wall sections.
Step VIII: Design of geothermal and evaporative cooling system based on preliminary cooling load calculations.
Step IX: Modeling and design of ventilation and air circulation system.
Step X: Integration of all the basic components into a mathematical model for prediction of thermal and structural behavior and simulation on the computer.
Step XI: Optimization of design.
Step XII: Building a scale model. Experimental testing and data collection under realistic weather conditions.
Step XIII: Improvement of design as suggested by tests, continued testing and redesign.
Step XIV: Construction of a model house.

It is necessary to state that while the above list looks like a linear progression, it need not be so in practice. A number of phases could proceed concurrently. In fact, Steps I, II and III are already underway in a somewhat organic process of conceptualizing, visioning and preliminary engineering (on paper) of a "dream natural house".

The beauty of this entire experiment, in our view, is that each participant in the group – students and the faculty team leaders, are free to individualize their "dream house". The requirement, as far as design objectives go, is merely to ensure thermal comfort using, as far as possible, only natural means. This being the guiding idea it is logical to look to nature and its resources and make use of some of its principles to achieve this objective. Although there are a number of secondary objectives, those too are flexible and allow each participant a free reign of imagination and ingenuity.

As an example and illustration, we present below a conceptualized and qualitative Natural House.

IV. A Model "Natural House"

Fig. 1 is an isometric view of the conceptualized house. From the outside the following features can be seen.

The structure is composed of separate wall sections arranged in the form of a polygon. The roof, which is isolated from the ceiling, is dome shaped and supports a solar collector-cum-solar shield assembly. The solar collector is composed of six separate triangular panels in the form of a low pyramid. The panels are equipped with concentrators and tapered water pipes enclosed in transparent hollow pipes. A verandah, with a roof that is angled upward at nearly 30 degrees, surrounds the walls. Sun screens (which close and open according to solar position) are situated on the east and west sides. On the south-east, south and south-west sides along the verandah enclosures with glass walls are provided for use as a sit-out and greenhouse.

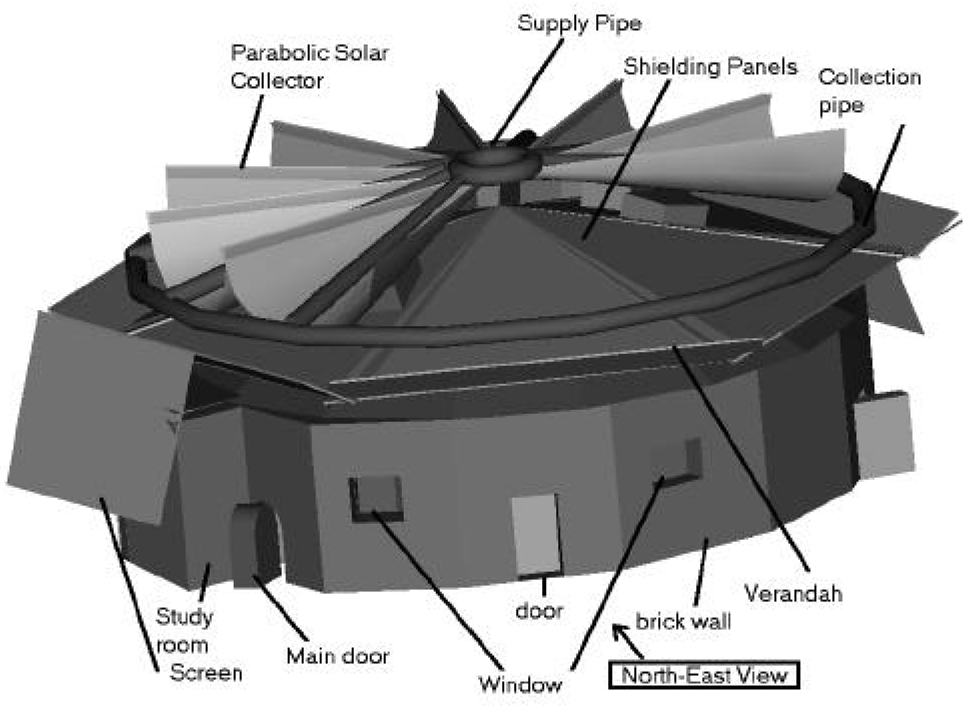

Fig.1 Isometric View Showing Visible External Features

Fig. 2. shows a floor plan. This particular arrangement has no special engineering or architectural significance, except for the usual considerations of adequate sunlight in winter for areas where the light is most desirable.

