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MEASURED PERFORMANCE ANALYSIS OF THE SHAKAWE-EC: A PROTOTYPE PASSIVE SOLAR HOUSE FOR BOTSWANA

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Preface

The Botswana Renewable Energy Technology (BRET) project is jointly funded by the Government of Botswana (GOB) and the U.S. Agency for International Development (AID). The BRET project is a part of the Ministry of Mineral Resources and Water Affairs (MMRWA). Technical assistance and project management are being provided by Associates in Rural Development, Inc. (ARD), of Burlington, Vermont, under AID contract number 633-0209-C-00-1024-00.

Summary of Significant Findings

1. During the monitoring period of July 1983 - March 1984, the SHAKAWE-EC achieved acceptable indoor conditions for its occupants with no use of electricity or coal for auxiliary heating or cooling.

2. During the winter months, monitored daily average temperatures were 6 degrees higher inside than outside. While winter nighttime temperatures normally went down to 10 degrees outdoors, the average minimum temperatures inside the SHAKAWE-EC were just over 20 degrees. When the outdoor temperature dipped to -2.8 degrees on the coldest night of the year, the indoor temperature minimum was 19.4 degrees. Under typical winter conditions, with the outdoor temperature varying almost 20 degrees from day to night, the indoor temperature varied less than 4 degrees.

3. During the summer months, monitored daily indoor and outdoor average temperatures were very similar, but the house design reduced day-night temperature swings from over 12 degrees to under 4 degrees. The design was very effective in reducing daytime maximum temperatures, typically keeping it 6 degrees cooler inside the house at the hottest time of the day. On the hottest day of the summer, when the measured outdoor temperature was 43.1 degrees, the indoor temperature maximum was 34.4 degrees. The house thermal mass was not able to cool off at night as rapidly as might be desired, typically keeping the house somewhat warmer at night than the outdoor air temperature.

4. While the occupants of the house felt that reasonably comfortable comfort conditions were maintained throughout the monitoring period, monitored data showed the house to have experienced average indoor temperatures below 20 degrees for 3.2% of the monitoring period and temperatures over 28 degrees 34.9% of the time in the monitoring period. The coolest month indoors was July, but even then the temperature was below 20 degrees only 15% of the time. The hottest month was January, when the indoor average temperature was above 28 degrees 84% of the time.

5. Based on the calibrated computer simulation model used in this evaluation, if the SHAKAWE-EC used heating and

air-conditioning to maintain tempertures between 20 and 28 degrees, the annual auxiliary heating load would be 2.4 Gigajoules and the auxiliary cooling load would be 20.4 Gigajoules. A similar non-solar house would have a 9.9 Gigajoule heating load and a 51.6 Gigajoule cooling load. On this basis, it can be said that the savings attributable to the building energy design of the SHAKAWE-EC are 63% compared to a similar, conventional design. If provided for with electrical heating and air-conditioning, this represents a savings of 6417 kWh. If calculated at P .11/kWh, this is a one-year savings of P 706.

6. The SHAKAWE-EC was a first experiment to demonstrate and evaluate a range of building energy design concepts for Botswana. It could not and was not intended to be an optimized design. Analysis has now suggested a number of modifications which should be considered in future designs. The most important are:

   - The "Trombe wall" passive solar heating system clearly benefitted winter performance, but in the context of annual performance, the benefit was small. Before this feature is incorporated into future buildings it is recommended that careful cost/benefit analysis be conducted.

   - The insulated wall design benefitted performance, but not very significantly compared to less-expensive and easier-to-build wall constructions. It is not a design to be recommended for replication in future buildings.

   - The ceiling insulation had the most significant impact on performance of any of the design elements examined, but the most cost effective thickness may be less than the 150mm used in the SHAKAWE-EC. Even a little ceiling or roof insulation appears to have a major benefit.

   - Improving the design of the SHAKAWE-EC to increase night ventilation cooling in the summer could improve energy performance by as much as one-third.

7. This project has clearly demonstrated that simple passive solar and energy-conserving building design concepts can (1) greatly reduce energy consumption of those buildings which consume energy for heating and cooling, and (2) greatly improve comfort levels in those buildings where little or no purchased energy can be used for heating and cooling.

8. Further research and development will be very beneficial in (1) optimizing the design components which have been initially investigated in this project, (2) adapting these concepts to different building applications in Botswana, and (3) investigating other promising passive solar design concepts which have not yet been evaluated.

1 Introduction

Most buildings currently being designed and built in Botswana tend to be cold in winter and hot in summer. The few buildings which are heated with electricity or coal, or cooled with electrical air conditioning, use large amounts of energy to achieve more comfortable conditions. To demonstrate that energy-conserving, passive solar design of buildings can achieve high levels of comfort with minimal energy consumption, one of the first activities of the BRET project was to design and build a demonstration passive solar house.

The house is based upon a standard design of the Botswana Housing Corporation (BHC) known as the SHAKAWE-A Type II. This was done so there would be a known reference against which to measure cost and performance of the house. Although the SHAKAWE-A Type II is a high-cost house, the passive design principles involved in the redesign may also be applied to medium and low-cost houses.

The redesigned house is called the SHAKAWE-EC. It was built between November 1982 and April 1983 and occupied continuously since May 1983. Microcomputer monitoring equipment was installed in the house in June 1983 in order to assess the performance of the house.

An initial report on the performance of the house was issued by the BRET project in late 1983. "Winter Performance of the Solar House - SHAKAWE-EC" presented initial results from the monitoring of the house during June and July.

The subject of this report is both longer-term and more detailed analysis of the thermal performance of the house. Cost issues are not addressed in this report, nor is the performance of the solar water- heating system, both of which will be dealt with in other reports.

The performance evaluation undertaken in this report addresses four questions:

1. How successful was the building energy design in attaining high levels of comfort with minimal energy consumption?

2. Where performance was not as expected, what explains the discrepancy?

3. How well does the building work compared to a non-solar house?

4. What modifications should be considered in future designs?

The first two of these questions are addressed though analysis of the hourly data on measured performance which were collected by the microcomputer data acquisition system in the house. Results are presented in Section 4 of this report.

The second two questions require the comparison of performance to alternative designs which have not been measured. While the BRET project is in the process of monitoring a similar, non-solar reference house of the SHAKAWE-A Type II design, this work will not be completed for some time and even then it will not be a parallel experiment where all variables except the building design are the same (the occupancy, for instance, is quite different). Accordingly, these questions of comparative performance are addressed using a computer thermal simulation model of the SHAKAWE-EC. Results are presented in Section 5 of this report.

2 House Description

The SHAKAWE-EC was based on the BHC SHAKAWE-A Type II design because this house had a long narrow plan, which was felt to be a thermally desirable building plan for passive solar design in the Botswana climate. It offered a long face of the building which could be oriented toward the north for passive solar heat collection and a narrow width to facilitate cross-ventilation and heat distribution from the south wall.

Figures 1-2 present the design of the SHAKAWE-EC. The house is a four-bedroom home with 125 m^2 floor area. The lounge, dining and kitchen areas are open to each other to improve heat circulation and cross-ventilation. Other primary energy conservation and passive solar design features of the house are:

1. North-facing windows to provide direct-gain solar heating (7.14 m^2)

2. North-facing Trombe wall to provide indirect solar heating (7.44 m^2)

3. Ceiling insulated with 150mm fiberglass insulation

4. Double walls constructed of 115mm concrete block with 115mm loose-fill polystyrene insulation inside (except for bedroom #4 which has no insulation in the west, east or south walls)

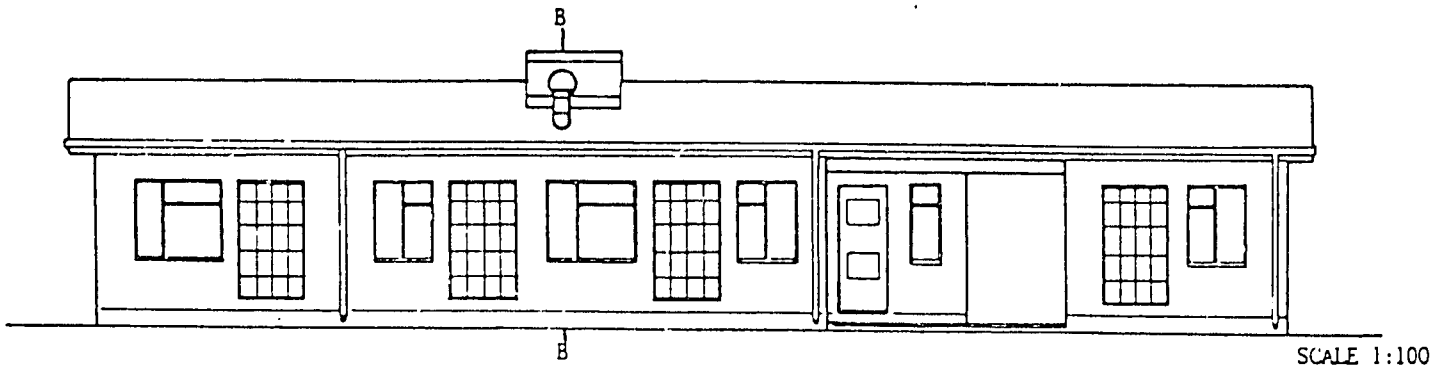
5. Roof overhangs of 0.5m on the south side and 1.0m on the north side to reduce solar gains in summer

6. Six operable vents high on the south wall to improve ventilation cooling in the summer

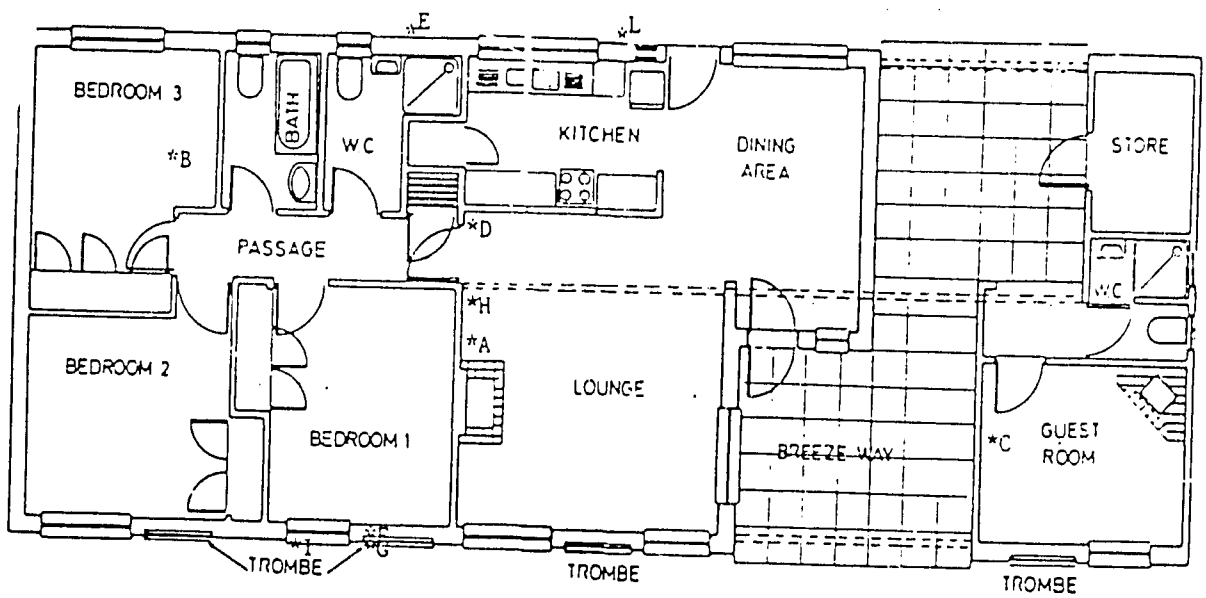
7. Vents in the top of internal partition walls to facilitate air movement between rooms

8. A breezeway intended to capture and funnel wind, thus further increasing ventilation

Figure 1.



North Elevation

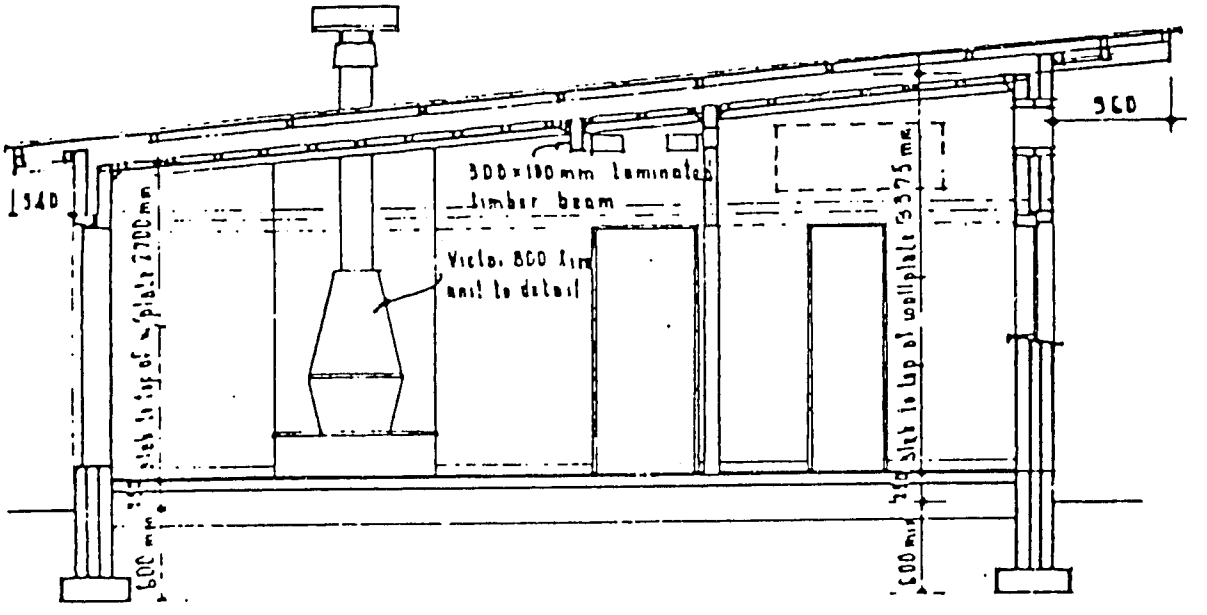


CONTINUOUS MEASUREMENTS

A. Living room temperature
B. Back bedroom temperature
C. Bedroom4 temperature
D. Living room radiant temperature
E. Ambient (outdoor) temperature
F. Bedroom1 Inner surface trombe wall temperature
G. Bedroom1 Outer surface trombe wall temperature
H. House average line voltage
I. Total vertical radiation
J. Total horizontal radiation
K. Average windspeed
L. Total house current at main box
M. Daily hot water uasage

House Plan

Figure 2.



A more detailed physical description of the house may be found in Appendix B. This is in the form of a complete listing of the house description which was used as an input to the computer simulations reported in Section 5 of this report.

