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THERMAL PERFORMANCE ANALYSIS

OF THE TUTUME HEALTH CENTER

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PREFACE

This report describes a portion of the work undertaken by Mr. Scott Matthews at the Botswana Renewable Energy Technology (BRET) project between December 15, 1984 and April 24, 1985. Mr. Matthews is an architectural consultant for Associates in Rural Development, Inc. (ARD), the contractor which is implementing the BRET project (number 633-0209) for the U. S. Agency for International Development (AID) under contract number 633-0209-C-00-1024-00. The BRET project is jointly funded by the Government of Botswana (GOB) and AID.

1.0 INTRODUCTION

The indoor temperatures of health centers are currently unregulated in Botswana. The centers are neither heated nor cooled to maintain comfort-zone temperatures, so patients can suffer some discomfort on summer afternoons and winter nights. Of the two, winter cold appears to be of greater concern to professional staff than summer heat. Consequently, the Ministry of Health (MOH) has expressed an interest in adding a central heating system to new health centers. The Ministry of Works' Buildings Department presumes that such a policy would substantially increase both the capital and operating cost of the new centers, which would far outweigh the benefits.

The Buildings Department has suggested an alternate strategy of improving the thermal performance of the buildings themselves. This policy also would increase the centers' capital cost, but by less than the addition of a heating system, and their annual operating cost would not be materially affected. The viability of this alternative depends on whether the comfort level of the patient wards is actually improved in proportion to the expenditures made to do so.

This paper reports on preliminary analyses made to quantify the effect on thermal performance of the design and construction options which are practical to apply to a health center. The performance of an architectural design option is not strictly comparable to that of a heating system, as a design does not "guarantee" a particular level of comfort, but rather shifts the daily cycle of interior temperatures so that more hours fall within the comfort zone. Comparisons, therefore, are relative, based on a design option's "worth" in terms of its reduction in the cost of heating the building relative to the cost of heating an identical building without the design option. If the decision were to provide heating systems in future health centers, these comparisons could be used in a life-cycle cost analysis of the design options to determine which combination of architectural measures would result in the lowest, long-term cost of building and operating a center. Conversely, decisions as to how many design options to include in future centers would depend on what value the Government of Botswana (GOB) places on incremental improvements in patient comfort on a seasonal basis. Temperatures in the wards would still be uncomfortable on extremely hot afternoons and cold mornings, but patients and staff would be comfortable more often than they are now.

This analysis is based on design options which are practical for inclusion in the general/TB ward building, designed for addition to the Tutume Health Center (the date of drawings was January 25, 1985). Its conclusions are applicable to both the new maternity ward and diagnostic unit, as they are similar in design and function. The weather descriptions used for computer simulations of building performance was typical of Gaborone,

which is slightly cooler than Tutume in winter with lower annual average windspeeds. The differences are not large enough, however, to significantly affect the results.

This study makes no attempt to determine the cost-effectiveness of various design alternatives, as their incremental construction cost is not known. The study does recommend options for further analysis, based either on their potential for improving patient comfort or reducing the cost of heating the ward, if heating is installed. Further study of these options should include analysis of their incremental cost by the Buildings Department and a review by the Department of Electrical Engineering of the assumptions and conclusions of the Appendix, "Heating Cost Comparison."

2.0 FINDINGS

The salient observations of this study are summarized below. However, it should be emphasized that they must be reevaluated in light of accurate cost projections made during the project's detailed design phase.

"As-Designed" Performance

The ward buildings will function quite well as designed. Their main deficiency, common to most buildings in Botswana, is that they will be chilly on early winter mornings and too warm on early summer evenings. Neither winter nor summer average maximum temperatures (16°C and 29°C) exceed the range of tolerance for patients, but improvement is desirable to speed recovery.

Heating Costs

Heating the Tutume Health Center with coal, as an adjunct to a coal-fired, domestic hot water system (DHW), is feasible. Its capital and operating cost, averaged over the first 10 years of the center's operation, might range from P500 to P1,100, depending on the extent of the heating system. Heating with any other fuel is prohibitively expensive and would increase Botswana's exposure to risks associated with importing energy. Heating only the patient rooms of the wards and diagnostic unit with portable LP gas or electric heaters would cost between P1,400 and P2,200 per year, three to four times the cost of coal heating.

Wall Insulation

Walls account for only 12 percent of the heat loss from the ward buildings, so their insulation is not a major factor in improving thermal performance. Nevertheless, given the existance of the cavity walls, they should be insulated with poured vermiculite or polystyrene beads, if doing so is not expensive. High-performance board insulation is not necessary.

Roof Insulation

A 50 mm fiberglass blanket laid above the ceiling is close to optimum for the Health Center buildings. More insulation reduces winter solar heating through the roof. Less or no insulation increases summer heat gain, raising afternoon temperatures in the patient rooms.

Thermal Mass

Health Center buildings, with their many interior partition walls, have sufficient thermal mass to provide a 24-hour "thermal flywheel," which is desirable and sufficient.

Trombe Wall/North Wall Solar Collector

The added expense of Trombe walls to increase passive solar heating is not justified, as there is sufficient interior thermal mass to provide a similar performance, if coupled to north facing windows. Replacing the north-facing cavity wall with a solid 230 mm block wall to act as a low- or no-cost solar collector provides a net benefit under some assumptions, but not under others. On balance, it is not worth any incremental investment, but is worth doing if it is cheaper than a cavity wall. This conclusion should be reconsidered when accurate costs are known.

