ENERGY CONSERVING HOUSING
FOR THE FEDERAL UNIVERSITY OF TECHNOLOGY
YOLA, NIGERIA

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A. SUMMARY

This study was part of a larger campus planning project for the new Federal University of Technology at Yola, Nigeria. Yola, a town of 100,000, is located in eastern Nigeria on the Benue River approximately 300 miles south-southwest of Lake Chad.

to Energy is of primary importance in new facilities design because of persistant electricity shortages and the high cost of diesel-generated electrical power. Mechanical cooling is typically the major consumer of energy, probably more than 80%, in university housing. Therefore strategies which reduce the energy used for cooling were the primary focus of this study. Daylighting and solar water heating were proposed as means of reducing the remaining 20% of the energy use. The proposed cooling method is stack assisted night ventilation of thermal mass. This cooling system can meet 100% of the average cooling load from June to February. During the three remaining months, the passive system must be augmented by mechanical refrigeration or evaporative cooling. The night ventilation of mass is a major departure from the cross ventilation system usually recommended for composite hot-humid, hot-arid climates such as Yola's.

The cooling system has major implications for housing design and campus planning. Night ventilation of mass can utilize courtyards and compact site planning which is quite different than the dispersed schemes required by cross ventilation cooling schemes. Compact planning results in substantially lower costs due to the sharing of walls within the building clusters and reduced length of utilities, sewers, and roads.

B. ENERGY USE IN EXISTING STAFF HOUSING

The University has built several types of housing in the past three years. Duplexes formed the basis for this study because they were inexpensive to build and will probably be a prominent type constructed for the permanent campus.

1. Characteristics of the Housing: All the single story housing is constructed from similar materials. The floors are concrete slabs, the walls are concrete blocks with cement plaster on both sides, the roofs are corrigated aluminum on purlins and trusses and the ceilings are 1/2" cellotac. The roof spaces are usually vented. The walls and roofs are not insulated. Windows are either louvers or casements. The house plans have a central room which extends the width of the house. The bedrooms and kitchen are usually double loaded on halls off the major space.

2. Estimate of Energy Use: Energy uses were not metered separately at the duplexes; therefore, energy consumption based on actual use is not available.

There are two energy sources used, bottled gas and electricity. The gas is used for cooking. Electricity is used for cooling, lighting, water heating, fans, and appliances. The majority of energy is used for cooling. Based on assumed use patterns 88% of the electrical energy is used for cooling, 3% for water heating, 6% for fans and appliances.

There are two basic strategies to reduce the amount of energy used for cooling. First, make use of the natural energies, like the wind and sun, for cooling. Secondly, improve the building design to reduce the magnitude of the cooling load.

C. CLIMATE ANALYSIS

Since residences, unlike offices or classrooms, do not generate a large amount of internal heat, the cooling load is primarily induced by the climate. Analysing the climate will reveal what causes the cooling load and what natural energies are available to assist in the cooling process.

1. Data Characteristics: Meteorlogical data has been collected in the Yola area for the past 15 to 20 years. The maintenance of the instruments has frequently not been to manufacturer's specifications. Therefore the data should be viewed with some skepticism.

	Average Maximum Temp. °F	Average Minimum Relative Humidity	Average Minimum Temp. °F	Average Maximum Relative Humidity	Average Wind Speed miles/hour
January	86	16%	66	36%	2.1
February	99	14	70	52	2.5
March	102	14	79	50	3.1
April (R)	104	18	77	97	2.9
May (R)	100	33	75	83	3.5
June (R)	95	64	75	91	2.6
July (R)	90	70	73	99	2.0
August (R)	88	62	73	92	1.8
September (R)	88	63	73	99	1.9
October (R)	93	65	73	91	1.5
November	95	28	66	75	1.7
December	95	21	63	53	1.9

(R) Rainy Season

Fig. 1 Temperature, Relative Humidity, and Wind Speed

The data used in this study (see Fig. 1) is from the meteorological station at Upper Benue River Basin Development Authority, Yola. The average monthly maximum and minimum temperatures are from the year 1982. The average monthly maximum and minimum relative humidities are from the year 1980-81. There is little data on maximum and minimum relative humidities. Usually only one humidity reading is taken at 10:00 a.m. By assuming that the water vapor in the air remains constant and the time of the day that maximum and minimum temperatures occur relative humidities that correspond to the minimum and maximum temperatures have been generated.