3 Description of Performance Monitoring

3.1 "The Monitoring System"

In order to determine quantitatively the thermal performance of the SHAKAWE-EC, a monitoring system was installed in the house in June 1983. The system consists of an Aeolian Kinetics PDL-24 microcomputer data acquisition system and 14 sensors used to monitor key performance variables. The variables monitored are as follows:

Channel A - Living Room Air Temperature
Channel B - Bedroom #3 Air Temperature
Channel C - Living Room Black-Globe Temperature
Channel D - Bedroom #4 Air Temperature
Channel E - Ambient Temperature
Channel F - Trombe Wall Inner Surface Temperature
Channel G - Trombe Wall Outer Surface Temperature
Channel H - Solar Water Heater Tank Temperature
Channel I - Solar Water Heater Flow Rate
Channel J - Average Household Electrical Voltage
Channel K - Total Household Electrical Current
Channel L - Total Solar Radiation on a Vertical Surface
Channel M - Total Solar Radiation on a Horizontal Surface
Channel N - Total Wind Run

The location of each of these sensors is shown in Figure 2. All temperatures are measured with AD-590 semiconductor temperature sensors. Air temperature sensors are shielded from radiant energy to measure true dry-bulb air temperature. The black-globe temperature sensor is mounted within a small (150mm) black sphere and is used to compute radiant temperature, a useful supplement to air temperature in evaluating human thermal comfort. Voltage is monitored with a small transformer plugged into a normal household electrical outlet. Current is monitored with a clamp-on amp transducer at the point where the electrical

service enters the house. Solar radiation is measured with Hollis pryranometers mounted on the outside of the house (one on the roof and one on the north wall) and wind velocity by a Maximum 3-cup anemometer mounted on the photovoltaic panels which are located on the roof. These photovoltaic panels charges batteries which are used to supply power for operation of the data acquisition system, thus protecting it both from power outages and high-voltage line transients which might damage the equipment.

The data acquisition system scans all the sensors every 15 seconds. The values sensed are then accumulated by the microcomputer to compute hourly totals or averages for each channel. In addition, the microcomputer is programmed to compute a number of performance factors on both an hourly and daily basis. For instance, total hourly electrical consumption in the house is found by multiplying voltage times current at each scan interval and summing these values for each hour. A list of the functions computed on-line by the data acquisition system is presented in Figure 3. The hourly, daily and monthly values of these functions can be printed automatically by the data acquisition system when they are computed, enabling immediate access to performance data. In addition, all hourly data were recorded on cassette tape for subsequent analysis.

3.2 Operation of the Monitoring System

After initial installation and debugging of the monitoring system, routine operation commenced in July 1983. Daily printouts were examined periodically, and those from the first two months of operation were used to prepare the BRET report, "Winter Performance of the Solar House - SHAKAWE-EC". The initial instrumentation did not include monitoring of wind or the solar water-heating system. The anemometer was added in August and monitoring of the solar water-heating system began in November.

Routine recording of hourly data on magnetic tape began July 20, 1983, and has been as continuous as possible since that time. There are numerous gaps in the data, but these are not serious enough to adversely affect analysis efforts. These gaps reflect either periods when the data acquisition system was not running or time when a tape was filled up but not replaced with a blank cassette. The analysis contained in this report is based on data collected up to March 30, 1984. The periods from which complete hourly data were recorded are as follows:

Figure 3.

Performance Factors Computed On-Line by the Data Acquisition System

1.	Time Weighted Average House Temperature (Daily)	°C
2.	Time Weighted Average No. 4 Bedroom Temperature (Daily)	°C
3.	Time Weighted Average Effective Temperature (Daily)	°C
4.	Time Weighted Average Ambient Temperature (Daily)	°C
5.	Time Weighted Solar Hot Water Temperature (Daily)	°C
6.	Total Radiation on Vertical Plane (Daily)	MJ/m^2
7.	Total Radiation on Horizontal Plane (Daily)	MJ/m^2
8.	Time Weighted Average Windspeed (Daily)	m/sec
9.	Time Weighted Average (Monthly)	°C
10.	Time Weighted Average No. 4 Bedroom Temperature (Monthly)	°C
11.	Time Weighted Average Effective Temperature (Monthly)	°C
12.	Time Weighted Average Ambient Temperature (Monthly)	°C
13.	Time Weighted Solar Hot Water (Monthly)	°C
14.	Total Radiation on Vertical Plane (Monthly)	MJ/m^2
15.	Total Radiation on Horizontal Plane (Monthly)	MJ/m^2
16.	Time Weighted Average Windspeed (Monthly)	m/sec
17.	Daily Hot Water Usage	litres
18.	Collector Effective	-
19.	Time Weighted Average Line Voltage	volts
20.	Electrical Heat Usage	kWh
21.	House Heat Loss	MJ
22.	Internal Heating and Gas Use	MJ
23.	Heating Degree Days	DD
24.	Maximum Average House Temperature	°C
25.	Maximum No. 4 Bedroom Temperature	°C
26.	Maximum Ambient Temperature	°C
27.	Maximum Trombe Wall Inner Surface Temperature	°C
28.	Maximum Trombe Wall Outer Surface Temperature	°C
29.	Minimum Average House Temperature	°C
30.	Minimum No. 4 Bedroom Temperature	°C
31.	Minimum Ambient Temperature	°C
32.	Minimum Trombe Wall Inner Surface Temperature	°C
33.	Minimum Trombe Wall Outer Surface Temperature	°C
34.	Less than 18°C Temperature Bin	Hr
35.	18-22°C Temperature Bin	Hr
36.	22-26°C Temperature Bin	Hr
37.	Greater than 26°C Temperature Bin	Hr
38.	Solar Fraction (Percent of Heat Load Met by Solar Energy)	-
39.	Hour of Maximum Inner Trombe Wall Temperature	Hr
40.	Hour of Maximum Outer Trombe Wall Temperature	Hr
41.	Minute of Maximum Inner Trombe Wall Temperature	Min
42.	Minute of Maximum Outer Trombe Wall Temperature	Min
43.	Hour of Minimum Inner Trombe Wall Temperature	Hr
44.	Hour of Minimum Outer Trombe Wall Temperature	Hr
45.	Minute of Minimum Inner Trombe Wall Temperature	Min
46.	Minute of Minimum Outer Trombe Wall Temperature	Min

20 July 11:00	-	5 August 14:00
9 August 16:00	-	12 August 17:00
12 August 19:00	-	19 August 15:00
26 August 18:00	-	29 August 15:00
30 August 16:00	-	20 September 0:00
23 September 19:00	-	10 October 23:00
18 October 16:00	-	22 October 8:00
22 October 19:00	-	31 October 23:00
1 November 17:00	-	2 November 9:00
7 November 14:00	-	12 November 16:00
22 November 16:00	-	12 December 16:00
16 December 15:00	-	26 December 9:00
16 January 13:00	-	18 January 10:00
18 January 20:00	-	5 February 1:00
8 February 9:00	-	25 February 17:00
25 February 19:00	-	14 March 13:00
28 March 9:00	-	30 March 4:00

3.3 Data Processing

Cassette tapes for all of the data periods listed above were read with no problem and reformatted for analysis in a microcomputer. ASCII and packed binary format files were created on IBM-PC compatible diskettes, both for data archiving and further analysis. Then, with the assistance of a BASIC reformatting program, the packed binary files were set up in a spreadsheet format for further analysis using the LOTUS-123 program. Once in the LOTUS spreadsheet format, the data were reorganized into separate files for each month. Then data were checked for reasonableness and completeness, monthly performance factors computed, and results printed out and graphed as appropriate.

4 Monitored Performance Results

During the monitoring period, the occupants of this house allowed the temperature inside to swing naturally, not using auxiliary heating or air-conditioning. Thus, the temperatures which were observed are a direct indicator of the performance of the house design. While reasonably comfortable conditions were achieved in this "passive" mode most of the time, it is recognized that some occupants might wish to use auxiliary heating and cooling to achieve greater comfort. An analysis of how the home would have worked under such conditions is presented in Section 5 of this report, which reports the results of comparative computer simulation studies. This section will examine monitored performance of the house as it was operated and used the specific occupants who were present during the monitoring period.

4.1 Measured Monthly Performance

Figure 4 summarizes the monthly performance of the SHAKAWE-EC as indicated by average indoor and outdoor temperatures. It can be seen that even with no auxiliary heating, the average monthly temperature of the house is always above the lower limit of the comfort zone (20 degrees). In July and August the average indoor temperature is about 6 degrees above the average ambient temperature, due to a combination of internal heat gains and passive solar heating. In summer, the average monthly indoor and outdoor temperatures are very similar, with the outdoor average rising to 1.6 degrees above the indoor average in January. This suggests that cooling features of the design are adequate, on the average, to dissipate internal heat gains and unavoided solar heat gains in the summer. However, the design does not appear to be able to cool the building beyond this point, which theory suggests is possible. Later in this report this will be explored further.

Figure 4.

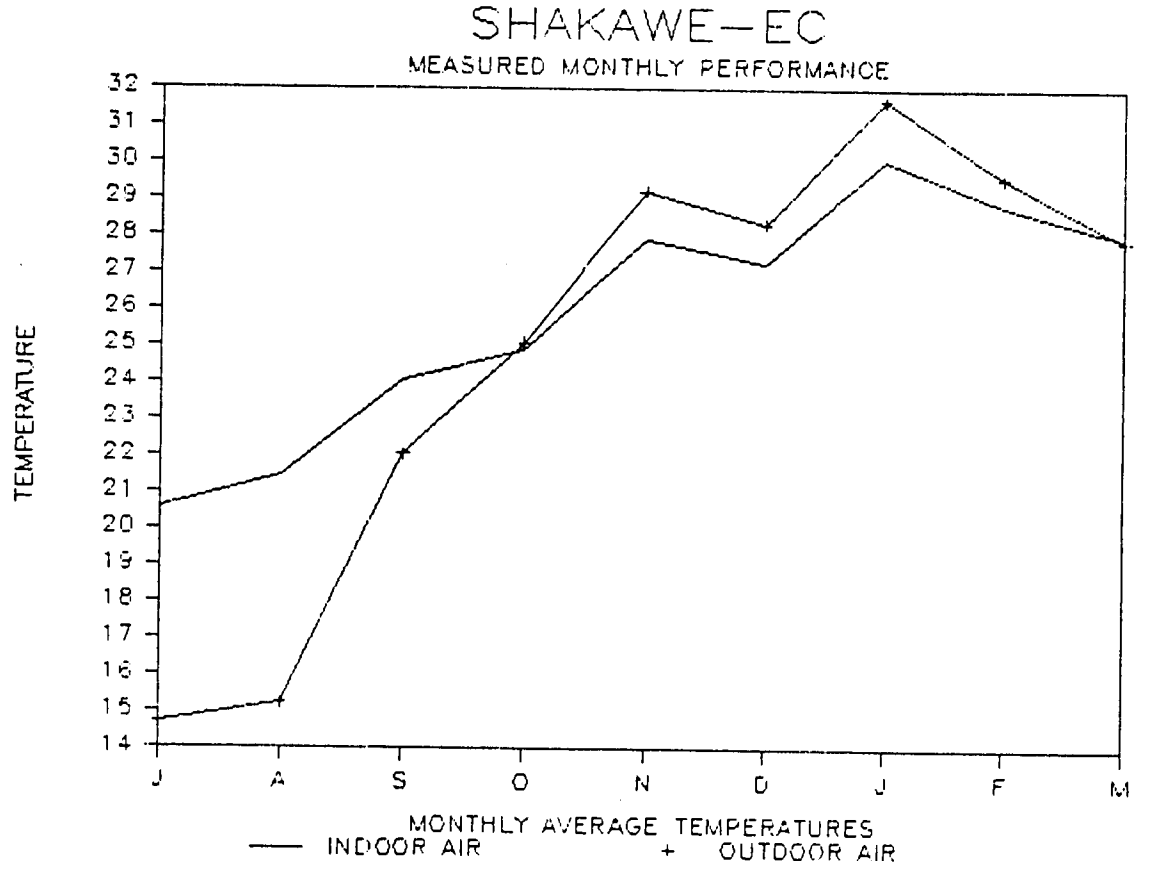
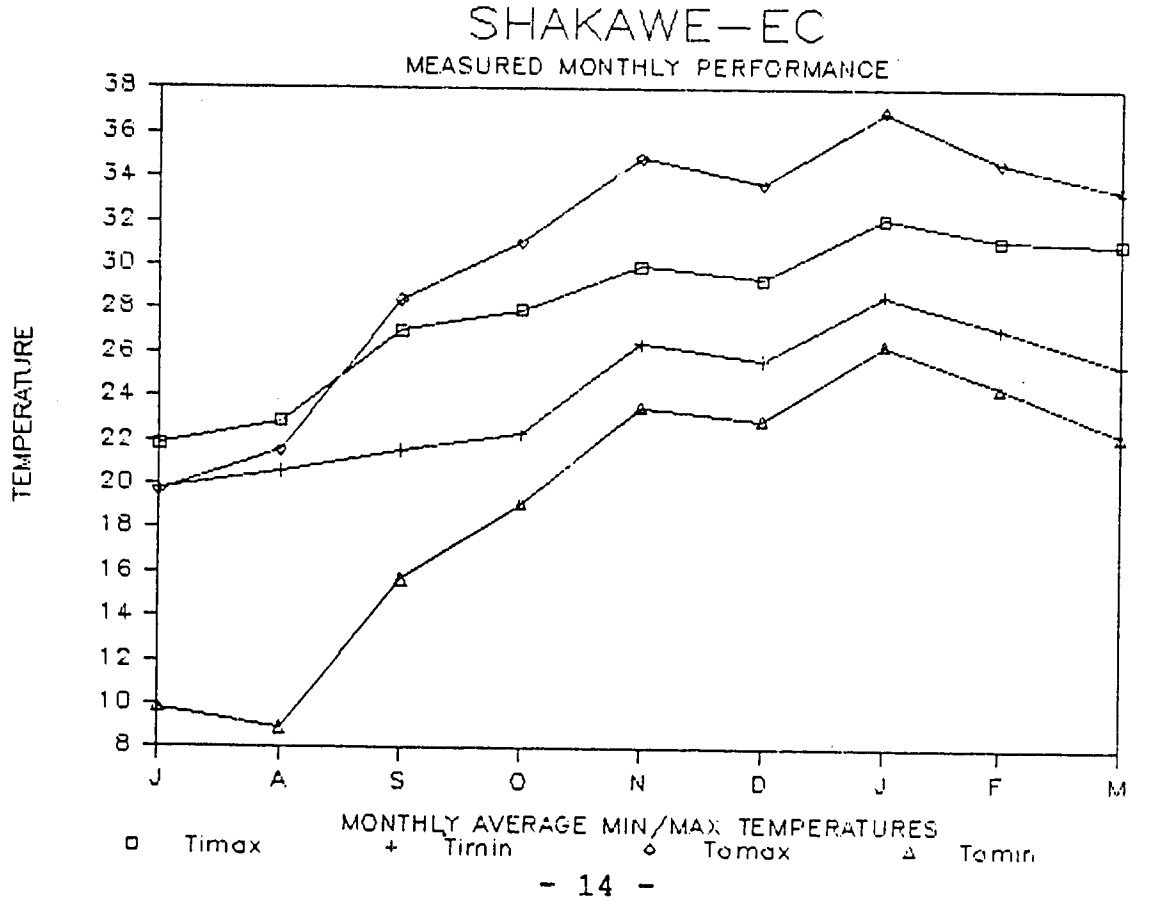


Figure 5.