Adding Windows for Passive Solar Heating and Ventilation

Adding standard, metal framed windows is not effective in improving winter average temperatures, as increased heat loss and infiltration offset much of the beneficial solar gain. The exception may be in patient rooms, where larger windows will warm the rooms earlier in the morning and provide more ventilation area on summer evenings. To balance this increased ventilation area, the size of the south-facing, clerestory windows should be increased, although the net result of this will raise the buildings' thermal load slightly.

Ceiling Fans

The Health Center's ward buildings will not rapidly cool on summer evenings, even with increased window area. Their windows should be shut during the overheated period of summer days to get the benefit of the "coolth" stored in their massive walls the night before. For a substantial portion of summer days, therefore, patients need increased air movement in order to remain comfortable. Therefore, each room housing patients and working staff should be provided with a ceiling fan. The capital and operating cost of fans, averaged over the first 10 years of the center's operation, would be approximately P40 per fan, or P400 for the general ward. The use of fans would assist somewhat in cooling the buildings' mass at night, but the cost of electricity is so high (36 t per kWh), that they should only be used for cooling people.

3.0 DESIGN CRITERIA FOR THERMAL PERFORMANCE

There are four major criteria to be satisfied if a building is to provide a reasonable level of thermal comfort in Botswana's climate. The performance of the general ward, as it was designed, was evaluated in terms of these criteria.

Low building U-value (rate of heat loss)

Generally, buildings in Botswana are not insulated; doors and windows are not weatherstripped; and gaps in construction are not sealed. These practices, which primarily affect winter comfort, have not been considered necessary in a climate having, by European or American standards, a short, mild winter. Furthermore, since the winter days are very clear, buildings do warm up by mid-morning and, because their masonry walls retain heat, remain comfortable through early evening. On the other hand, their high rate of infiltration rapidly cools them during the night so that they are distinctly chilly by morning.

This is not a desirable situation for a hospital ward, as sick people are often sensitive to low temperatures and, if very ill, can be in some distress in the hours before dawn. The U-values for the general ward, as designed, are shown in Table I.

Table I - General Ward U-Value

Surface	Construction	U-Value	% of Total
Roof	IBR Roof Air Space 50 mm Fiberglass Softboard	217 W°C	15
Walls	115 mm Cavity Wall No Insulation Paster Both Sides	167 W°C	12
Floor	Slab on Grade	128 W°C	9
Windows	Single Glazed Steel Frame	329 W°C	24
Infiltration*	1.5 air changes/hour	552 W°C	40
Total		1,393 W°C	100

* Estimated

It is clear from inspection of the sources of the ward's heat loss that measures taken to reduce infiltration would be by far the most effective, followed by improvements in window performance or a reduction in window area. Unfortunately, these measures are also the most difficult to accomplish. Reducing infiltration would require careful attention to construction details and importing windows and doors equipped with durable weatherstripping. Heat loss through windows could be halved by double glazing, at substantial expense. Window area should not be reduced, as it is needed for light, ventilation, and view. In fact, some increase in window area may be desirable to improve winter solar heating and summer night cooling.

Orient building correctly with respect to sun's path

Minimize east- and west-facing walls and glazing; orient building generally on a north-south axis; shade windows and walls from summer sun; emphasize north-facing windows; and design north wall for passive solar heating.

The buildings to be added at Tutume are well conceived in this regard. Their glazing is equivalent to 14 percent of the floor area, a reasonable fraction for energy-conserving design practice. Half the glass area is in the north wall, comprising 28 percent of the wall area, also a reasonable proportion. Only 10 percent of the glass faces east and west. The buildings may benefit from adding more glass to the north wall for passive solar heating, but the current window sizes and locations are representative of good practice.

Provide interior thermal mass having a high heat capacity and large surface area to store heat and dampen diurnal temperature swings

Buildings in Botswana inherently meet this criteria due to their masonry construction and concrete slab floors. The design goal is to provide sufficient thermal mass, combined with a low rate of heat loss, to provide a thermal "flywheel" capable of storing heat for many hours. In winter, the thermal mass should store enough heat to temper the building through a night and into the following day, still giving off heat as the building begins to warm from solar heating. In summer, the opposite effect occurs. The mass, cooled during the night, should have sufficient capacity to absorb heat from the building throughout the following day.

A measure of how much mass is enough is suggested by the calculated "time constant" of the building, which evaluates the area, thickness, and density of the building's mass, and its rate of heat loss, to determine the time the building would take, if heated or cooled, to reach equilibrium with a steady-state outdoor temperature. It takes one "time constant" for a heated building to cool 63 percent of the way to outdoor equilibrium, but three "time constants" to actually reach it. A time constant

of 20 hours or more is recommended for passive solar heating in climates having clear winter skies and large diurnal temperature swings. The general ward building, as designed, has a 24 hour "time constant," largely due to its many masonry partition walls. The building has a very large mass surface area and, thus, a high heat capacity, which more than offsets its high rate of heat loss. Improving its performance depends, therefore, not on adding more mass, but rather getting more solar heat into the mass on winter days and reducing heat loss at night.