Hourly wind speeds are not recorded. The average speeds per hour can be determined by dividing the daily wind run by 24 hours. Since the wind usually blows much harder during the day than at night, the average wind speed overstates the night time condition and understates the speed during the day.

The predominant wind direction for the year 1983 was from the NE - NW quadrant according to the data from the Upper Benne River Basin Development Authority, Yola. The wind data from Vol. 1, "The Environment," of The Land Resources of North East Nigeria, Ed., P. Tuley indicates that the predominant wind direction is from the NE - NW quadrant from November to March (the dry season) but changes to predominately from the NW - SW quadrant from April to October (the wet season).

2. Bioclimatic Analysis: The bioclimatic chart (See Fig. 2) relates human comfort to four major climatic variables: temperature, relative humidity, wind speed and solar radiation. Any combination of temperature and humidity can be plotted on the chart and compared to the shaded area on the chart, the comfort zone, which is the range of temperatures and humidities at which people feel comfortable. The chart assumes low activity levels i.e. office work and temperate acclimatization. People accustomed to hot climates would probably have a comfort zone 2 to 5°F higher than shown.

The diagonal lines plotted on the chart represent the range of temperatures and humidities for an average day in each month in Yola. There are a number of observations one can make based on the plots. All daytime temperatures/ humidities fall above the shading line (the bottom of the comfort zone). This means that buildings should provide shade all year long. Shading is the single most important architectural strategy in Yola's climate.