The monthly thermal performance of the building can also be examined by looking at the typical daily temperature swing inside and outside the building, as presented in Figure 5. The top line in the chart is the mean daily maximum outdoor temperature (Tomax). This is the mean value of the maximum outdoor temperature achieved on each day of the month. Following the same pattern, but just below, is a line representing the mean daily maximum indoor air temperature for each month (Timax). The other two lines on the chart indicate the mean daily minimum indoor (Timin) and outdoor (Tomin) temperatures for each month. Clearly, the design of the building has a significant effect in buffering outside temperature swings. Over the entire monitoring period, outdoor air temperature had an average day-night swing of 11.2 degrees while the average indoor day-night swing was only 4.2 degrees.

The extreme temperatures for each month, both inside and outside the house, are presented in Figure 6. On the coldest day of the monitoring period, the outdoor temperature dipped to -2.8 degrees. At the same time, the indoor temperature minimum was only 19.4 degrees. On the other hand, on the hottest day of the summer, when the outdoor measured temperature rose to 43.1 degrees, the indoor temperature maximum was 34.4 degrees.

Figure 7 presents the average daily household electrical consumption for each month. As can be seen, electrical energy use is remarkably constant, averaging 11.84 kWh/day. It should be noted that these energy consumption figures do not reflect total energy consumption of the house. Cooking in the monitored house was done with gas, which was not monitored, and water-heating was accomplished with a solar water heating system.

Peak hourly electrical consumption for the month went from a low of 2.16 kWh in July to a high of 2.53 kWh in September, averaging 2.29 for all nine months. These values are both very constant from month to month, and very low. While in the mode this home was operated (no auxiliary heating or cooling) one would not expect high peak demands, they are important to examine in building energy performance evalution because they indicate the extent to which different buildings may have an impact on the electrical utility supply.

4.2 Winter Performance

In order to look at dynamic performance under winter conditions, a typical three-day period in July has been selected

Figure 6.

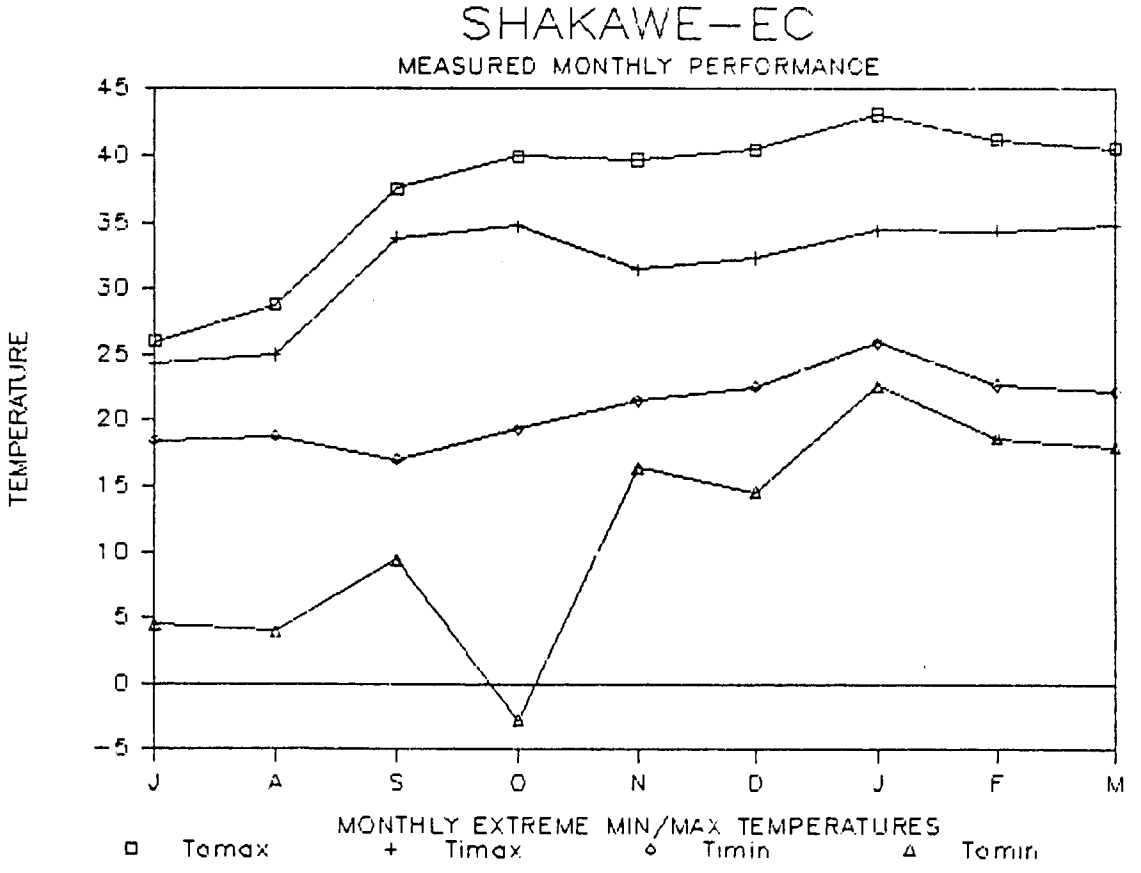
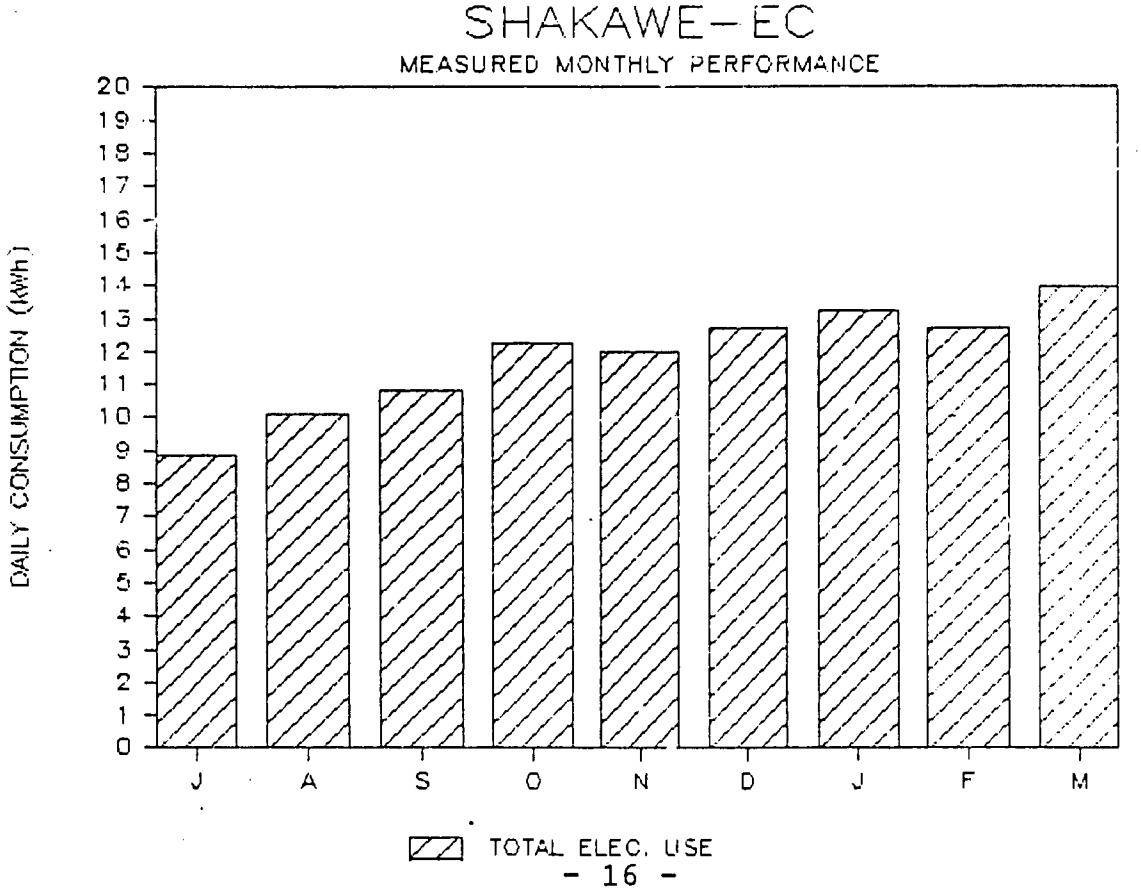


Figure 7.



for closer examination. July 21, 22 and 23 were sunny days with typical outdoor temperatures and wind conditions for the middle of winter. Figure 8 shows the hourly average indoor and ambient temperatures for this period. In this instance the indoor average temperature which is shown is a space-weighted average of the temperatures measured in the living room and bedroom #3. Obviously, the house does a very good job of buffering the indoor environment from the outside. Even though the outdoor temperature varies almost 20 degrees from day to night, the average indoor temperature varies less than 4 degrees.

Figure 9 takes a closer look at the indoor temperatures on these three days. The living room temperature varies slightly more than 4 degrees from day to night and is well within the comfort zone most of the time. It only gets cool at the end of the night, with a minimum temperature at 8:00 in the morning. The bedrooms on the north side of the house can be assumed to be following a similar pattern. In all these rooms, passive solar gains on the north wall of the house have a direct impact. In contrast, the temperature of bedroom #3 varies only about one degree from day to night and remains substantially cooler than the living room. This room is on the south side of the house, where it is heated only indirectly. While temperatures in the range of 19 degrees, such as were found here, are certainly acceptable for sleeping, they could have been higher if it were easier for solar heat to get to this room. This graph also shows hourly temperatures in bedroom #4, which is not part of the main house. Possibly due to a much higher surface-to-volume ratio than the rest of the house a lack of insulation in three walls, the nighttime temperatures in this room fall below the comfort zone, although they are still far above the ambient temperature. A daily temperature rise of over 6 degrees can be seen, similarly attributable to the relatively large solar collection surface for the size of the room.

Figure 10 takes a more detailed look at what is going on with passive solar gains through the north wall of the house over a 27-hour period on July 21-22. As the sun comes up a little after 7:00, the temperature on the outside of the Trombe wall starts a rapid climb. The air in the living room also starts to warm up, but at a far lower rate, due to direct solar gain through the north-facing windows. About three hours later, the inside surface of the Trombe wall starts to warm up, as heat conducted from the outside surface penetrates the wall. The outside wall surface achieves a maximum temperature of over 49 degrees at 15:00, about the same time as the ambient air temperature maximum occurs. The maximum temperature on the inside of the Trombe wall is reached at about 19:00, indicating a time lag through the Trombe wall of about four hours. The

Figure 8.

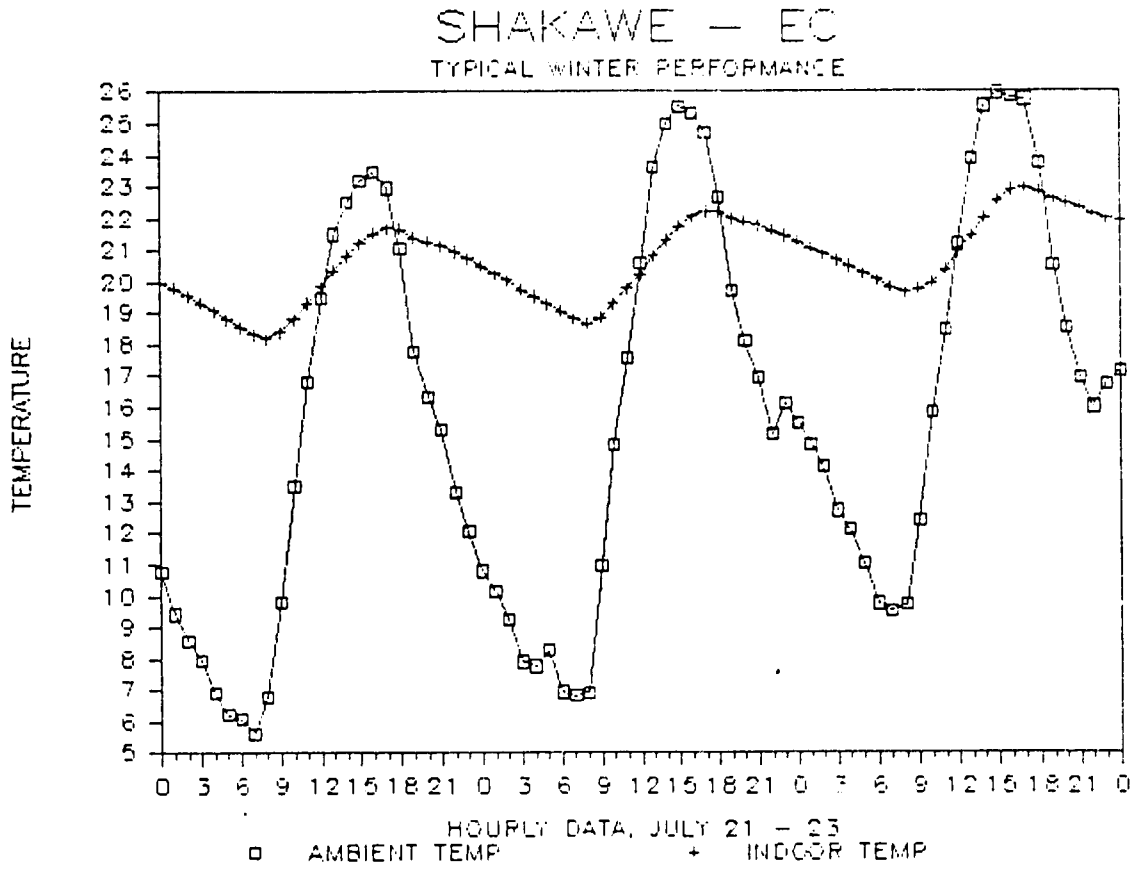


Figure 9.

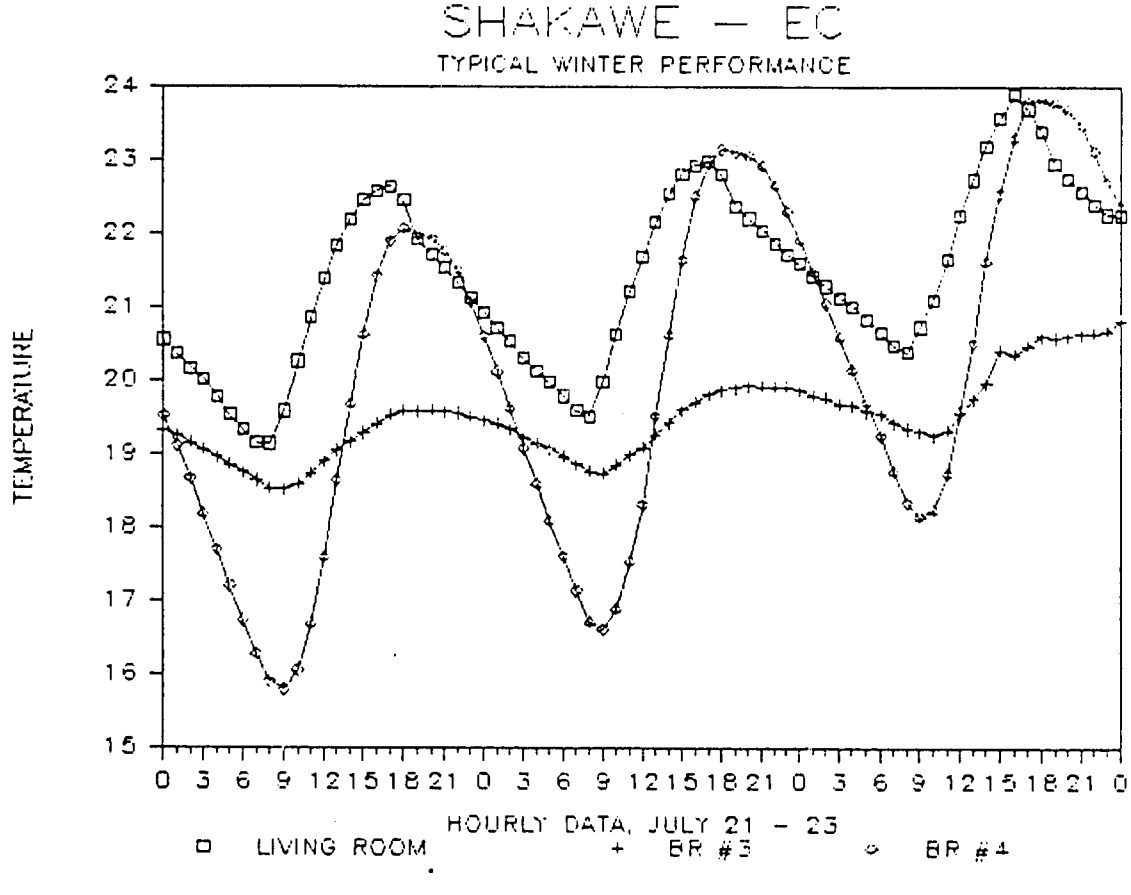


Figure 10.