Provide sufficient operable window area, on opposite sides of the building, to ensure breeze and buoyancy-driven, ventilation cooling of thermal mass on summer nights

Calculating ventilation performance, like infiltration, is not an accurate procedure, as both calculations depend on assumptions about how much air moves through the building and what outdoor wind speeds are likely to be when windows are open. An indication of how much vent area is needed can be estimated from a second version of the building "time constant," this one modifying the building's U-value with a very high infiltration rate, corresponding to the effect of open windows. The design goal for the "open-building time constant" is six hours or less, which corresponds to the need to cool the mass overnight so that it will have the capacity to absorb heat from the building during the overheated hours of the following day. The "as-designed" building's "open time constant" is 12 hours, assuming the use of insect screens on all windows and a constant breeze of .9 meters per seconds. (This is the average summer wind speed in Gaborone, which may not be relevant to conditions in Tutume). In any case, the calculated value is far enough from the design goal to suggest an increase in operable window area on both north and south sides of the building. This recommendation may hurt winter performance if the building's heat loss is increased more than its ability to collect winter sunlight.

4.0 THERMAL PERFORMANCE OF "AS-DESIGNED" BUILDINGS

The additions to the Tutume Health Center are sound in their basic design when judged by the thermal performance criteria already discussed. Nevertheless, because the building's rate of heat loss is quite high and its north-facing glazing area limited, it will not be as warm as needed during winter. Table II gives the monthly average temperatures of the general ward, as predicted by the CALPAS 3 thermal simulation program. The weather used for the simulation (Gaborone) has somewhat lower winter temperatures than the north-eastern region of the country, so the building's average temperatures in Tutume would be one degree higher in winter than those shown.

Table II - "As-Designed" Ward Monthly Average Temperatures

	Indoor (°C)			Outdoor (°C)			
	Low	High	Mean	Low	High	Mean	(kWh/m2dy)
JAN	23	29	26	19	32	26	5.22
FEB	22	28	25	19	31	24	5.75
MAR	21	27	24	18	31	24	6.21
APR	19	24	21	13	28	19	6.23
MAY	18	22	20	8	24	16	6.15
JUN	15	19	17	4	23	12	5.17
JUL	14	19	17	4	22	12	6.76
AUG	17	22	19	6	26	14	6.38
SEP	19	25	22	12	29	19	6.09
OCT	20	27	23	15	31	22	6.51
NOV	21	28	24	17	31	23	5.90
DEC	22	29	25	18	32	25	5.43
ANNUAL	19	25	22	13	28	19	5.99

Both the summer and winter indoor high and low average temperatures are almost reasonable for an unheated building, and they would likely be acceptable to healthy people in a residence. To hospital patients, however, they would cause additional discomfort and might even prolong recuperation. Moreover, the temperatures predicted by the simulation depended on two assumptions as to how the ward would be operated, which affect the results. First, the ward was assumed to be operating at about 75 percent of its patient capacity, with some use of electric lighting and light cooking. Second, it is assumed that the staff would operate the building's windows correctly to help cool the wards in summer, closing them and drawing light curtains during the heat of the day and opening them in early evening. If the ward has only a few patients, it would be cooler in winter and summer, and if the windows are left open throughout the summer, it would run close to outdoor temperatures during the day.

5.0 HEATING THE "AS-DESIGNED" BUILDINGS

Limitations of the Simulation

Predictions of the amount of heat needed to maintain a certain level of comfort in a building rarely agree with actual experience, since the outcome is easily influenced by variations in weather patterns from year to year and the behavior of the occupants. The main value of predictions is in comparing the performance of competing design options in a relative sense. For example, if the simulation of design option "A" requires 20 percent less heat to maintain a certain set of conditions than design option "B", it is likely to perform better under actual conditions, although the absolute amount of heat needed may be very different from that predicted. Furthermore, because the simulated building is "built" from assumptions about every aspect of its design and construction, many of which will be different from what is actually constructed, differences in the performance of design options must be enlarged (i.e., greater than 15 percent) for them to have any validity.

Annual Heating Costs

Figure 1 compares the annual heating load of the general ward for several combinations of operating and design assumptions (see Table III for key). Design Options TEMP, GAIN, and INFL investigate the sensitivity of the building to different assumptions as to its operation, in order to place the comparison of design options in context. Option BASE corresponds to the "as-designed" building with the addition of poured insulation in the cavity wall. The simulated buildings are operated as described for the unheated simulation (Table II), except that they are heated as necessary in winter to maintain the lower of two thermostat settings.

Table III - Thermostat Settings

Low	18°C	6AM - 7PM
	13°C	7PM - 6AM
High	20°C	6AM - 7PM
	13°C	7PM - 6AM

To heat the general ward to the "low" temperature setting would require about 15 gigajoules (GJ) of heat per year. This is equivalent to the energy of approximately 1.1 metric tons of coal burned at a 50 percent seasonal efficiency in a boiler, and the resulting heat distributed through a hot water circulation loop and radiators in each room.

Figure 1

Annual Heating Load

(to maintain 18C day, 15C night)