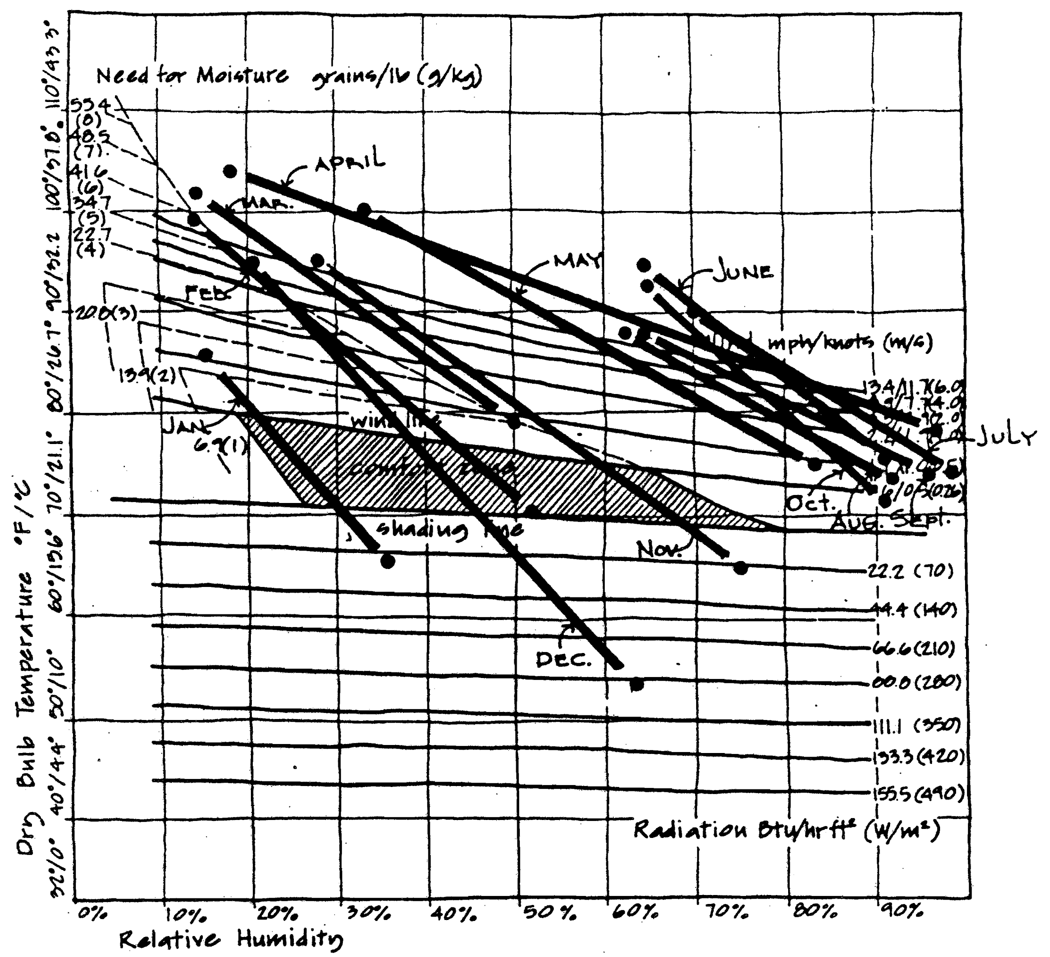

Fig. 2 Bioclimatic Chart

The average day lines divide themselves into two groups corresponding to the wet and dry seasons. It is this feature of Yola's climate which makes it particularly difficult to design for because part of the year is hot-arid and part of the year is hot-humid. The generic architectural responses that use natural energies in those climate types are totally different. Buildings designed to utilize the natural energies available in hot arid climates are clustered together, have small openings and are built from materials with high thermal capacity. Buildings for hot humid climates require just the opposite, they are spread apart and have large openings for ventilation and are built from materials with low thermal capacity.

The days plotted on the right of the chart, April through October, are intersected by a series of wind lines which run parallel to the top of the comfort zone. The wind lines represent different wind velocities. If a given temperature and humidity plot fall within the wind lines and there is that much wind available, then a person would feel comfortable at that temperature and humidity because of the increased rate of evaporation caused by the wind. For example, the lower end of the average August day falls at 73°F and 92%RH, slightly above the comfort zone. However if there were a wind of .6 to 1.1 mph available, a person would feel comfortable rather than too hot.

The average days plotted on the right hand side of the charts are good candidates for achieving comfort by moderating the high temperature and humidity by ventilation if the wind is available. The lower ends of the temperature/ humidity lines representing the time after sun set, can be moderated with windspeeds of 4.5 mph or less. The upper ends of the plots representing late afternoon are beyond the capacity of wind to make one feel completely comfortable.

The average days plotted on the left side of the chart (the dry season), while representing somewhat higher maximum temperatures, also tend to have lower minimums. The lower minimums are particularly valuable because the lower temperature can be used for cooling building mass at night. The tops of the curves intersect a series of dotted lines which parallel the top of the comfort zone. The dotted lines indicate how much water must be evaporated into the air to cool it and make it comfortable. For example, the top of the average January day plot indicates that if between 1 and 2 grams of water per kilogram of air is evaporated into the air it will be cooled sufficiently to render the 86°F, 16% R.H., comfortable. As with the family of lines on the right, ventilation is a viable strategy for cooling if wind is available.

3. Mahoney Analysis: Mahoney proposed an analysis technique especially designed to deal with composite climates like Yola's combination of hot-arid and hot-humid. The analysis is based on determining which climate type is dominant, deriving most design strategies from that type, and then modifying those strategies to accommodate the secondary climate type. The result of the analysis is a series of design recommendations. The recommendations for Yola are:

(i) Building layout - Elongated along the east-west axis so that the principal elevations face north and south and the predominant areas of glazing are easy to shade.

(ii) The buildings should be spaced apart, but protection from hot dusty winds should be provided.

(iii) The rooms should be single-banked with windows on the north and south to ensure air movement by cross-ventilation.

(iv) Openings should be 20 to 40% of the wall area. There should not be any openings on the east or west elevations.

(v) Both interior and exterior walls should have large thermal capacity.

(vi) The roof should be heavy with at least an 8 hour time lag.

(vii) Provision should be made for outdoor sleeping.