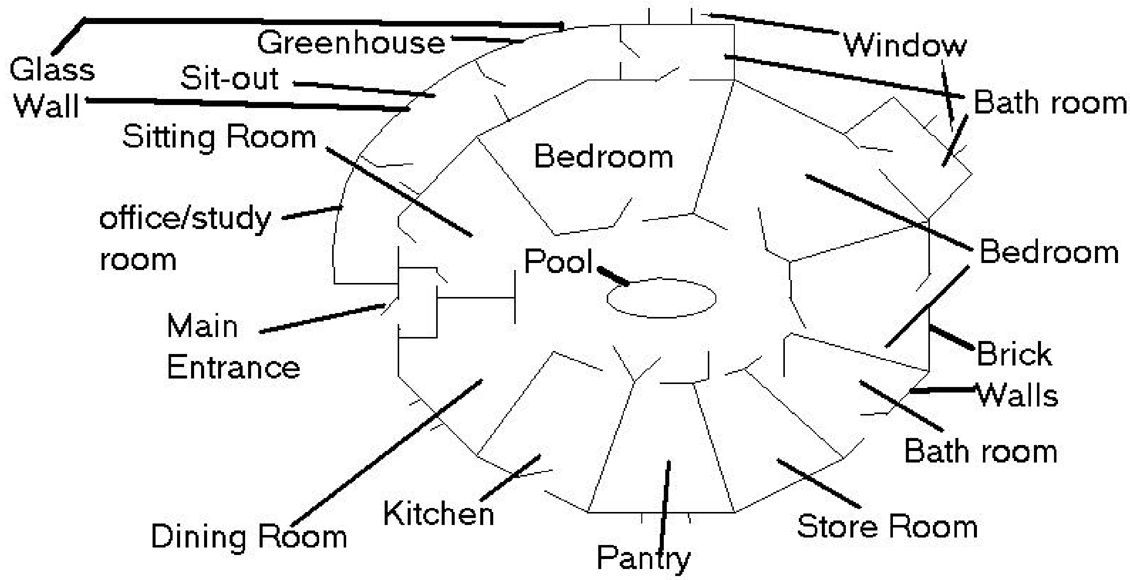

Fig.2 A Representative Floor Plan

Several innovative features of the design, described and discussed below in detail, should be mentioned at the outset.

The polygonal structure permits flexibility in optimally situating and orienting various panels, such as full-length glass panels, to enhance functional efficiency and architectural and aesthetic advantage. Most of the panels are brick and concrete sections, with good inside insulation. (We are researching the use of certain solid waste materials, such as cotton waste, to make loose-filled insulation panels, which can be mounted on the inside.) Inclining the verandah roof allows more sunlight to enter in winter. In summer the screens block the sun. The six sided pyramid solar collector is so designed that water flow in each section can be regulated independently. This allows some sections of the collector to be active, and the rest inactive, according to a microprocessor controlled program based on solar trajectory. The sections on the north side are not part of the collector (have no water pipes) and serve only as radiation shields. The design ensures that no part of the walls or upper surface of the ceiling would receive any direct solar input in summer. Fig. 3 shows a front view of the house.