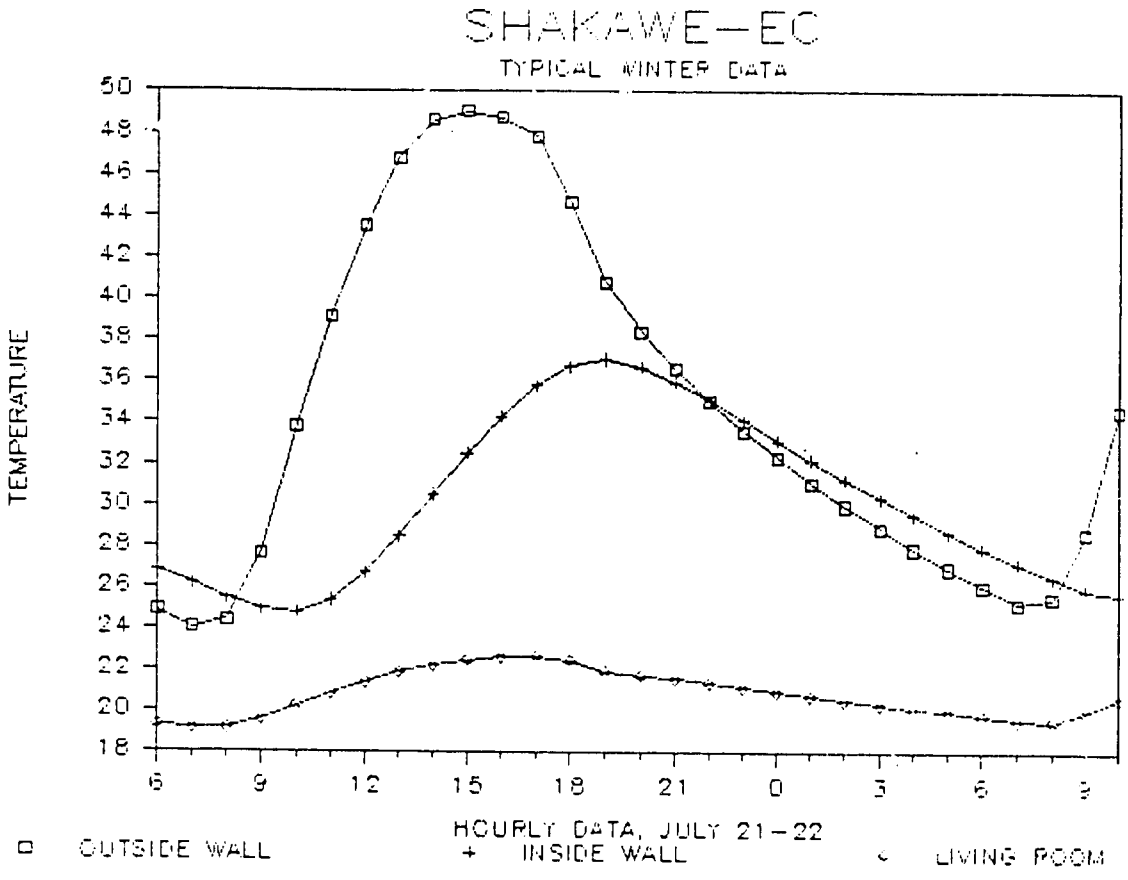
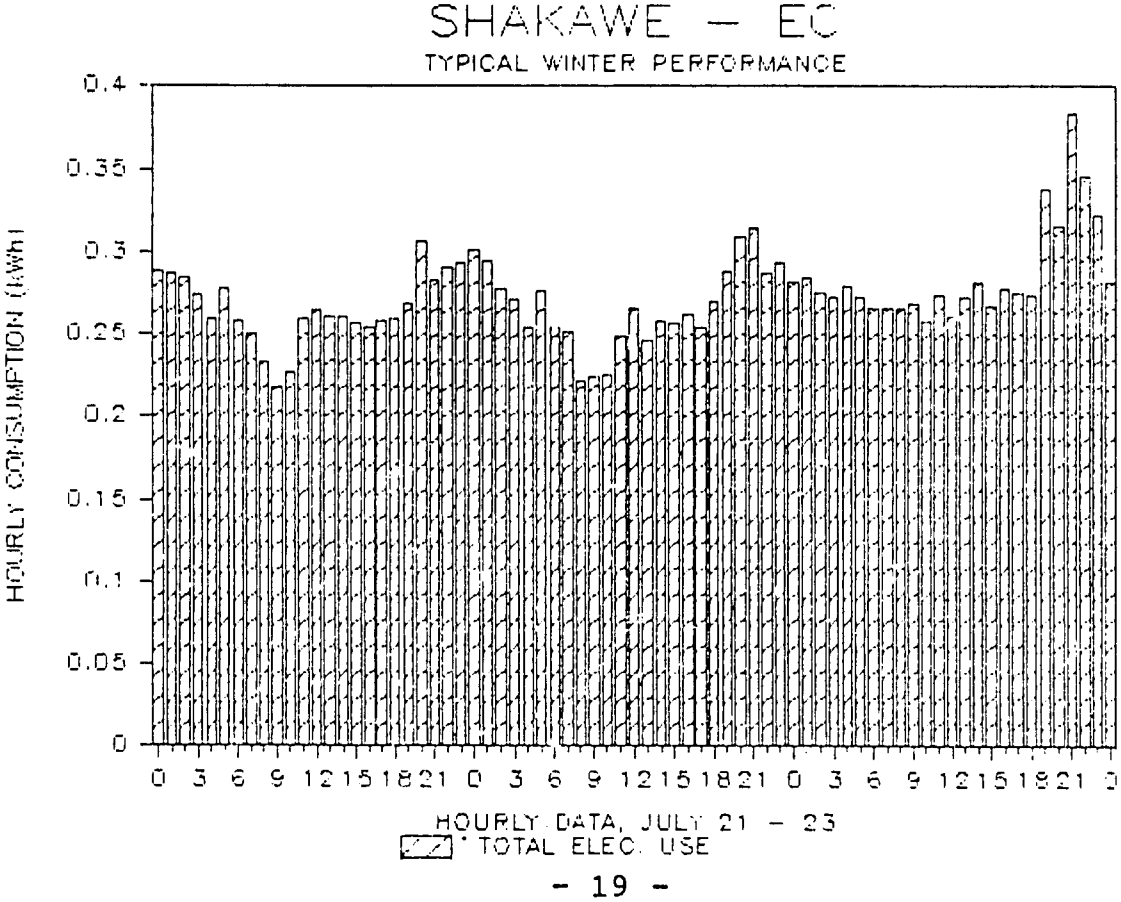


Figure 11.



maximum temperature in the living room occurs about 17:00. While unmonitored internal heat gains (such as cooking) may have also had an effect, the time of the living room peak suggests that more heat is being provided by conduction through the wall than comes directly in through the north-facing windows (direct gains probably peaked about 13:00). While the Trombe wall temperatures then continue to fall through the night, they do so slowly and remain well above the indoor temperature. At night, heat is only provided to the inside air by internal gains and heat stored in the thermal mass of the building. With the relatively small internal gains (about 500 watts) and the relatively cold temperatures outside during this period, it must be concluded that substantial heating of the house is occurring largely due to heat which has been stored from day until night in the thermal mass of the house, either in the Trombe wall, or in the inside walls and slab. This is reflected in the very slow and steady downward drift of the living room temperature from about 19:00 until 8:00 the next morning, at which point the cycle begins again.

Figure 11 displays the hourly total household electrical energy use for the three-day period discussed above. Just as the electrical use was very constant from month to month, it is relatively constant from hour to hour, at a rate of about 250 watts.

4.3 Summer Performance

Dynamic performance under mid-summer conditions is represented by the three-day period of January 19-21. Figure 12 shows the hourly measured indoor and outdoor air temperatures for these three days. In this graph, the indoor temperature shown is a space-weighted average of the measured indoor air temperatures. At the time of year when keeping the inside of a house from getting too hot is the primary environmental control concern, it is clear that the house design is doing a good job at reducing mid-day temperature peaks. This is largely attributable to the thermal mass of the house, which heats up only slowly over the course of the day. On the other hand, this same thermal mass cools slowly at night, and in this case keeps the average indoor temperature substantially above ambient. Presumably, a means of increasing heat loss from the space at night, such as a higher ventilation rate, would allow the inside temperature to track the outside temperature more closely.

Figure 12.

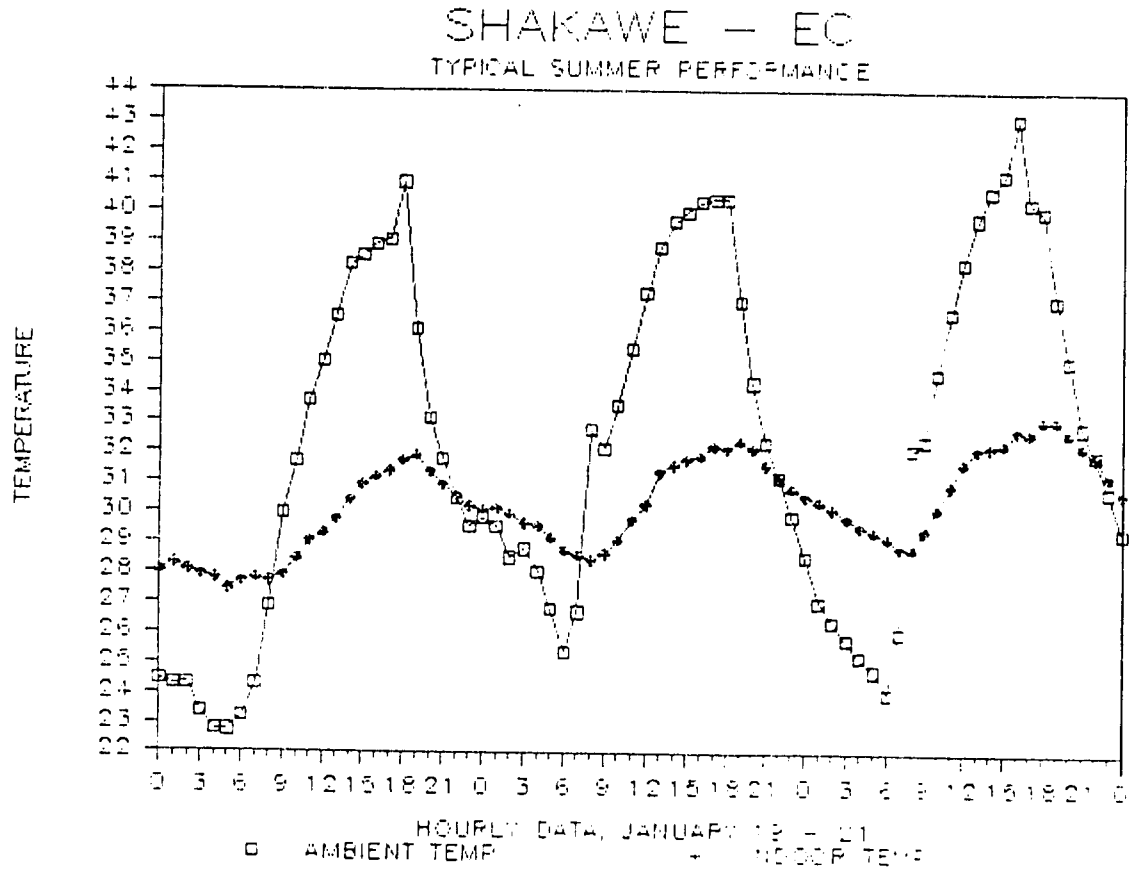


Figure 13.

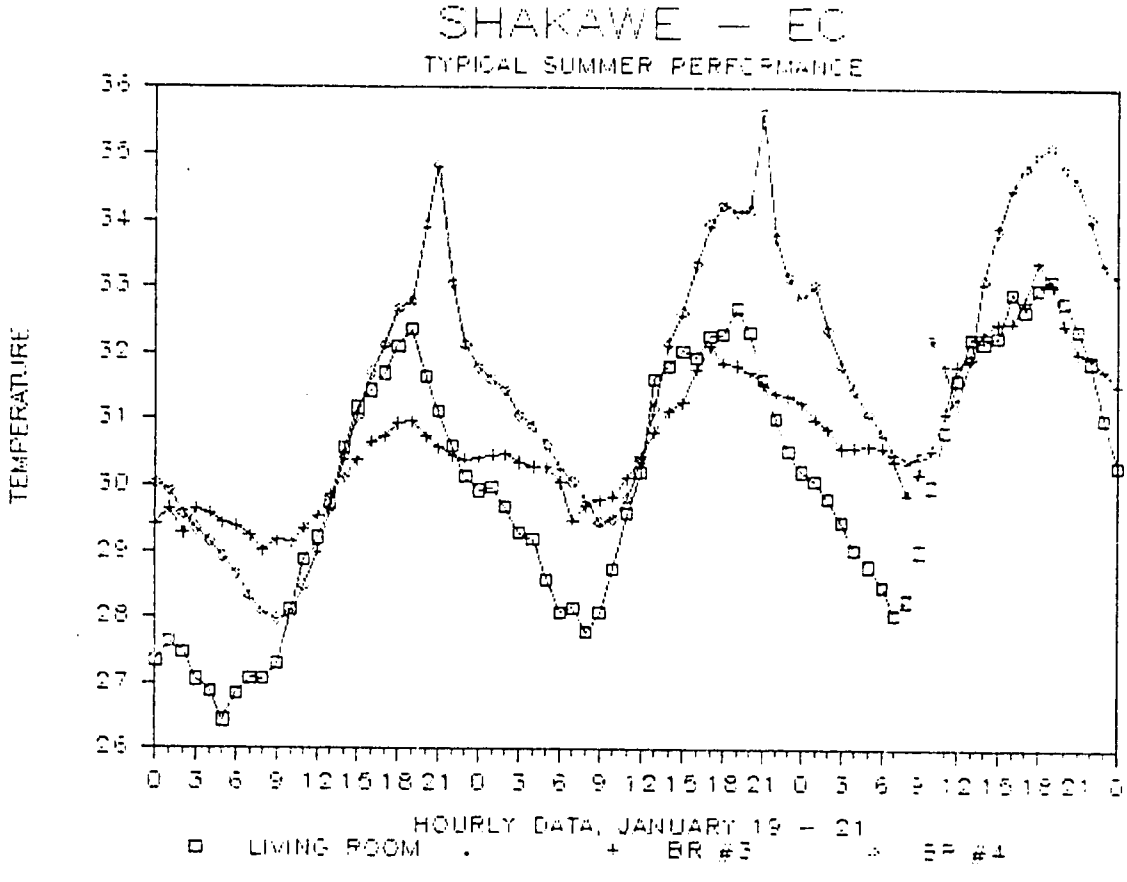


Figure 13 looks more closely at the individual monitored indoor air temperatures over this three-day summer period. As was the case in winter, bedroom #4 has the largest temperature swings. It is also uncomfortably hot through almost all of the period shown, presumably due to excessive solar gain and/or lack of adequate ventilation (only the single operable window was used to provide ventilation - the lack of a screen on the door resulted in it never being opened for ventilation). Bedroom #3 shows the smallest temperature swings, but also appears to be significantly hotter, on the average, than the living room. The daily peak temperatures in the living room are higher than those in bedroom #3, but the nighttime lows are much lower. While the living room does not get as cool at night as the outdoor air temperature, it comes much closer than bedroom #3. This suggests that summer night ventilation in rooms like bedroom #3 is not very good and that, while the living room is much better, it too could be improved. The cause of the higher daytime peak temperature in the living room is not obvious. It could be due to reflected solar gains through the windows (which are relatively larger in the living room), the higher internal heat gains in this area (it is open to the kitchen and is the primary area occupied in the day), conductive heat gain through the windows, infiltration, or windows being left open even when it is hot outside.