Many of the colonial houses in Yola incorporate most of the features recommended by the Mahoney analysis. This is especially true in regard to east-west elongation, shading, single loaded rooms for ventilation, building spacing, and massive wall constructions.

D. DESIGN CONSIDERATIONS

1. Compact vs. Dispersed Site Planning: The Mahoney analysis clearly indicates that buildings should be dispersed and designed for cross-ventilation. The bioclimate analysis indicates that in the months during the rainy season, ventilation is a good strategy. The recommendations of both of these analyses are predicated on the availability of wind for ventilation. The bioclimatic analysis indicates that ventilation air speeds during the wet season months would have to be 1 to 4.5 mph at night and 4.5 to 13 mph during the late afternoon to achieve comfort.

Outside air velocity is likely to be reduced by 50% on the average by insect screens, window configuration and size, and less than optimum wind direction. Therefore, the exterior velocities would need to be 2 to 9 mph at night and 9 to 26 mph during the day. The wind data from the section C, "Climatic Analysis" reveals that the average daily wind speed in the rainy months is 2.3 mph with a maximum monthly average of 3.5 (May) and a minimum monthly average of 1.5 mph (October). As noted earlier, the average probably understates the day speed and overstates the night speed due to the fact that the wind is powered primarily by high temperatures created by solar energy during the day. These temperatures are greatly reduced at night and the windspeed is correspondingly reduced. If the wind during the day were twice the average, it would be 4.6 mph. If the wind at night were half the average it would be 1.15 mph. It is clear that there is not sufficient wind speed in Yola to produce comfort by cross-ventilation. Of course, any wind ventilation will make one feel more comfortable. The lack of wind puts the design recommendations, based on cross-ventilation i.e. spaced buildings, single banked rooms, and east-west elongation, into serious question as appropriate strategies for Yola.

The inadequacy of wind speeds for ventilation and the fact that during several months of the year cooling can be achieved by compact organizations, suggest that cooling strategies associated with compact planning should be considered. Compact planning clusters buildings close together so that most of the walls are shared and therefore shaded from the sun. The buildings use massive construction so that cooler night air can be flushed through the building, ventilating its mass. The building is then closed tightly the following day, and the heat gain of the day is absorbed in the building's mass, which is then cooled the following night. Because the rooms in the building are clustered rather than spread out they present less skin area per unit volume of interior space and therefore gain less heat through the exterior skin. This also means that mechanical cooling methods which rely on cooling the inside air volume to below the outside air temperature, like evaporative cooling or refrigerative cooling, are very compatable with compact planning.

2. Wind vs. Stack Ventilation: Wind powered ventilation has the advantage of cooling the occupants of the building by increasing their rate of heat loss in addition to removing heat accumulated in the building from the sun, etc. However, while there is probably enough wind speed in Yola to remove the accumulated heat from the building there is not enough to completely cool the occupants.

Stack ventilation, by contrast, is powered by hot air rising. Cool air is drawn low into a building and exhausted through a chimney. The rate of ventilation is dependent on the height of the stack and the temperature difference between the top and bottom of the stack, so the system can work without wind. The resulting rate of air movement is low, and, while able to remove accumulated heat from the building, it does not cool the occupants by increasing their rate of heat loss. The system works well in compact building arrangements and does not require the building spacing that a wind powered cross-ventilation system does.

3. Night Ventilation of Mass Cooling Versus Cross Ventilation Cooling: Proper building spacing, orientation, and window sizing will allow the wind to blow through the building removing heat and cooling the occupants at the same time. As has been mentioned, there is insufficient wind speed in Yola to completely cool the occupants. In addition, the wind is predominately from the west during the wet season making buildings that have their openings facing north and south for easy shading more difficult to ventilate.

Buildings which are constructed of massive materials that have a large thermal capacity can take advantage of the diurnal temperature change to cool the building. The buildings are flushed with cooler air at night to remove accumulated heat from the building's mass. During the day, the building is tightly closed to reduce heat gain from infiltration. The mass absorbs what heat penetrates the skin of the building and is generated inside the building by lights, people, and cooking. The next night, the building is again flushed with cooler air to remove the heat accumulated in the mass.