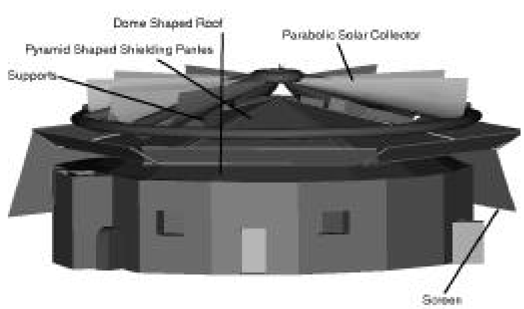

Fig.3 Front View

V. Achieving thermal comfort

It is generally recognized that thermal comfort is a subjective physical and psychological experience involving a wide range of factors, not all of which can be objectively studied and quantified. Nevertheless, researchers have developed "thumb rules" that seem to work reasonably well. A temperature range of 23 ^{0}C to 27 ^{0}C, relative humidity 35 to 50% and air velocities between 0.2 to 0.8 m/s, are usually assumed to represent a reasonable comfort range [2]. The human body is required to maintain internal thermal homeostasis, which is specified by control and maintenance of deep body temperature and skin temperature within relatively narrow limits. Depending on the level of a person's physical activity, the body generates anywhere from 100W to 500W of heat and this must be dissipated to the surroundings through convection, radiation and evaporation. If the surroundings are very warm, convection and radiation are likely to be relatively ineffective and increased evaporation through sweating would tend to regulate the heat dissipation. If the surroundings are excessively cold, heavy clothing becomes necessary to reduce convective and radiative losses. In summary, it is desirable that the indoor air temperature be maintained around 25C and the average wall temperature not exceed that value by too much [3].

As noted, in and around our location in India, except for the relatively pleasant winter months, day temperatures through most of the remaining part of the year are in the mid to high 30's, or over 40 ^{0}C. Hence the primary consideration in designing for thermal comfort is the need for cooling.

Our preliminary design (Steps II & III on the above list) makes use of the following "natural" means of achieving thermal comfort.

(i) Closed loop geothermal cooling panels attached to inside walls.
(ii) Open loop evaporative cooling panels attached to ceiling and surrounded by an air channel.
(iii) Sun screens at various sections (on east and west sides), which hang down from the verandah roof to keep out direct solar radiation and open (automatically) when no direct radiation is present, i.e. when the sun has moved up in the sky and at evening and night.
(iv) Ceiling isolated from the roof. The roof serves as a solar collector-cum-radiation shield, preventing all direct radiation from reaching the ceiling and being conducted inside.
(v) An air channel with a very low speed blower blows oxygenated air from the greenhouse across cooling panels and into the house.
(vi) Cross ventilation using venturi effects induce diagonal air currents.
(vii) Evaporative cooling panels in the ceiling with air channels provide symmetric cooling and induce natural vertical circulation, while preventing thermal stratification. The evaporatively cooled air, instead of being released into the room, serves to keep the lower surface of the channel cold. Thus excessive and uncontrolled increase in room humidity is avoided.

Note: It should be emphasized that use of such a diverse set of cooling means is aimed at achieving a high level of thermal comfort using mostly passive or relatively low energy input devices (fans and periodically operated pumps). It is by no means necessary to include all or most of these features in a particular model of the house. We estimate that merely by cutting out all direct solar radiation and providing sufficient insulation on the walls the house will keep reasonably cool in summer, since summer night temperatures at our location tend to be around 25 ^{0}C or lower [(4)]. If geothermal cooling is to be incorporated as a value-added feature we estimate that only infrequent pump operation (perhaps once or twice a day in peak summer) to fill and drain the cooling panels would be necessary. Controlled evaporative cooling may be needed only to provide additional comfort and refreshment by keeping the relative humidity in the desired range.

(i) The Geothermal Cooling System

In an attempt to understand natural mechanisms of thermal regulation, we noted that the annual mean temperature for our region - an approximate average of summer highs and winter lows, is in the human comfort range of around 25 ^{0}C. We know from elementary transient conduction heat transfer analysis that the underground earth temperature below one meter depth tends to remain constant throughout the year at a value close to the weighted mean summer-winter value [(5)]. Data was obtained from the local center of National Geophysical Research Institute, which confirmed that these values for the Hyderabad region are between 25 ^{0}C and 28 ^{0}C.

These numbers suggested that our design of The Natural House should aim at achieving thermal equilibrium with the infinite underground sink by locating a water tank below ground level and circulating the water drawn from it. In Hyderabad, it is very common for houses to have such tanks to receive and store municipal water, which is supplied by the city discontinuously (normally every other day for a few hours). It is also very common for homeowners to dig bore-wells in their yard to augment the scarce municipal supply. Thus it is not impractical to make use of this feature, viz. the availability of underground water at 25 ^{0}C to 28 ^{0}C, in the design. For the particular model under discussion, we have incorporated **closed loop geothermal cooling of walls** in the design and construction of the house (Fig.4). The supply pipes are partly or completely embedded (or sandwiched) in the brick sections of the wall periphery and supply water to a set of cooling panels attached to the inside wall surface. Water taken from the underground sump is pumped up to the wall panels and stored there and its temperature is monitored by a thermometer and thermostat. The thermostat is set for a limiting comfort temperature, 29 ^{0}C or 29.5 ^{0}C When this temperature is reached due to absorption of heat from inside and outside the house the drain valve opens. The water is drained into a receiving underground tank and the panel is refilled using an automated control system, which opens and closes the valves and turns the pump on and off, as signaled by thermostats. The underground receiving and supply tanks are connected through a valve, which opens when the water in the receiving tank cools down to the sink temperature. Insulation at the inside surface of the walls helps to minimize heat flow from outside and keeps the house thermally stable. The geothermal cooling system thus functions as a closed loop. The arrangement is illustrated in Fig.4.