In Figure 14 a single day-night cycle of temperatures across the north wall of the house is presented. During the summer, the Trombe wall apertures were covered by vertical shading devices. This, together with the high sun angles and roof overhang, has cut way down on solar heat gains compared to the winter. The outside surface of the Trombe wall stays well below the daytime ambient temperature, instead of rising to near 50 degrees as it did in the winter. A pulse of heat is still transferred, with a four-hour time lag, through the Trombe wall to the inside of the house, but it is of much smaller magnitude than in winter. It should be noted, however, that the inside surface of the Trombe wall runs about three degrees warmer than the inside air temperature, and is thus a net contributor to the cooling problems of the house. At night, the indoor air temperature drifts downward almost perfectly in parallel with the inside Trombe wall temperature, again indicating the strong nighttime coupling of the indoor air temperature to the thermal mass of the house.

Hourly electrical energy consumption during this three-day summer period is shown in Figure 15. As reported in Section 4.1, the average daily electrical consumption varied very little from month to month, and, during the winter from hour to hour. The hour-by- hour situation in summer appears to be much different. While the average rate of electrical use remains about 500 watts, there is more variability than in winter and a few peaks where hourly consumption is two to three times as great. The monitored data do not provide an explanation of the cause of these peaks, but they appear to have some correlation with typical daily meal times.

Figure 14.

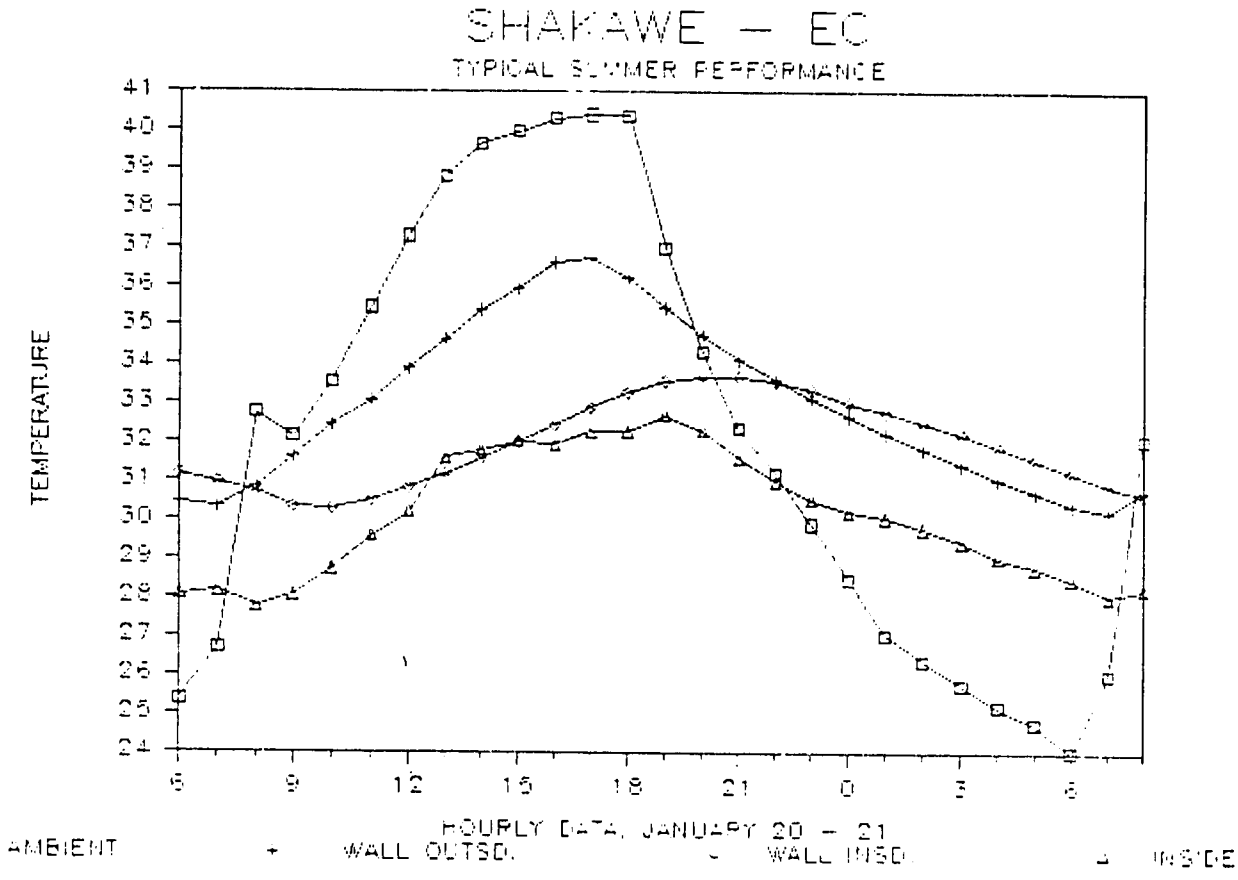
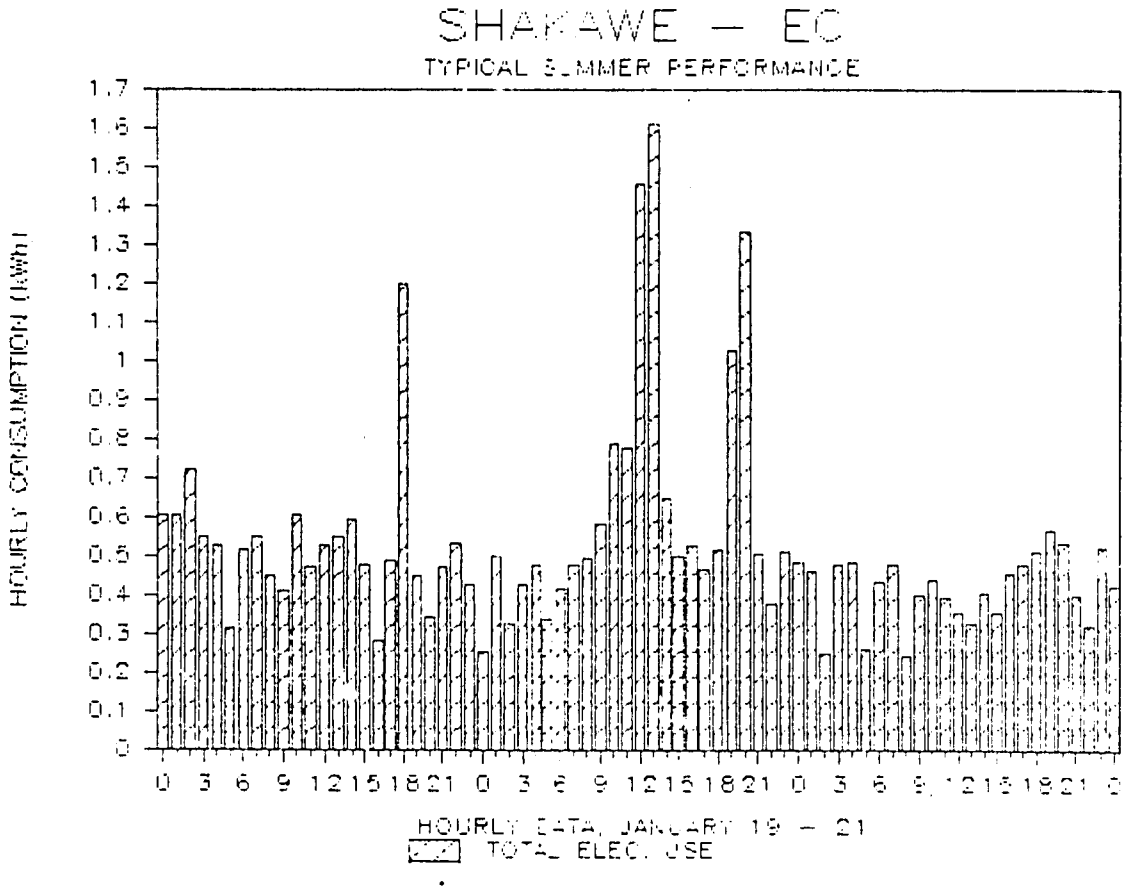


Figure 15.



4.4 Thermal Comfort

Given that there was no coal or electrical energy consumed by the SHAKAWE-EC for auxiliary heating and cooling, the best indicator of the overall success of the building design is the extent to which it created comfortable temperature conditions inside the house.

The occupants of the house felt that reasonably comfortable conditions were maintained throughout the monitoring period. This reflects their particular life-style and perception of temperatures which are "comfortable." It also may reflect their experience in other homes, suggesting that the SHAKAWE-EC is relatively more comfortable than other homes under similar conditions. Still, a more quantitative assessment is useful in understanding the performance of the building and evaluating how comfortable it would seem to other occupants.

The typical hourly and monthly minimum, maximum and average temperatures presented earlier do not give as clear a picture of overall performance as can be presented. A good technique for this is to take the hourly temperatures for each month and sort them into 2° temperature "bins". Each bin will then represent the relative amount of time that the temperature was within a certain 2° temperature range. When presented as a histogram, a clear visual picture is created of just how much of the time the temperature was at different levels during each month. Temperature bin histograms for each month of the monitoring period are presented in Figures 16 - 24.

The determination of the limits of comfortable temperatures is very difficult. It varies from person to person and is influenced by concurrent factors such as relative humidity, air movement, level of activity and type of clothing being worn. It is also somewhat comparative perception, that is, it is influenced by previous experience in comparable situations. However, it is possible to define limits to what most people would find to be a comfortable temperature under typical conditions. In the "Passive Solar Design Workbook" published by BRET in May, 1984, a full discussion of comfort and the comfort zone is presented. That publication suggests that thermal comfort conditions can be assumed to exist if the dry-bulb temperature is between 19° and 27° in winter and 20° and 28° in summer. The seasonal shift assumes the body adjusts its comfort zone to a range of higher temperatures in summer and lower ones in winter. Other literature similarly indicates that in Botswana

Figure 16.

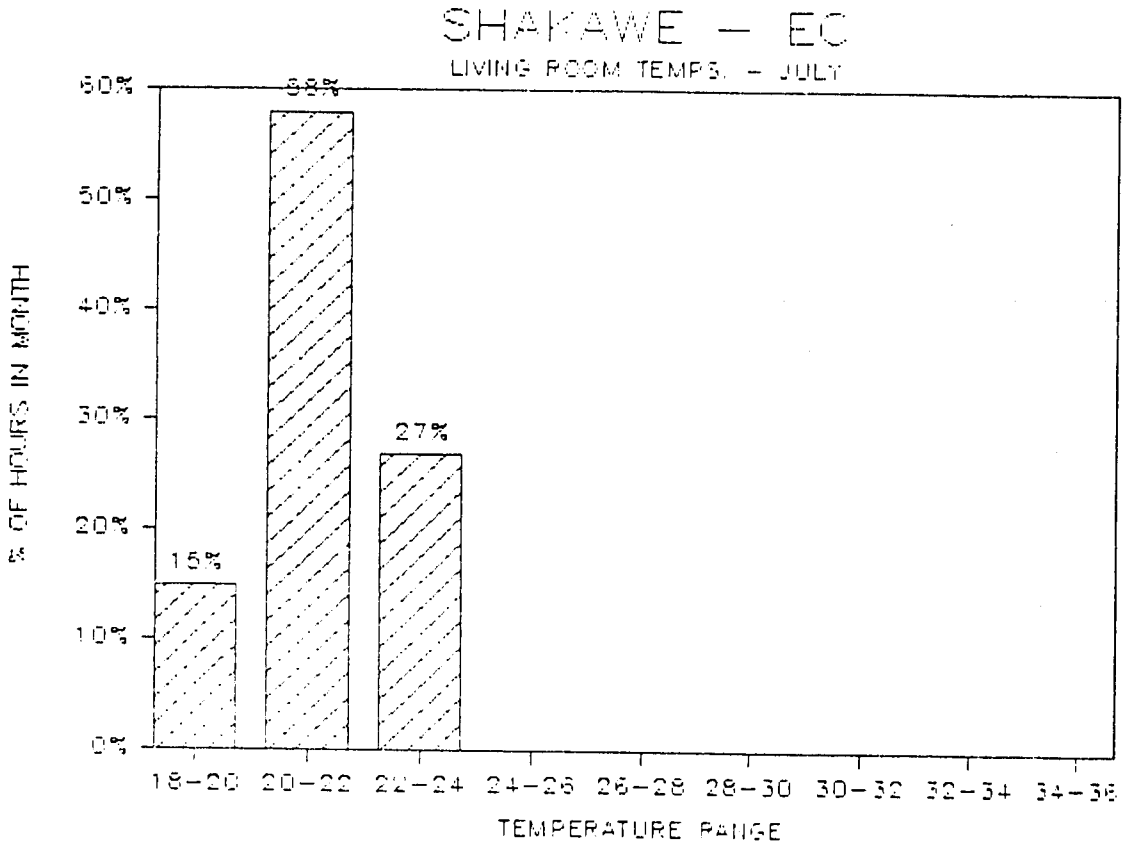


Figure 17.