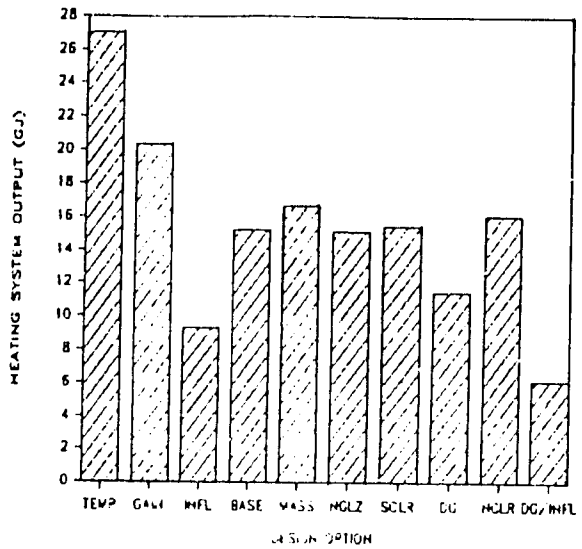


Table IV - Simulation Key*

TEMP	BASE, high thermostate settings (20°C)
GAIN	BASE, -1/2 interior heat gain
INFL	BASE, -1/3 infiltration
BASE	"As-designed," vermiculite wall insulated, exterior white
MASS	BASE, 230 mm solid north wall painted dark color
NGLZ	BASE, increased north glazing area (E7H vs. D7H windows)
SCLR	NGLZ, increased south clerestory area (1-HCH vs. GX7)
DG	NGLZ, double glaze all windows
NCLR	SCLR, add north clerestory equivalent to south clerestory
DG/INFL	DG, -1/3 infiltration

*Lower thermostat settings unless noted.

The cost of heating has been estimated for coal, LP gas, and electricity (see Appendix). For several reasons, a centralized coal-fired boiler appears to offer the lowest long-term cost, although its initial capital cost is much higher than the cheapest alternative--portable electric heaters. Alternate approaches to heating the Tutume Health Center would result in the following approximate annual costs:

- heat only patient rooms of the wards and diagnostic unit (425 m^2) with coal-fired, hot water radiators: P530/year;

- same as above, heated with portable LP gas heaters: P1,400/year; or electric heaters: P2,200/year;

- heat buildings housing the primary functions of the Tutume Health Center (CWC/OPD, pharmacy, diagnostic unit, general and maternity wards, administration, 1,100 m^2) with coal: P1,114/year.

6.0 SENSITIVITY OF HEATING COSTS TO OPERATING ASSUMPTIONS

The estimates of the cost of heating stated earlier are useful for comparing the relative merit of different types of heating systems and, to a lesser degree, placing a value on architectural measures used to reduce the cost of heating. The costs given, however, are not likely to be accurate predictions of actual experience. The annual heating loads of the TEMP, GAIN, and INFL design options given in Figure 1 illustrate the effect of three assumptions concerning the operation of the building.

Infiltration

Forty percent of the building's heat loss rate is due to infiltration. The simulations assume an infiltration rate equivalent to 1.5 air changes per hour, which is typical of standard, residential scale construction. Design option INFL shows a 38 percent reduction in heating load (from the BASE option), if the infiltration rate were only one air change per hour. Because the predicted heating load is very sensitive to this assumption, and because the assumption can only be an educated guess without detailed testing of the actual building, the actual load may vary from predicted by a very large margin.

On the other hand, the simulation is valuable in indicating the substantial benefit to be gained from careful construction and the use of weatherstripped windows and doors, if they were available. In addition, there appears to be no practical justification for the use of air-bricks in the health center building's exterior walls. Eliminating them would close off the equivalent of a 7 cm diameter hole per brick, or one third of the air change/hour for a patient room, assuming a seasonal average 0.9m per second wind speed.

Interior Gain

"Interior gain" is the heat added to a building by its inhabitants and their activities. The simulation program automatically varies the rate of interior gain to account for variations in routine through a typical day. This investigation's simulations assumed a maximum rate of interior gain for the general ward (occurring at 7pm) equivalent to a population of 21 people, 16 lights and the operation of a one-kW burner under a tea kettle for half an hour. Even if this estimate is unreasonable, it is likely that changes in clinic operation or the health of Tutume's residents will substantially change the heating load. For example, if the ward had only half the daily population and nighttime use assumed above, its annual heating load would increase by 33 percent (design options GAIN versus BASE). Of course, the building would also be a few degrees cooler in summer.

Thermostat Settings

The choice of what temperature to maintain in the patient rooms has the single largest affect on annual heating load of any operating or design decision. Luckily, it is also the easiest aspect of performance to change. Most of the simulations assume that patient rooms would be maintained at a relatively cool 18°C during the day, and that the heat would be turned off at night (a 13°C night thermostat setting was used, but since the building never cools below 15°C the heating system is always off at night). It would be desirable to maintain patient rooms at the low boundary of the comfort zone (20°C), but doing so is expensive, even if the heating is turned off at night. Raising the thermostat level even two degrees has the effect of increasing the annual heating load by over 75 percent (design options TEMP versus BASE).

An explanation for this radical increase is suggested by comparing the average July interior temperatures of the BASE design option for the general ward.

Table V - BASE Design Option--July Interior Temperatures

	Low	Median	High	Annual Load (GJ)
Unheated	15	17.2	19	0
Low Thermostat	16	18.9	21	15.2
High thermostat	17	20	22	27

The "unheated" building-- which actually is heated by interior gain and the sun--stabilizes at an 17°C median temperature. Heating the building raises the median temperature by 1.67 degrees. Heating the building to a warmer level increases the median temperature 2.8 degrees, thus increasing the amount of heat loss by two thirds. This comparison illustrates the most effective recommendation for energy conservation in new health centers: If health centers are to be heated, heating should be limited to patient wards and examining rooms, and those rooms should be heated only to the level needed to prevent additional stress to patients.

7.0 DESIGN OPTION COMPARISON

Botswana's climate is favorable to the use of passive solar and night ventilation cooling design techniques to improve comfort. It would even be possible, given enough construction funds and conscientious building operation, to provide almost continuous thermal comfort in the patient wards without additional heating or cooling needs, although electricity for fans would be required. However, this possibility would be unrealistic, given the construction materials and practices available in Botswana, and would also be very expensive. This study, therefore, limits the investigation of design alternatives to those which appear to be practical and economically feasible.