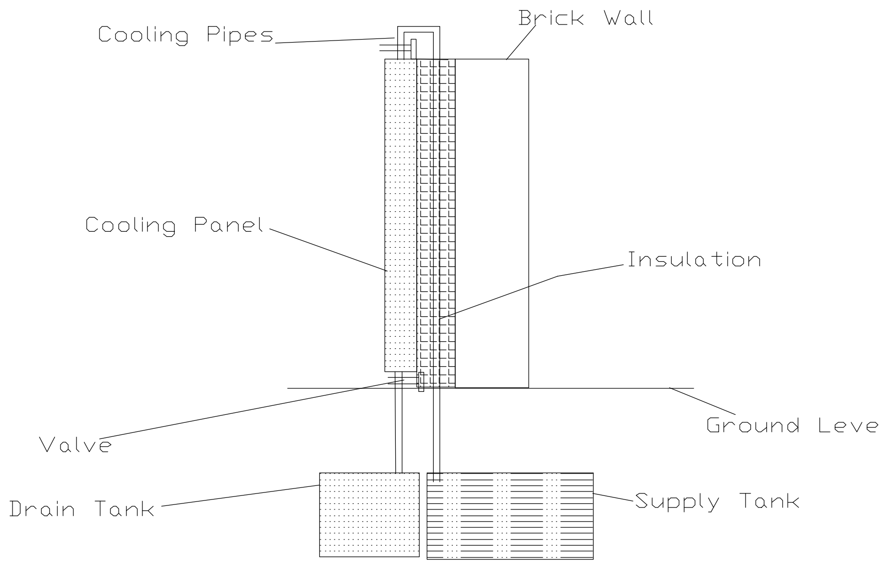

Fig.4 Geothermal Cooling System

In our floor plan we have also shown a small water pool in the living area. This could serve as an aquarium, if desired, and have a fiberglass or glass cover. Functionally, it would be a cooling source, with or without a link to the underground water tank.

(ii) Evaporative Cooling System

Once again, using nature as a guide, we noted that continuous and controlled evaporation of water from the surfaces of leaves is principally responsible for the cool and refreshing feeling experienced in the shade of a tree. Our design attempts to simulate this by attaching evaporative cooling panels at various places on the inside of the ceiling. A suitable spongy material is used, which is kept moist from a drip system fed by a suitably placed tank. An evaporatively cooled air current blowing through the channel keeps it cool and also generates a convective circulation cycle. The air is exhausted outside, so room humidity is not increased. Fig.5 shows the arrangement.