Because the nighttime temperatures are not very low for some months compared to the comfort zone, the ability of the night air to remove heat from the mass is limited. This means that the building must be carefully protected from heat gain during the day by shading, high insulation levels and relatively air-tight construction so that the amount of heat accumulated in the mass is as small as possible. The cooling capacity is a function of the amount of mass area exposed to the buildings interior. Therefore, interior surfaces, walls, floor, ceilings, should be massive.

4. Compatability with Mechanical Cooling Systems: Mechanical cooling systems maintain a temperature difference between inside and out. This is quite different than cross-ventilation systems in which the inside air temperature is slightly higher than the exterior temperature. It is similar to night ventilation systems which maintain a temperature difference during the day but not at night.

The amount of energy used by mechanical systems can be greatly reduced by reducing heat gain by shading, insulating, reducing skin area, and infiltrations. Therefore, mechanical cooling systems are more compatable with night ventilation systems than they are with cross-ventilation systems.

E. DESIGN RECOMMENDATIONS

1. Compact Courtyard Plan: Based on an analysis of the Yola climate, a compact site planning of court yard houses using night ventilation of mass as their primary means of cooling was recommended.

Figure 3 shows the diagramatic design of a two bedroom house similar in size to the two bedroom duplex currently being built at the FUTY campus. The design principles apply equally well to larger or smaller houses. All of the rooms look out to the interior courtyard with the exception of the kitchen which looks out to the work/parking court. The public entrance to the building is through the entrance court into the living room.