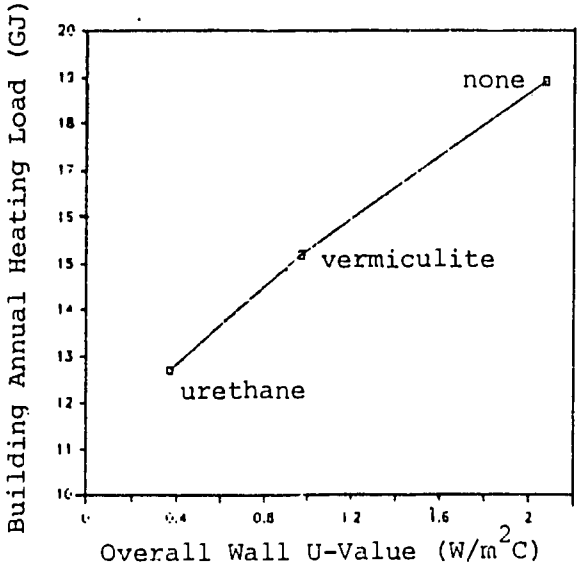
8.0 WALL INSULATION

The "as-designed" addition to the Health Center is assumed to use cavity wall construction consisting of 115 mm stock brick walls separated by a 50 mm air cavity. The wall is plastered on both sides, and the exterior is painted white. Heat loss and gain through the walls of the general ward is significant, but not by comparison with other factors (see Table I). The value of wall insulation, therefore, does not justify the additional cost of cavity wall construction. If cavity walls are used for other reasons, adding insulation is probably a good investment. Figure 2 compares the annual heating load of three versions of the general ward having different levels of insulation in the wall cavity. The two options graphed correspond to carefully poured vermiculite beads with no voids (or poorly done polystyrene beads) or the use of urethane board stock. The 50 mm urethane boards are assumed to be carefully placed, with no large voids.

Poured insulation is good for a 20 percent reduction in the building's annual heating load, or a one- to two-degree increase in the average minimum temperature in the building. Using the most expensive insulation in the cavity is good for another 12 percent reduction. Patients may feel some benefit to insulating walls, primarily in the wards at the ends of the building for reduced west-wall temperature on summer afternoons, and somewhat warmer walls on winter nights. If both ward buildings and the diagnostic unit were heated, vermiculite insulation would be "worth" about P1,300 in terms of cumulative reductions in coal heating costs over 10 years. Urethane insulation would be "worth" P2,100.

Figure 2

Wall Insulation Performance



9.0 ROOF INSULATION

The buildings of the Tutume Health Center have gabled roofs covered with galvanized steel sheets. Ceilings are provided, nailed to the underside of rafters or on brandering with an air space between the ceiling and the roof. A 50 mm blanket of fiberglass is laid above the ceiling.

Roof insulation increases comfort in summer by reducing heat gain through the roof. In winter, however, it can reduce comfort. The roof acts as a solar collector because the daily heat gain through the roof is high enough to exceed its heat loss. Insulating the roof decreases its heat loss but also its heat gain. The net result is reduced solar heating of the building.

Table VI shows that the winter benefit of an uninsulated roof is offset by increased summer afternoon temperatures, which is unacceptable in this climate. On the other hand, most of the benefit of insulation can be had at a minimal level, the point of diminishing return reached with one thickness. Adding more does not substantially help summer performance, but does reduce solar gain through the roof to the point that the heating load actually increases, as shown in Figure 3. There is no need, therefore, to increase the depth of roof insulation.

Table VI - Design Option BASE July Average Temperatures*

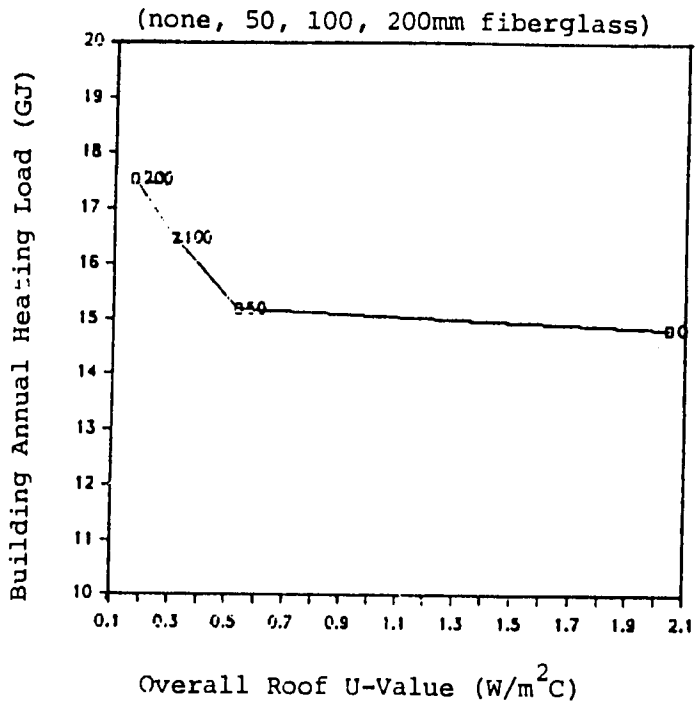
	January			July		
	Low	Mean	High	Low	Mean	High
Uninsulated	23	27	32	15	19	23
50 mm Fiberglass	23	26	29	15	17	19
100 mm Fiberglass	23	26	28	14	17	18

* ^{o}C, unheated

The common alternative to fiberglass insulation is a reinforced, highly reflective, aluminium foil, which serves as a radiation barrier. It is slightly more effective than 50 mm of fiberglass in blocking heat moving downward, but much less so for heat moving up. It would, therefore, perform slightly better in summer, but substantially worse in winter.