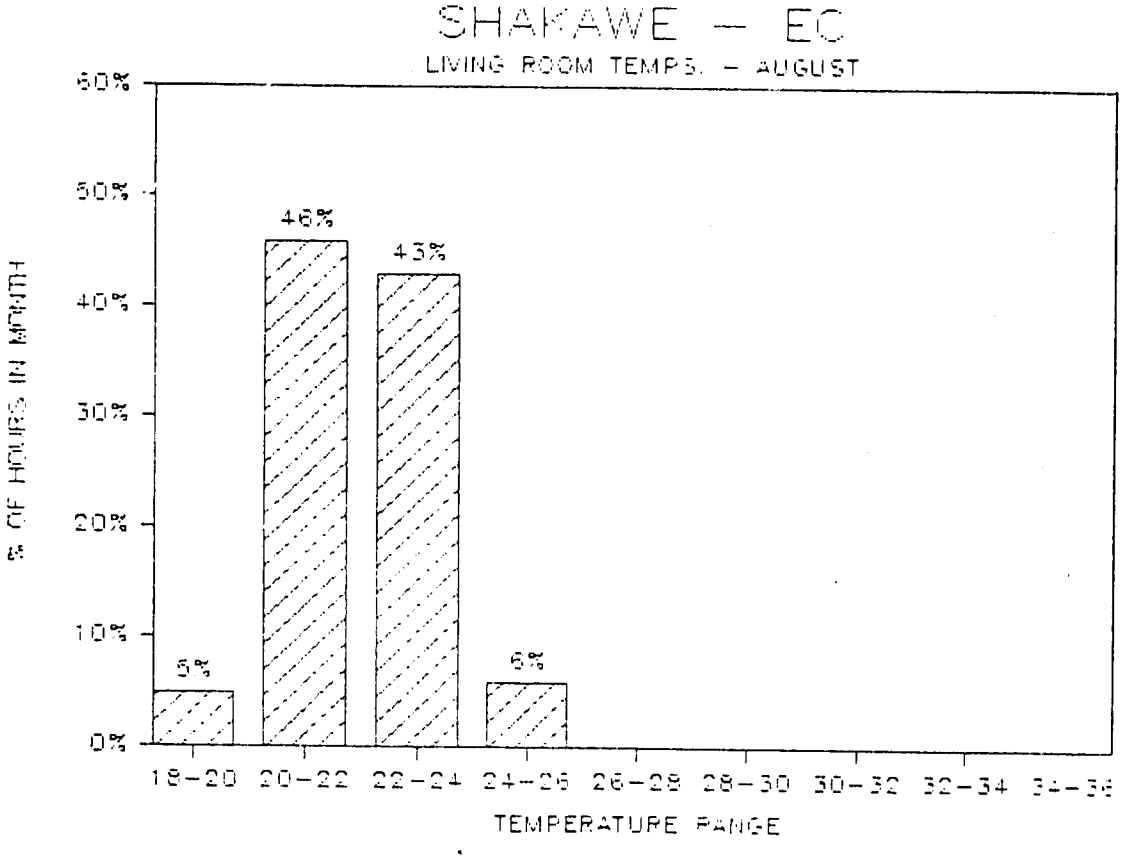


Figure 18.

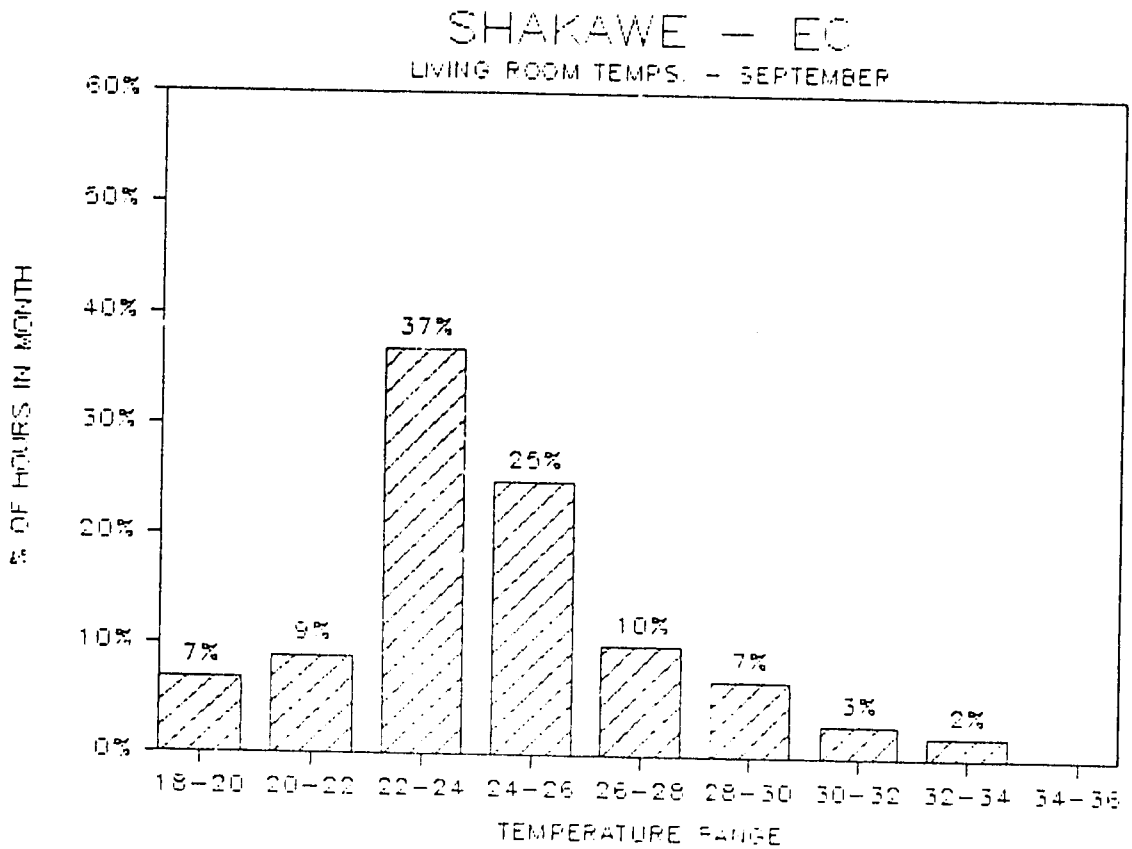


Figure 19.

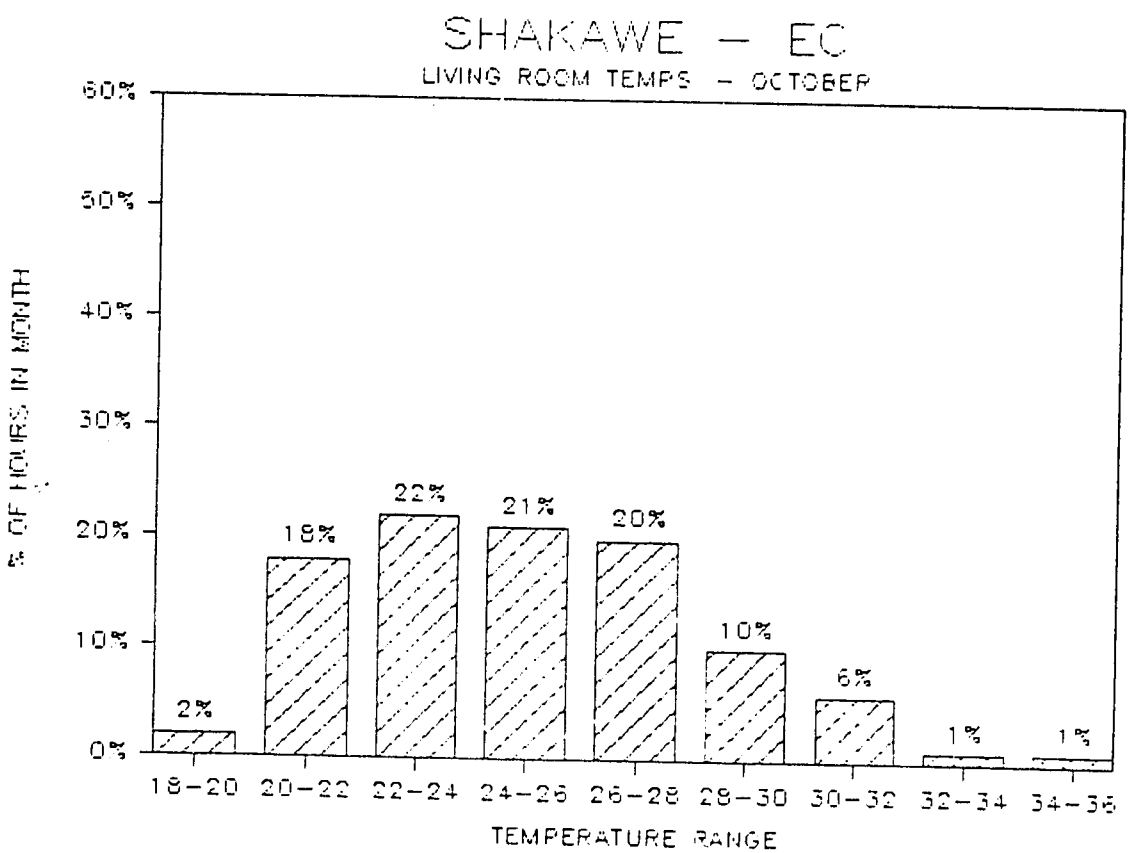


Figure 20.

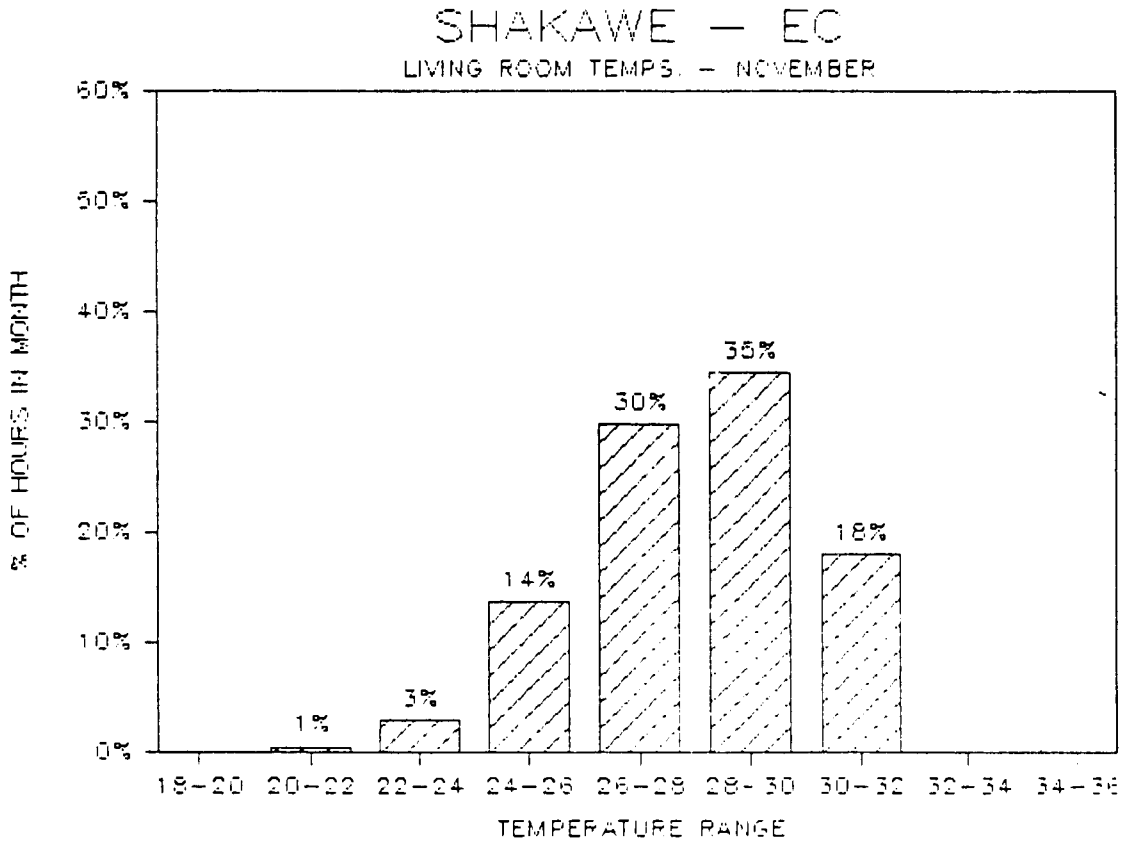


Figure 21.

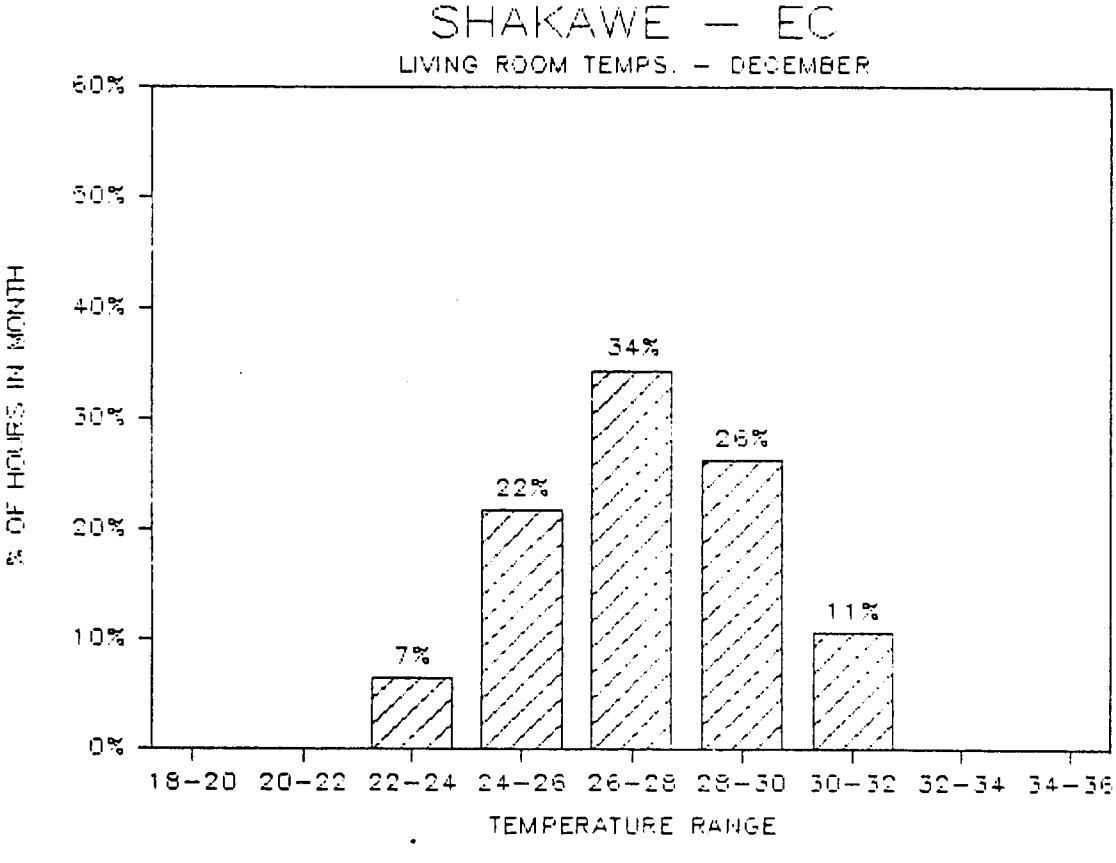


Figure 22.