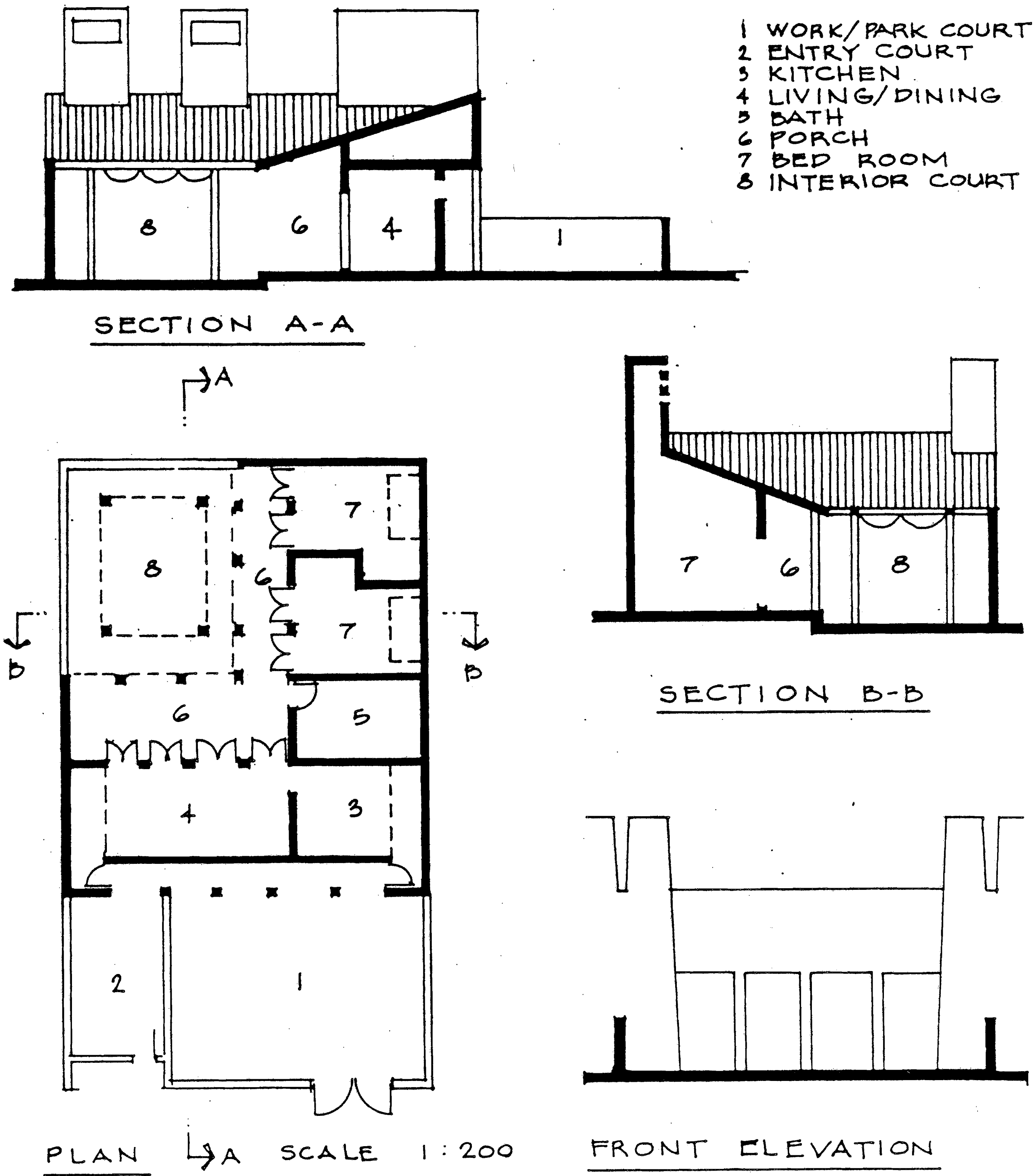

Fig. 3 TWO BEDROOM COURTYARD HOUSE

The plan is designed so that it can face either north or south to facilitate clustering. Figure 4 shows a series of building clusters between two streets. The clustering allows much of the buildings' walls to be shared and therefore protected from the sun. The work/parking courts provide a private outside area for cooking/vehicle maintenance, gardening or animal husbandry. The interior court, besides providing a private exterior living space which greatly expands the apparent size of the house, plays an important cooling role.