Figure 3

Roof Insulation Performance



10.0 NORTH WALL AS SOLAR COLLECTOR

In winter, a north-facing wall in Botswana receives more sunlight per unit area than a low pitched roof. This is usually exploited by orienting windows for passive solar heating, but the wall itself can also be used as a solar collector, which is typically achieved by glazing its outer surface to reduce heat loss--the Trombe wall. The benefit of this option is that the room behind the wall can be heated using solar gain without the glare of direct sunlight, and the mass of the wall reduces heat flow, so that its time of maximum release is several hours after the sun is off the wall. The first of these advantages obtains in the design of patient wards, but the second does not. Given that the "time constant" of the building is over 20 hours and that of individual patient rooms is over 17 hours, the time lag is sufficient. There is no justification for providing additional thermal storage if it is serving only that purpose, nor if it increases the cost of the building. What is needed is a means of getting more solar energy into the building so that it can be stored by the mass already there.

The north wall is "free," however, and it is exposed to direct sunlight. If it were solid and painted a dark color to increase its absorptivity, it would act as a solar collector, or unglazed Trombe wall, at little or no cost increase. On the other hand, heat loss back out through the wall during the early morning hours is greater than that of an insulated cavity wall, as is its heat gain during the summer. Under the conditions assumed for this study's simulations, the result is that the building averages one degree cooler in winter, one degree warmer in summer, and has a slightly higher heating load than the BASE version (MASS versus BASE, Figure 1).

The range of performance of a solid north wall, however, is very close to even with that of an insulated cavity wall. If the wall had no overhang, it would work better in winter yet only a little worse in summer. (An abbreviated 0.5 m overhang was assumed). On the other hand, if the average winter wind speed in Tutume is higher than the .9 meters per second assumed, the wall performs substantially worse than the insulated cavity wall. On balance, it does not appear to be worth additional investment unless its incremental cost is very low. If this is the case, then further study of its effect on individual, north-facing patient rooms is recommended.

11.0 INCREASING WINDOW AREA FOR PASSIVE SOLAR HEATING AND VENTILATION

Given that the Health Center buildings have a sufficient area of interior mass for thermal storage and can be inexpensively insulated to the point of diminishing return, they would derive the greatest improvement to their performance from:

- decreasing the rate of winter infiltration;
- increasing the amount of winter solar heat entering the building; and
- increasing the volume of air drawn through the building during summer ventilation.

The size, location, and construction of the buildings' windows can simultaneously respond to all three factors. In this regard, the "as-designed" size and location of the ward buildings' windows is very reasonable. All glass faces either north or south, and glazing areas are relatively balanced for efficient cross ventilation. A high, south-facing clerestory is included to help ventilate the central passageway by both wind- and buoyancy-induced ventilation. The glazing area is quite generous (over 25 percent of the wall area), and cannot be drastically increased without interfering with the function of the north-facing wards or the patients' visual and thermal comfort.

A series of simulations investigated the improvements possible with combinations of increasing glass area, applied to the general ward. Their performance is compared in Figure 1 and in Table VII, below. In rough order of their increasing cost, they are as follows:

- NGLZ retains the existing fenestration pattern on the north facade of the general ward, but lowers the window sill height from 86 cm to 26 cm (using standard window E7H). This increases the patient rooms' glazing by 48 percent, all of which is operable. The intention is to improve the solar heating of patient rooms and provide more summer ventilation.
- SCLR increases the size of the south-facing, clerestory windows to balance the increased north-facing window area of NGLZ. This is needed to provide the best use of the added north-facing window area, since increasing the size of a window on one side of the building improves air movement only slightly compared to an equal inlet and outlet area. Clerestory windows would be increased from 34 cm to 84 cm high (1-HCH center pivot).

- DG double glazes all windows of the NGLZ version. This would require the importing of windows from South Africa, which may be too costly for the project.

- NCLR alters the roof design of the general ward by putting a roof monitor over the central passageway, with equal areas of clerestory windows facing north and south. North-facing glass area is increased, which helps to bring winter sunlight into the passageway. The cross-ventilation path through the monitor helps draw air out of the building in summer. The added high-level vent area would also tend to increae the ventilation due to bouyancy difference, which is a much less powerful driving force than moving air, and thus, needs much larger window areas to provide equivalent ventilation. On the other hand, this option is very expensive relative to its benefit, and substantially increases winter night heat loss. It does improve the quantity and quality of daylight in the passageway, but that is not a critical need as daylight from the south-facing clerestory is adequate.

- DG/INFL adds the logical next step to double glazing, and provides imported, weatherstripped windows and doors, as well as double glazing the NGLZ option. This, plus careful construction detailing and doing without air bricks, might reduce the winter infiltration rate to one air change per hour, which is typical of current standard residential construction in Europe and the United States. This option, like double glazing, may not be practical for health centers in rural areas.