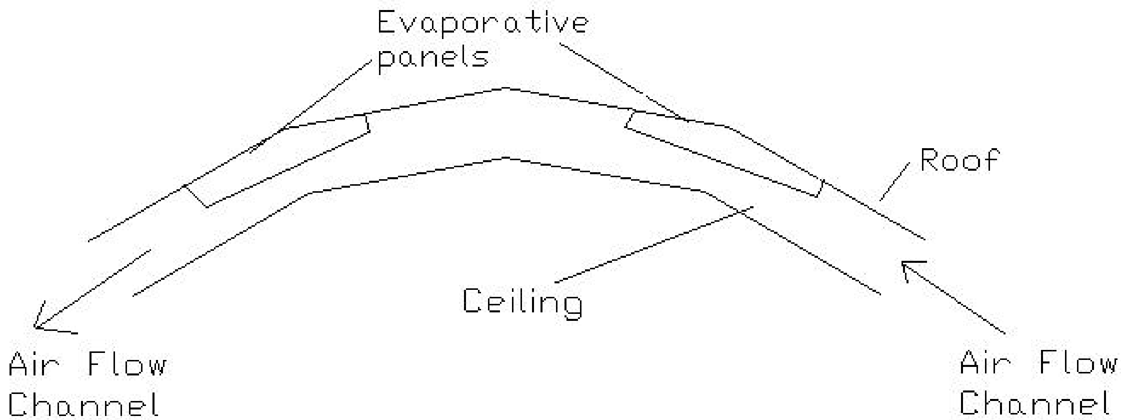

Fig.5 Evaporative Cooling System

(iii) Maneuverable Screens

Screens that hang down from the edge of the verandah roof on east and west sides protect the house from direct solar radiation in summer and other warm months. The screens are made from a light, weather-proof material in the form of a thin sheet. In the evening or night, or after the sun has moved out of sight range, the screens are lifted (manually by pulling on a rope, or electrically through a motor, which may be programmed and microprocessor controlled or switch operated). For winter application a screen is provided on the south side, which is kept open during the day and closed at night. This system helps to insulate the house at night, while allowing solar heat to come in through the large glass panels on the south side during the day.

(iv) Solar-collector & Radiation Shield

The roof, which we have designed as a dome for structural strength, supports a massive solar collector and heat shield, spanning the entire roof area (Fig.6). The assembly is a low pyramid with six panels. The panels on the north side are not part of the collector. Other panels – those on the east, south and west sides, function independently of each other, such that the ones receiving mostly direct normal radiation are active at a particular time in the day. Parabolic concentrators made of a low cost material covered with high reflectivity foil are used to generate high water temperatures in the pipes. The water pipes are enclosed in transparent tubes to reduce convective loss. (We are investigating the possibility of producing thermal power from this system, either through generation of steam and/or by operating it as a solar-heat based compressed air generation system [(6)]). The collector supplies hot water for domestic use. In winter, if needed, it can be used to supply hot water to the water panels inside the house, thereby helping to warm the house.

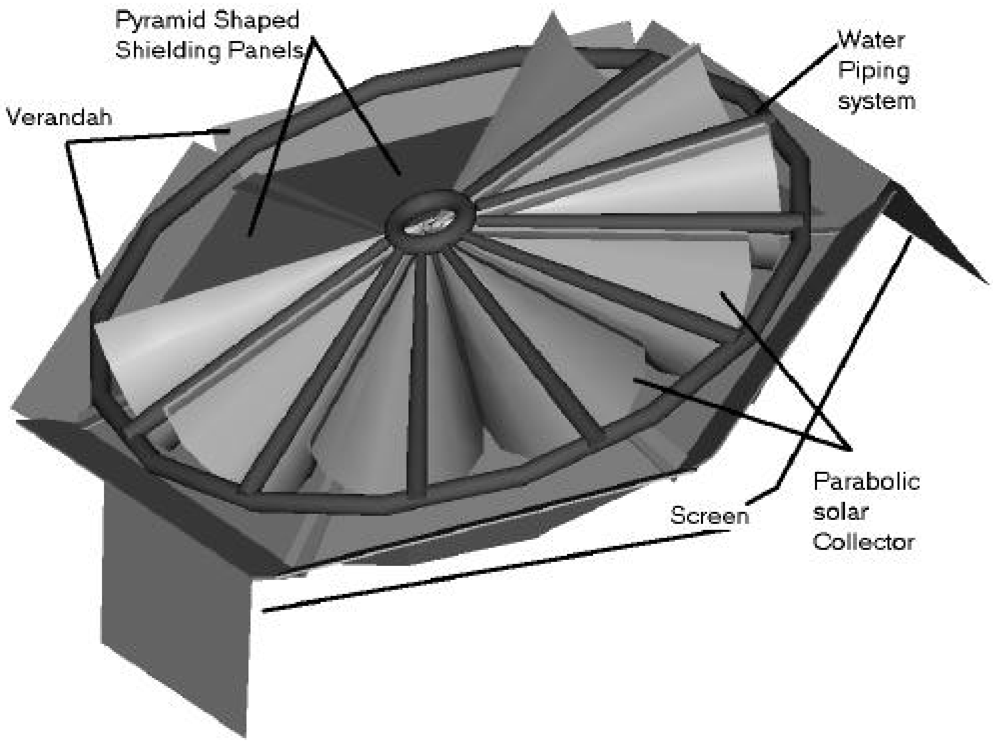

Fig.6. Solar Collector & Radiation Shield

(v) Oxygen-enrichment

One or more greenhouses at different sides on the verandah contribute to a refreshing environment, with air channels blowing oxygen-rich cool air (evaporatively cooled or sensibly cooled by water-filled panels) into the house. A distributed system could be built if desired to ensure ventilation of central areas.