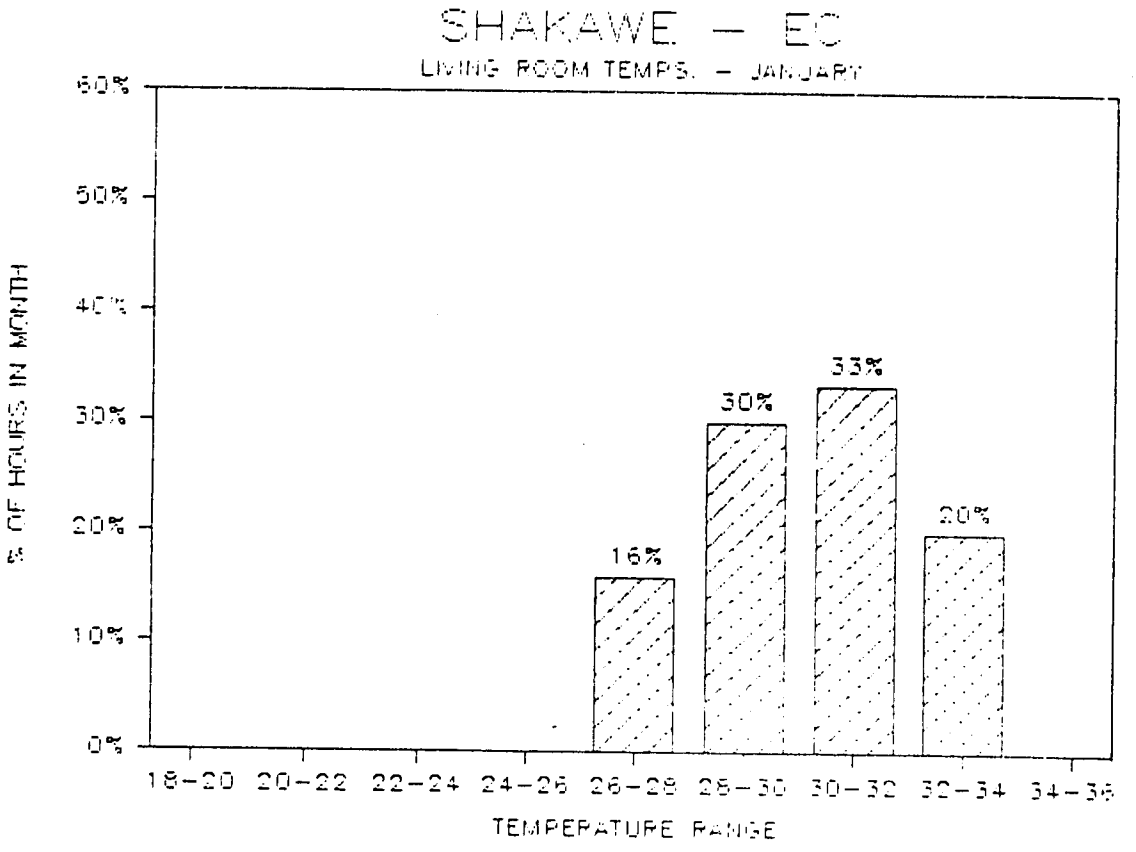


Figure 23.

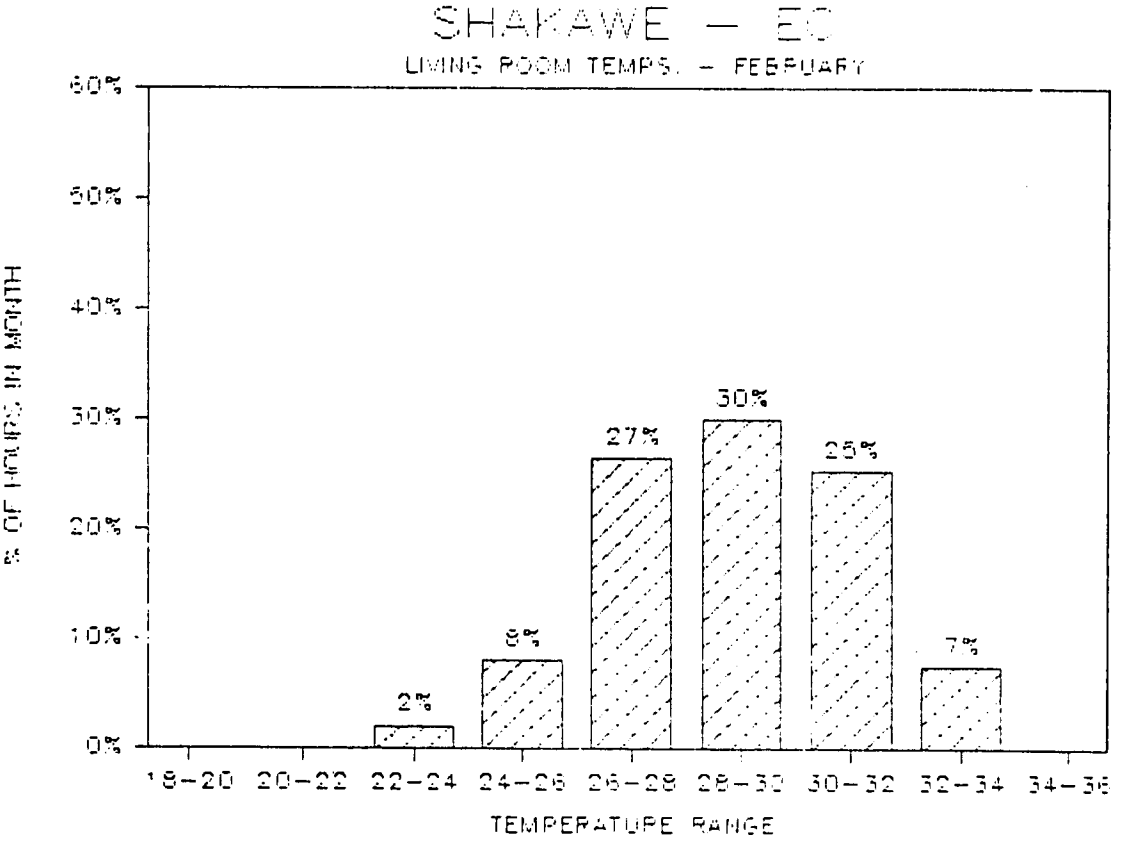
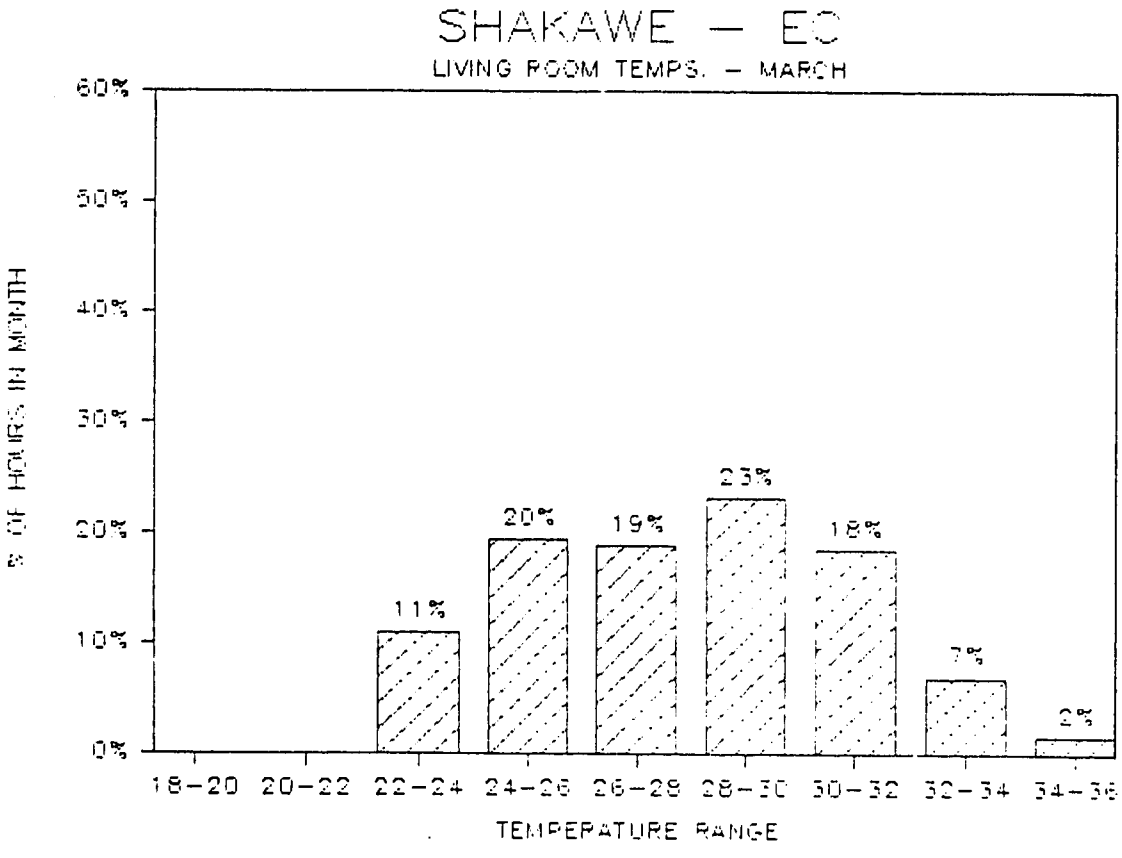


Figure 24.


SHAKAWE — EC
LIVING ROOM TEMPS. — MARCH
% OF HOURS IN MONTH
60%
50%
40%
30%
20%
10%
0%
11%
20%
19%
23%
18%
7%
2%
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
TEMPERATURE RANGE

and other parts of southern Africa, suggested limits for temperatures that most people would consider to be very comfortable are from about 20 to 28 degrees. Using this comfort zone definition of between 20 and 28 degrees, the fraction of the time that the living room temperature is outside of the comfort zone, in each month is as follows:

MONTH	% OF TIME TOO COOL	% OF TIME TOO WARM	TOTAL % OF TIME TOO WARM OR COOL
JUL	15%		15%
AUG	5%		5%
SEP	7%	12%	19%
OCT	2%	18%	20%
NOV		53%	53%
DEC		37%	37%
JAN		84%	84%
FEB		62%	62%
MAR		50%	50%

While these numbers may seem high, it should be remembered that this performance was achieved without <u>any</u> auxiliary heating or cooling. It is also clear from looking at the monthly bins that a great number of the hours are between 28 and 30 degrees. Accordingly, if the upper bound of the comfort zone was defined to be 30 degrees, the total percentage of the time too warm or too cool would be reduced by 47%.

5 Comparative Performance Studies

Evaluating performance of a building design is very difficult in the abstract. Performance is relative, and is truly useful only when it is stated in terms of an absolute reference framework (such as an energy standard) or relative to some other alternative design. When we say a building performs well or poorly, we must answer the "compared to what?" question. In this case, the question of primary interest is probably how well the SHAKAWE-EC performs relative to a similar, conventional house, and that will be the primary topic for the present section of this report.

While many of the energy conservation and passive solar design features of the SHAKAWE-EC did not cost more than a conventional house, other features required additional material and/or labor costs. In order to assess the value of various elements of the design, we would like to know how much better or worse the building would perform with and without each of these features.

Of course, one obvious way to assess all of these alternatives would be to build individual houses representing each of the options of interest and monitor them all in a side-by-side experiment. This approach has two difficulties. Obviously, it would be costly to build and monitor so many homes. Additionally, it is obvious that the way a home is lived in and operated by its occupants affects thermal performance. Opening and closing windows and shades, the number and activities of occupants, appliance usage, and personal preferences of comfort conditions all affect building energy performance. Unless these were all measured or controlled to be the same, results would not be comparable.

An alternate approach to assessing comparative performance is to use models to represent the alternative buildings to which we wish to compare the SHAKAWE-EC. This is much less expensive and many options can be examined in a short period of time. The danger in this approach is that the models used may not accurately represent the actual performance of buildings.

The original project design called for monitoring a coventional SHAKAWE-A Type II house, as a comparative reference to the SHAKAWE-EC. This was delayed due to a number of technical difficulties while, at the same time, some comparative performance studies using computer simulation models were performed. The usefulness of these simulation studies was greater than first anticipated, and checks against the measured data from the SHAKAWE-EC indicated the simulation model to represent the actual house with reasonable accuracy. Based on this development, as well as continued technical and logistical difficulties with the reference house, a decision was made to abandon the original plan to monitor a reference house and rely solely on simulation for comparative performance evaluation. The techniques used to conduct these studies and their results are presented in the following sections of this report.

5.1 Techniques Used

The computer simulation model used in these studies was the CALPAS3 model, version 3.13. This is a computer program specifically designed to analyze the energy performance of passive solar and conventional residences. It was originally developed by Prof. Philip Niles of California Polytechnic State University. It was further developed and made commercially available by the Berkeley Solar Group (3140 Martin Luther King Jr. Way, Berkeley, California 94703, USA). It was selected because it was the only currently available full-year, hourly simulation program which would run on a microcomputer. Because the climate of Botswana is such that buildings can have both heating and cooling requirements on the same day, models which operated on a daily or monthly level would lead to inaccuracies. A program which would run on a microcomputer made a large number of simulation runs possible at a low cost.

CALPAS3 is an hour-by-hour thermal network simulation program. It is based on ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) heat transfer and ventilation algorithms. It uses backward (implicit) differencing equations for modelling transient heat conduction in mass elements and combined radiant-convection coefficients to achieve fast execution.

The inputs to the model are a detailed thermal description of the building (areas, orientations, material properties, etc.) and its operating parameters (thermostat setpoints and other occupancy variables), as well as one year of hourly weather data (temperature, wind, solar radiation, etc.).

The output of the model is a series of tabular reports which give energy flows, temperatures, heating and cooling loads, etc. on an annual, monthly, daily or hourly basis. In preparing this report, the outputs of the CALPAS3 program were graphed, for easier understanding, using the LOTUS-123 program.

5.1.1 Weather Data

Annual measured hourly weather data for Botswana are not available at this time, so it was necessary to synthesize a weather file to run the CALPAS3 program. Not only are hourly data on temperature, humidity, solar radiation, wind speed and wind direction required, they must be in a computer-readable format.

The most difficult element of a weather tape to synthesize is solar radiation. Accordingly, a search was made of existing availble weather tapes to find the one with solar radiation most similar to Botswana. Both the intensity of solar radiation over time and the sun angles needed to be considered. The selected location was Dhahran, Saudi Arabia, which has monthly total solar radiation values almost identical to those for Botswana. It also is located at a latitude of 26° North, giving sun angles identical to southern Botswana but offset by six months. The hourly solar radiation values on this tape were used intact, but the temperatures needed to be changed. This was done by offsetting the temperatures from Dhahran for each month until the monthly mean temperature matched the measured long-term monthly mean for Gaborone. Then the amplitude of the diurnal temperature swing was modified until the mean monthly minimum and maximum matched the measured values for Gaborone. The resultant weather tape was formatted as a CALPAS3 input file and used for all the simulations described in this report.

Wind velocity was not corrected inside the weather file, but instead adjusted inside the simulation program. This enabled a better match to the wind velocity actually measured at the SHAKAWE-EC site. CALPAS3 allows for such an adjustment to input wind velocity with the "Windfactor" command, where a value of .4 was used.