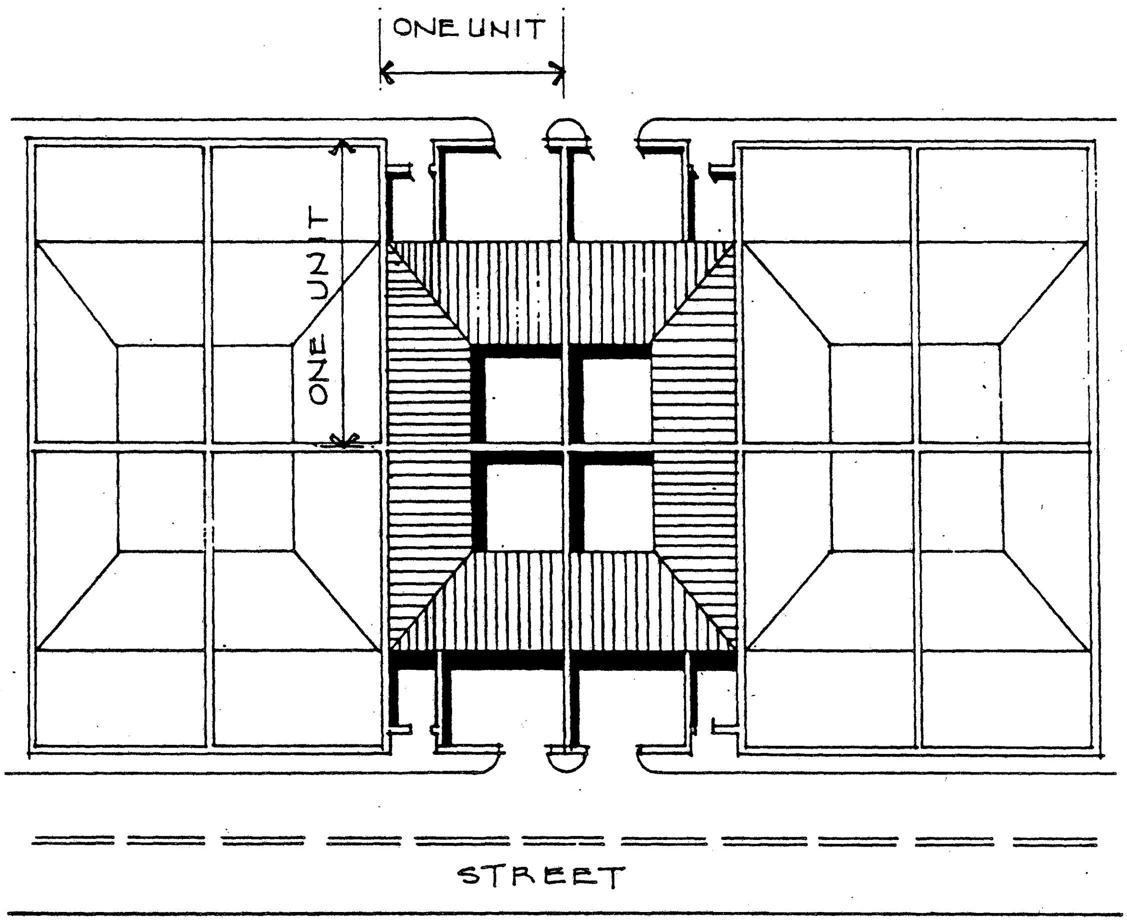

Fig. 4 CLUSTER PLAN

2. Night Ventilation of Mass - Cooling: The basic cooling strategy employed is stack assisted night ventilation of thermal mass. As Figure 5 shows, at night the roof and courtyard of the building are cooled as a result of radiating their heat to the cold night sky. The ambient air is cooled by these surfaces and because the cool air is heaviest, flows down the roof and collects in the courtyard. The cool air from the courtyard is drawn into the building through windows and doors, picks up heat from the massive construction of the walls and floor, becomes lighter because of its higher temperature, rises to the top of the room, and flows out through the stack. The system will continue to operate as long as the air in the courtyard is cooler than the air in the building. Fans can be used in the stacks to increase the rate of air movement and ensure that maximum cooling occurs. The interior courtyard should be designed as a cool outside sitting and sleeping area.

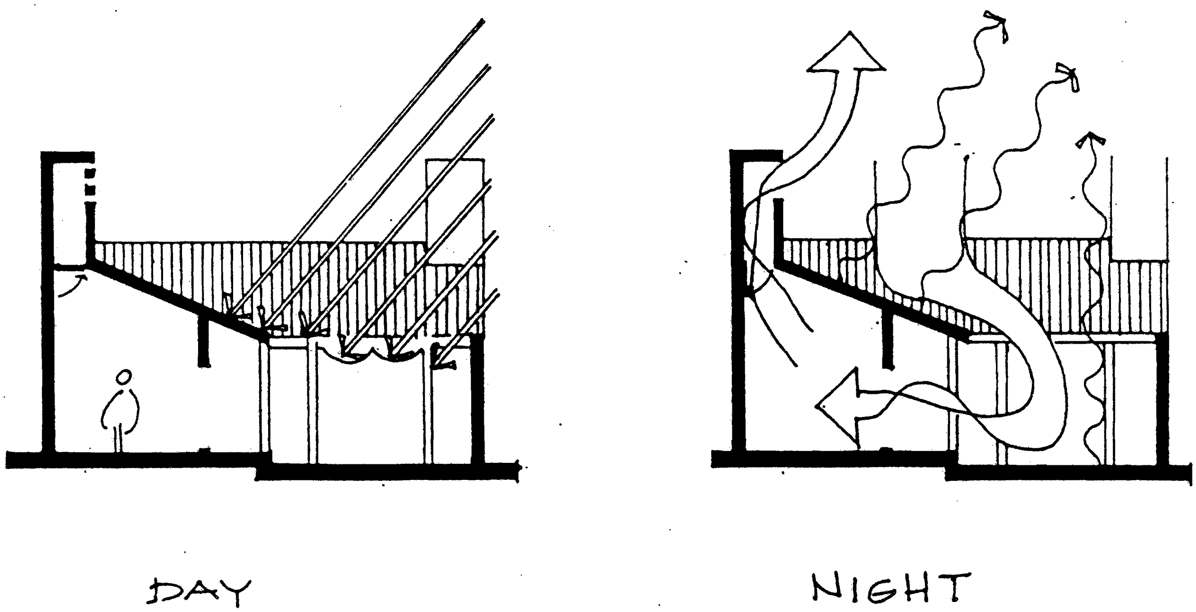

Fig. 5 NIGHT VENTILATION OF MASS

During the day, the shade should be extended over the courtyard to protect it from solar radiation. The windows and vents are closed to stop the warm outside air from entering the building. The mass in the building which has been cooled the night before absorbs the heat generated in the building by lights and people and the heat which penetrates the skin of the building.