Table VII - Performance of Increased Glazing Area

	BASE	NGLZ	SCLR	DG	NCLR	DG/INFL
Glass % Increase						
North	$26.5m^2$	40%	--	40	83	40
South	21.2	--	28	--	28	--
Total	52.7	20	32	20	53	20
"Closed" Time Constant (hours)	24	22	22	26	21	29
"Open" Time Constant (hours)	12	11	10	11	9	12
Annual Heating Load (GJ/year)	15.2	15.1	15.5	11.5	16.1	6.1

Ventilation Performance

The primary benefit of increasing window area is to improve cross ventilation. The "open" building "time constant," which provides an indication of the ability of the building to cool itself during summer nights by ventilation with outside air, steadily decreases as the building's window area is increased. The improvement is not dramatic because all windows are assumed to have insect screens, which reduce air flow by almost half. The large thermal inertia of the building and its relatively long "time constants" suggest that patient rooms will be substantially warmer than the outside air on summer evenings, even if the building's window area is increased over 50 percent. Increasing window area does eventually result in a cooler building by the following morning, although the improvement may not be perceptable to patients. Increasing the window area to the NCLR level (+53 percent) reduces the summer minimum building temperature by two degrees, although the median is unchanged, due to higher diffuse solar gains during the day through the additional window area.

Given that adding windows alone will not provide patient comfort, a medium cost alternative is the use of ceiling fans to increase air movement within the patient rooms. One, one-meter diameter ceiling fan per room would be sufficient. The 10-year average cost of providing and using ceiling fans for the general ward might be:

- capital cost: 10 fans @ P200 installed = P2,000.
- 10-year maintenance: replace 2 fans = 400.
- operation: 60W/fan * 7 on * 6 hrs/dy * 180 dys * 10 yrs * P.36 = 1,630.
- total: P4,030 or P403/year.

Solar Heating Performance

Adding glass for passive solar heating does not substantially improve the building's thermal performance, nor does it increase winter average indoor temperatures. The additional heat gain from increased glass area is offset by increased night-time heat loss. For this option to show a substantial benefit, the windows would have to be double glazed, and the non-north glazing area would have to be reduced, which is desirable neither for summer ventilation or the building's function. On the other hand, warming the patient rooms on winter mornings is also desirable, as patients cannot go outside until the chill is off the building in mid-morning. A reasonable compromise would be to increase window size in the north-facing patient rooms only (NGLZ). This would not substantially affect the average temperature of the entire building, but might warm

the patient rooms more rapidly. If larger windows are reasonable in cost, this alternative should be investigated further.

Double Glazing and Weather Stripping

Double glazing the building's windows and reducing its infiltration are the most effective ways of improving the winter thermal comfort of the Health Center buildings (double glazing increases the average July minimum temperature by one degree, reducing infiltration by two degrees). If the buildings are heated by LP gas or electric heaters, attention to these issues should be considered mandatory, as the use of high-quality windows, doors, and attention to construction details would be "worth" between P7,000 and P10,000 in reduced heating costs over the first 10 years of the center's operation. If coal heating is used, the economic benefit is P2,500, which alone may not justify the additional capital cost. In this case, detailed cost projections should be prepared before windows and doors are specified.

APPENDIX

HEATING COST COMPARISON

Capital and Maintenance Costs

Estimating the cost of heating a health center is complicated by several interdependent factors:

- Domestic hot water is to be provided wherever needed. If a heating system is provided, it would also be used to heat domestic hot water.

- An incinerator for pathological waste is to be provided. If a coal-fired boiler were used for heating and domestic hot water, it could be modified to serve as the incinerator, thus saving an estimated P3,000 in capital cost, as well as daily fuel consumption.

- Localized solar water heating will be considered as an alternative to central hot water generation, but an incinerator would still be required. Further, the uneven experience in the United States with large-scale systems using pumps, electronic controls, and remote storage tanks suggests that the most reliable option for Botswana would be providing one or more residential-scale thermosiphon systems for each building.

- A domestic hot water heating system has not yet been designed for Tutume, so the incremental cost of adding space heating can only be estimated. The estimates given below are useful only for relative cost comparisons between alternate systems:

  --A coal-fired, combined heating/hot water system would cost P15,000. One third of that amount would be for the heating system pumps, piping, and radiators. No incinerator would be required.

  --An LPG-fired heating/hot water system, including a separate incinerator, would be comparable in cost to a coal-fired system.

  --A decentralized system of electric geysers for hot water only, plus an incinerator, might cost between P5,000 and P7,000.

  --A decentralized system of thermosiphon solar heaters, with in-tank electric backup elements (seven units @ P2,000), plus an incinerator, might cost up to P17,000.

The Department of Electrical Engineering estimates that an LPG-fired boiler would require five service calls per year against one for a coal-fired system. Each service visit might cost P300, using government technicians from Gaborone. An electrical/solar domestic hot water system might require two service calls per year.

Fuel Costs

The cost of fuels for heating, delivered in Tutume, is estimated below. Estimates are based, in part, on extrapolations of estimates made in June 1984 by the Department of Electrical Engineering for the MOH. All costs have been escalated by 20 percent to account for the effect of inflation through 1986.