(vi) Cross-ventilation

Fig. 7 shows the position of vents on the peripheral walls, designed to produce venturi driven crosscurrents. Shutters may be provided on all such openings for better control of ventilation [7].

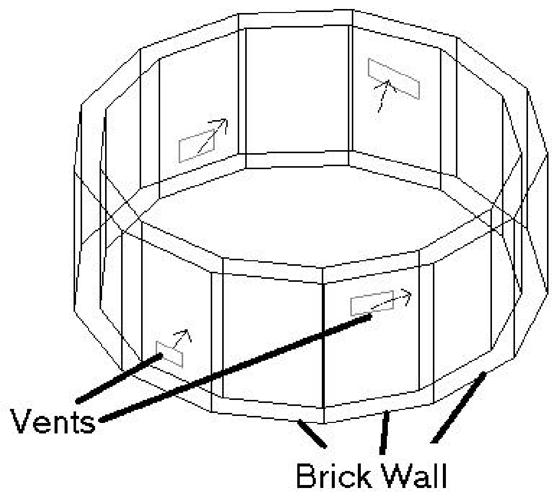

Fig.7. Cross-ventilation Enhancement

V. The project as a Teaching/Learning experiment

A.S. Neil, a pioneer of "alternative education" and founder of Summerhill, the famous British "free school", paraphrased a basic element of his philosophy in a memorable statement: "I hear and I forget. I see and I remember. I do and I understand".

Infants and preverbal children have the natural advantage of understanding the world by doing. Like all living organisms, they are instinctive experimenters, and even natural engineers. But as children make their way up and through school, their "learning" becomes increasingly associated with thinking, and even more so, with remembering. Since so much of what goes on in an educational institution, from grade school to college, revolves around testing and the importance attached to it, the inevitable result is the identification of learning with something that can be measured and easily and quickly tested.

In India the situation is made much worse by the sudden mushrooming of schools and colleges and the huge numbers of students in college – often as many as sixty in each engineering class. Virtually all "learning" in this scenario is reducing to hearing a lecture or reading a textbook and doing one's best to remember what has been read or heard. The Natural House Project is thus a radical break from tradition. It represents, in our view, the consummation and bringing together of many components of learning, thereby making it more than the sum of its parts.

Recently, an initiative at the University of Tennessee, called The Engage Program, has come to our notice [8]. In this program, designed for freshmen, students do physical homework to practice the concepts introduced in lectures. For our project we have taken mechanical and civil engineering juniors, who have had almost all the basic courses, such as thermodynamics, fluid mechanics, structural mechanics, heat transfer and material science, so that they can be assigned a truly meaningful design problem and challenged to carry it through to completion in two years.

Can they do it? Will we see a model "Natural House" on our campus (or elsewhere) next year – a standing testimony to undergraduate engineering creativity? We don't know the answer. What we do know is that as teachers we have tried to fulfill a longstanding obligation: to help our students learn by doing, rather than remembering.

The Natural House project offers a radical paradigm for engineering education by bringing art, science, engineering and technology together into an application that impacts our life profoundly – the nature of the homes we build and live in and whether our homes would, or would not, communicate with and respond to the ecology of life around us.

VI. Conclusion

The Natural House project offers a radical paradigm for engineering education by bringing art, science, architecture, engineering and technology together into an application that impacts our life profoundly – the nature of the homes we build and live in and whether our homes would, or would not, communicate and integrate with the vast and beautiful web of life around us. It is in the nature of life to support itself through local resources of energy and materials. It is not inconceivable that a house could be designed to behave like an organism, drawing primarily on locally available energy (sun), earth as a cooling source, water as coolant, plants as a source of oxygen-rich environment, warming of walls through solar-heated water, opening and closing of screens and solar shields in response to the movement of the sun, etc. Vernacular materials, such as bamboo and different types of clay, can also be used to enhance integration with local ecology. For insulation, the possibility of using recycled natural materials, such as cotton waste, can be investigated.

All in all, the project has proved to be a novel experiment in learning and teaching, in addition to making a contribution to nature-friendly engineering and architectural practice.

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