During the dry season, water sprayed in the court will greatly reduce the air temperature in the court making it more comfortable during the day and will lower the temperature of ventilating air at night.

Stack assisted night ventilation cooling will meet the average cooling load for the months of June through February. During the months of March, April, and May the system cannot supply 100% of the cooling. The worst month is March when the system can supply approximately 23% of the cooling. During these months and extreme days all year, mechanical cooling and ceiling fans should be used to supplement the stack assisted night ventilation of mass system.

3. Insulation and Shading: The stack assisted night ventilation system has limited cooling capacity; therefore every effort should be made to reduce heat transfer from the exterior to the interior. The building should be heavily insulated with walls of R-13 and a roof of R-26, and tightly constructed to reduce infiltration to one air change per hour. High levels of insulation are difficult to achieve using readily available materials. The development of a building insulation based on indigenous materials would be a welcome addition to the building industry and the economy.

Shading of glazing is also crucial to reduce heat transmission. All openings should be 100% shaded. As Figure 3 indicates, the windows which face the interior court are protected by a roof overhang which forms a screened walkway and porch. The openings which face the exterior court are recessed into the building's facade to form a porch which protects them from the sun.

4. Massive Construction: The larger the surface of the mass that is exposed to the night ventilating air, the larger the cooling capacity of the system. Therefore, it is important that all interior surfaces be constructed of at least 4" thick masonry. The design diagramed in Figure 3 utilizes a metal roof system because it is readily available and inexpensive. However, a concrete roof (ceiling), if used, would increase the cooling capacity of the system by about 30%. Obviously any insulating material should go on the exterior of the skin surfaces so that the mass may be exposed inside the building.

5. Stack Assisted Night Ventilation of Mass Cooling Capacity - Average Conditions:

February - Cooling capacity of 168,870 Btu per day exceeds the cooling requirement of 12,4921 Btu per day by 43,949 Btu's. Therefore, the mass temperature will not reach the maximum limit of 85^{o}F. The minimum mass temperature will however, be above 80^{o}F.

July - The cooling capacity of 109,512 Btu per day easily exceeds the cooling requirement of 55810 Btu per day. Therefore, the mass temperature will not reach its allowable maximum of 85^{o}F however, it will be above 80^{o}F.

March - The cooling capacity of 44,034 Btu per day meets 23% of the daily cooling requirement of 188,030 Btu's.

F. IMPLICATIONS FOR CAMPUS PLANNING AND OTHER BUILDING SYSTEMS

Compared to housing designed to utilize cross-ventilation for cooling, housing utilizing night ventilation of mass has several advantages. Because the site planning is compact rather than dispersed, more buildings can be put in less land area. This means that less land needs to be purchased and utility lines, sewers, and road ways may be significantly shorter, resulting in much lower costs. Because of the density of housing, centralized waste treatment facilities are probably necessary rather than the decentralized septic tanks which are now in use. The cost of individual buildings is less in compact schemes because walls between buildings can be shared.

It is important to realize that while compact planning that relies on a night ventilation of mass cooling strategy for cooling is appropriate for housing, it is not appropriate, in Yola's climate, for buildings with large amounts of internally generated heat from people, lights or equipment like classrooms, lecture halls, some laboratories and large office spaces. This is because the nighttime temperature does not drop very low and the cooling capacity of the building's mass is limited. Buildings which generate large amounts of internal heat easily exceed this capacity. Appropriate strategies for these buildings are daylighting to reduce the internal heat from electric lighting, and daytime cross-ventilation to discharge internal heat as it is generated and to cool the occupants.

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