Coal

Cost of Coal:	P17.00/ton loaded at Morupule Colliery
Private Transport:	24t/m^3/km, 20m^3 dump truck
Distance:	Morupule to Tutume = 250 km
Transport Cost:	P.24 * 20m^3 * 250km = P1,200/truck load
Cost at Tutume:	20m^3 * .88ton/m^3 * P17 + P1,200 = P1,500/truck P1,500/17.6tons/truck = P85.23/ton P85.23/29GJ/ton = P2.94/GJ

LP Gas

Cost of Gas:	P1.25/kg at Shell Depot, Francistown
Govt Transport:	P1.0/km, 6-ton CTO truck, plus P10.0/day driver wage
Truck Capacity:	60 x 45kg tanks = 2,700 kg
Distance:	Francistown to Tutume to Francistown = 200 km
Transport Cost:	P1.0 * 200km + P10.0 = P300/truck load
Cost at Tutume:	2,700kg * P1.25/kg + P300/truck = P3,675/truck P3,675/truck/2,700kg = P1.36/kg P1.36/kg/.05015GJ/kg = P27.12/GJ

Electricity

Cost at Tutume:	36t/kWh (diesel generated) P0.36/.0036GJ/kWh = P100/GJ

Ten-Year Capital and Operating Costs

The annual heating requirement of a health center is small relative to its hot water annual heating load. If heating is installed in future health centers, it is likely that the cost of hot water heating will govern the choice of system and fuel for space heating. A 10-year cost projection for hot water heating is given below, using the estimates of capital, maintenance, and fuel costs set forth above. The escalation in future costs is assumed to be at the same level as general inflation, and thus, does not change in terms of "current Pula." The estimates compare the cost of heating 1,000 liters of water per day from 20°C to 55°C. This volume of water might be sufficient for daily cooking, washing, and bathing for 10 to 20 patients, depending on the season.

Coal

Capital Cost:		P10,000
10-Year Maintenance Cost:	10 yrs * 1call/yr * P300	= 3,000
	Parts @ 10% of Cap. Cost	= 1,000
Fuel Cost:	10 yrs * 53.56GJ demand * 1.67 eff. * P2.94	= 2,624
Total:		P16,624
		(fuel = 16% of total)

LP Gas

Capital Cost:		P10,000
10-Year Maintenance Cost:	10 yrs * 5call/yr * P300	= 15,000
	Parts @ 20% of Cap. Cost	= 2,000
Fuel Cost:	10 yrs * 53.56GJ demand * 1.67 eff. * P27.1	= 24,239
Total:		P51,239
		(fuel = 47% of total)

Electricity

Capital Cost:		P7,000
10-Year Maintenance Cost:	10 yrs * 2call/yr * P300	= 6,000
	Parts @ 20% of Cap. Cost	= 700
Fuel Cost:	10 yrs * 53.56GJ demand * 1.0 eff. * P100	= 53,560
Total:		P67,260
		(fuel = 80% of total)

The combined weight of the 3:1 overall cost differential and the overwhelming fuel-cost advantage of domestic coal makes a coal-fired system a clear choice for domestic water heating of institutional buildings having a large hot-water demand. Even if the estimated costs are very inaccurate, the magnitude of the difference between system costs is so great that the conclusion would still stand. The only option which might effectively compete against a centralized coal-fired system would be a

decentralized solar-electric system designed for a high solar fraction, but it could not provide space heating to supplement the passive solar heating of the buildings.

Incremental Cost of Heating

If the Tutume Health Center is provided with space heating, the costs can be estimated for the "as-designed" general ward, and extrapolated for heating other buildings in the Health Center, as follows:

Coal--Ward Patient Rooms and Diagnostic Unit Only (425 m^2)

Incremental Capital Cost: (piping, pumps, radiators) = P2,500
Incremental Maint. Cost: 10 yrs * 1/2call/yr * P300 = 1,500
Parts @ 10% of Cap. Cost = 250
Fuel Cost: 10 yrs * 18 GJ demand * 2.0 eff. * P2.94 = 1,060
Total: P5,314 or P29/GJ load year
(fuel = 20% of total)

Coal--Ward and Diagnostic Unit Buildings (700 m^2)

Incremental Capital Cost: (piping, pumps, radiators) = P3,000
Incremental Maint. Cost: 10 yrs * 1/2call/yr * P300 = 1,500
Parts @ 10% of Cap. Cost = 300
Fuel Cost: 10 yrs * 28.5 GJ demand * 2.0 eff. * P2.94 = 1,675
Total: P6,475 or P23/GJ load year

Coal--All Medical Buildings (1,100 m^2)

Incremental Capital Cost: (piping, pumps, radiators) = P5,000
Incremental Maint. Cost: 10 yrs * 1call/yr * P300 = 3,000
Parts @ 10% of Cap. Cost = 500
Fuel Cost: 10 yrs * 45 GJ demand * 2.0 eff. * P2.94 = 2,646
Total: P11,146 or P25/GJ load year

LP Gas--Ward Patient Rooms and Diagnostic Unit Only (425 m^2)

Incremental Capital Cost: (21 portable heaters @ P150) = P3,150
Incremental Maint. Cost: replacement @ 100% Cap. Cost = 3,150
Fuel Cost: 10 yrs * 18 GJ demand * 1.6 eff. * P27.1 = 7,800
Total: P14,100 or P78/GJ load year
(fuel = 55% of total)

Electricity--Ward Patient Rooms and Diagnostic Unit Only (425 m^2)

Incremental Capital Cost:	(21 portable heaters @ P75) =	P1,575
Incremental Maint. Cost:	replacement @ 100% Cap. Cost =	1,575
Fuel Cost:	10 yrs * 18 GJ demand * 1.0 eff. * P100 =	18,000
Total:		P21,150 or P118/GJ load year (fuel = 85% of total)