In order to verify that this synthesized weather file could reasonably be used for this study, monthly weather file values were compared against the actual measured values from the monitoring period. Figure 25 shows a comparison of measured wind velocity and the assumed wind velocity in the simulations. Figure 26 shows a comparison of measured solar radiation and the values assumed in the simulations. Figure 27 shows a comparison of measured ambient temperature and the assumed ambient temperature used in the simulations. In all of these cases the agreement is reasonable, and certainly within the bounds of the year-to-year variability that can normally be expected in the

Figure 25.

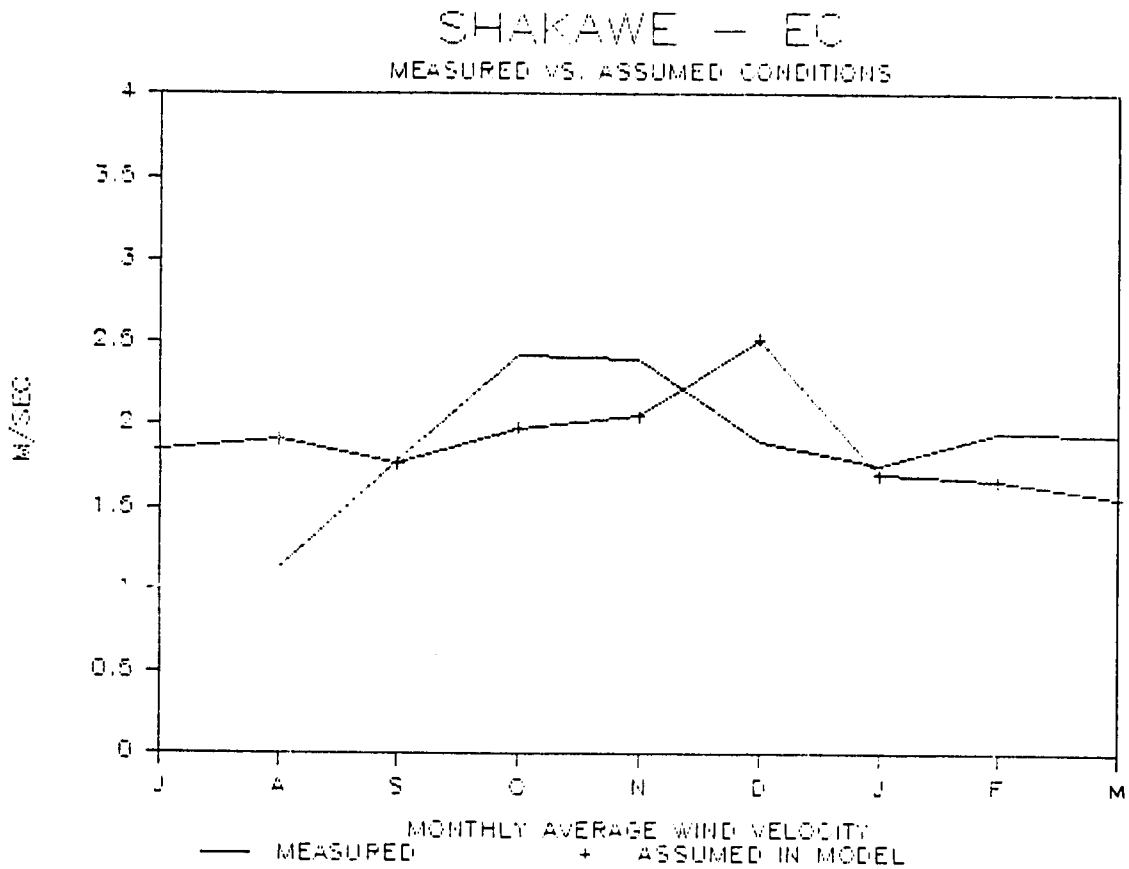


Figure 26.

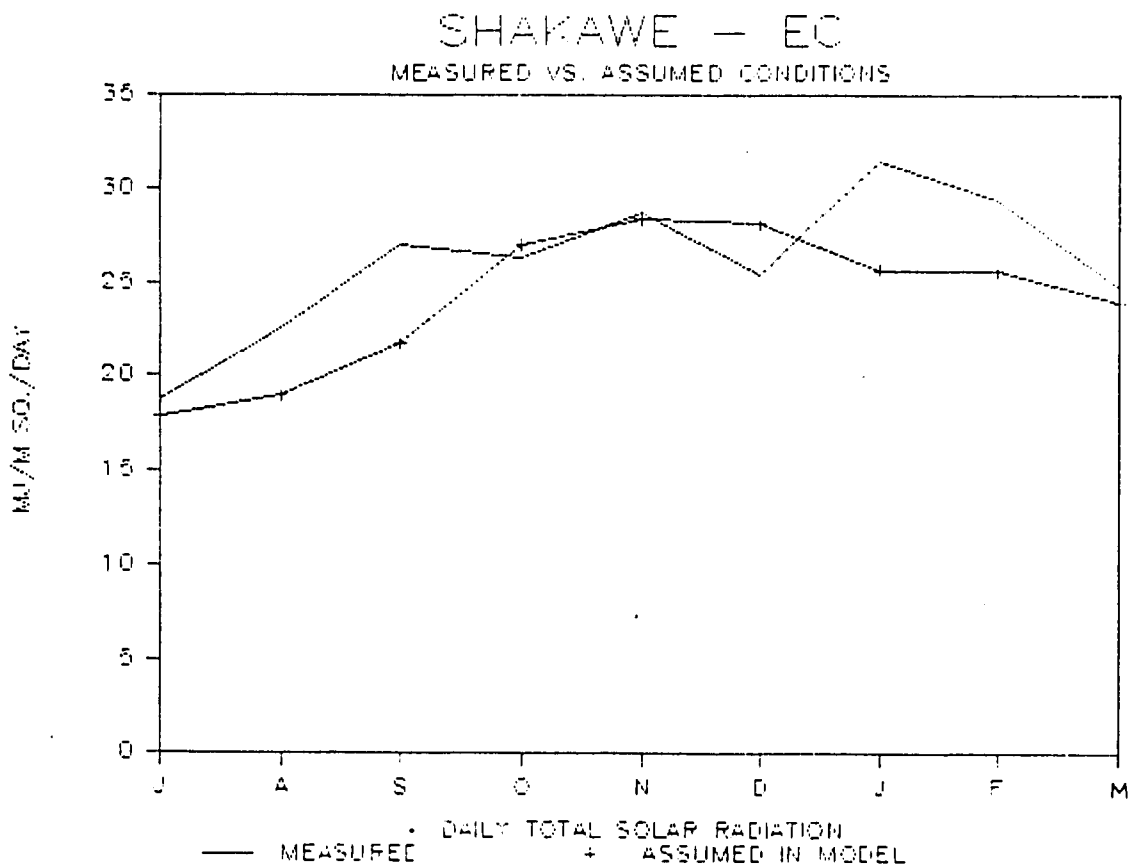
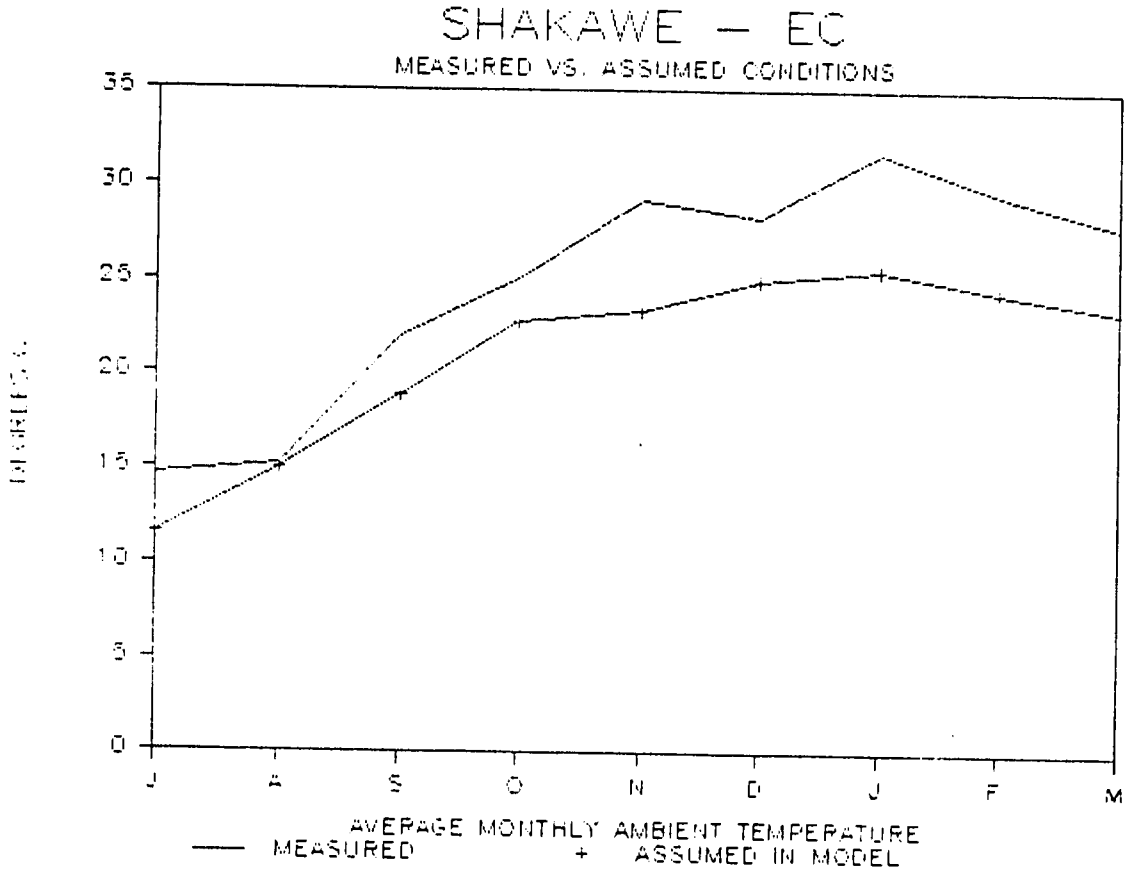


Figure 27.


SHAKAWE — EC
MEASURED VS. ASSUMED CONDITIONS
35
30
25
20
15
10
5
0
J
A
S
O
N
D
J
F
M
AVERAGE MONTHLY AMBIENT TEMPERATURE
MEASURED
+ ASSUMED IN MODEL

weather. The one case where there appears to be some uniform bias is with the ambient air temperature, where the measured value is uniformly higher than that used in the simulations. The problem here is not so much a discrepancy between the simulation and the measured values, but rather a discrepancy between the measured values and the long-term data reported by GOB Meteorological Services for Gaborone. Two explanations are possible. First, it is possible that the period when data were recorded was unusually hot compared to previous years. The second is that the temperature sensed in the monitoring did not truly represent the ambient temperature. An examination of the mounting of the outdoor temperature sensor on the SHAKAWE-EC shows that it could have given erroneously high readings due to locally higher temperatures close to the wall of the house where it was mounted; however, this cannot be ascertained without further investigation. In any case, the ambient air temperatures assumed in the model are consistent with long-term measured values for Gaborone and are, therefore, the correct values to use in predicting the average performance of the buildings being examined.

5.1.2 Building Description and Operation Inputs

The complete listing of building description and operation inputs to the simulation model for the SHAKAWE-EC can be examined in Appendix B. Dimensions and geometry of building components were taken from the construction drawings used to build the house. Additional information was provided by the occupants and the building designer.

The building was simulated assuming the occupancy of the SHAKAWE-EC, as monitored. Key assumptions were:

1. Window shades or curtains were not closed during the winter when there was a need to provide heat to the house.

2. Windows and vents were opened in to vent excess heat out of the house when it rose above 24 degrees in winter and above 22 degrees in summer.

3. All electrical energy consumption monitored for the SHAKAWE-EC resulted in a heat gain to the inside of th house (continous at 500 watts).

4. Heat given off by occupants, heat from gas cooking, and heat loss from domestic hot water provided an additional

internal heat gain of 10.6 kWh/day.

5. Infiltration in the house can be expressed as (air changes per hour) = .0125 (inside-outside temperature) + .375 (wind speed in m/s), which results in an average air change rate in winter of .75.

6. Removable shades reduce solar radiation incident on the Trombe wall by 80% from October through March.

Obviously, these assumptions are not accurate for all the ime during the monitoring period. Occupancy was not the same on very day, and operating strategies were not always as assumed. his should be kept in mind when comparing short-term differences n modelled and actual performance.

When alternate building designs were simulated, all these ssumptions remained the same; only the physical description of he building was varied. This means that the results indicate ow an alternative design would perform under the same conditions f occupancy and operation.

There are two basic approaches which were used to compare he performance of alternate designs. The first of these was to xamine temperatures in the SHAKAWE-EC and alternate designs here no auxiliary heating or cooling is used. This parallels he actual conditions which were monitored in the SHAKAWE-EC. In his case, the monthly and typical hourly indoor air temperatures an be examined to see what effects the building design has.

Extremes and averages don't tell the whole story, however. A better quantitative feel for relative thermal comfort which can be achieved by alternate designs needs to examine the integrated magnitude and duration that indoor temperatures rise above or fall below the comfort zone. A simple way of accomplishing this is by simulating building performance with heating and cooling thermostat set points at the top and bottom of the comfort zone. The resultant heating and cooling "loads" then represent two key performance parameters. First, they represent the actual heating and cooling loads which would have to be met if the building were mechanically heated and cooled to maintain comfort conditions (this certainly is the case for some buildings in Botswana). In this case, the difference in the loads represents the real energy savings that would be achieved by using one design over another. The heating and cooling loads also give a measure of relative performance for the building if it were not heated or cooled with electricity or oil. For this situation, a single value is produced which represents the integrated magnitude and length of time that one design would be too hot or cold compared to another. For simulation runs made with thermostat set points, the winter heating set point was set at 20°, and the cooling set

point at 27°. These limits are somewhat arbitrary, but are felt to represent the limits that would normally be maintained in a house which where temperaturte was controlled with full heating and air-conditioning. It should also be noted that the relative performance of different designs is relatively insensitive to the exact specification of these limits.

5.1.3 Checking the Model Against Monitored Data

Obviously, one of the primary concerns with using a model to predict relative performance of different building designs is that the model may not accurately reflect how buildings perform in reality. A model is necessarily a simplification, and it is important to investigate whether these simplifications result in unreasonable results. While the CALPAS3 model has been used widely and has been the subject of numerous studies where predicted and measured value were compared, there are enough unusual aspects to this application that it was felt important to check the model against monitored data from the SHAKAWE-EC. Accordingly, the first simulations run were of the SHAKAWE-EC, as built, and with no auxiliary heating and cooling.

Figure 28 shows the measured average monthly indoor temperature for the SHAKAWE-EC compared to the results of the simulation model. The agreement is generally good, with the measured temperature running slightly higher than the predicted during the summer months. This would be consistent with the outdoor air temperature being warmer than normal this summer, as discussed earlier in this section of the report. Figure 29 shows the monthly average minimum and maximum indoor temperatures, both as measured in the SHAKAWE-EC and predicted by the simulation model. These show the model is doing a good job not only at predicting the indoor temperature on the average, but taking account of mass effects to predict the right magnitude of day-night temperature swings. On the basis of these checks, it was felt reasonable to proceed with using the model to investigate comparative performance of the SHAKAWE-EC design.

5.2 SHAKAWE-EC Performance Compared to a Reference House

In order to compare the performance of the SHAKAWE-EC to a similar, non-solar house, it is first necessary to define the

Figure 28.

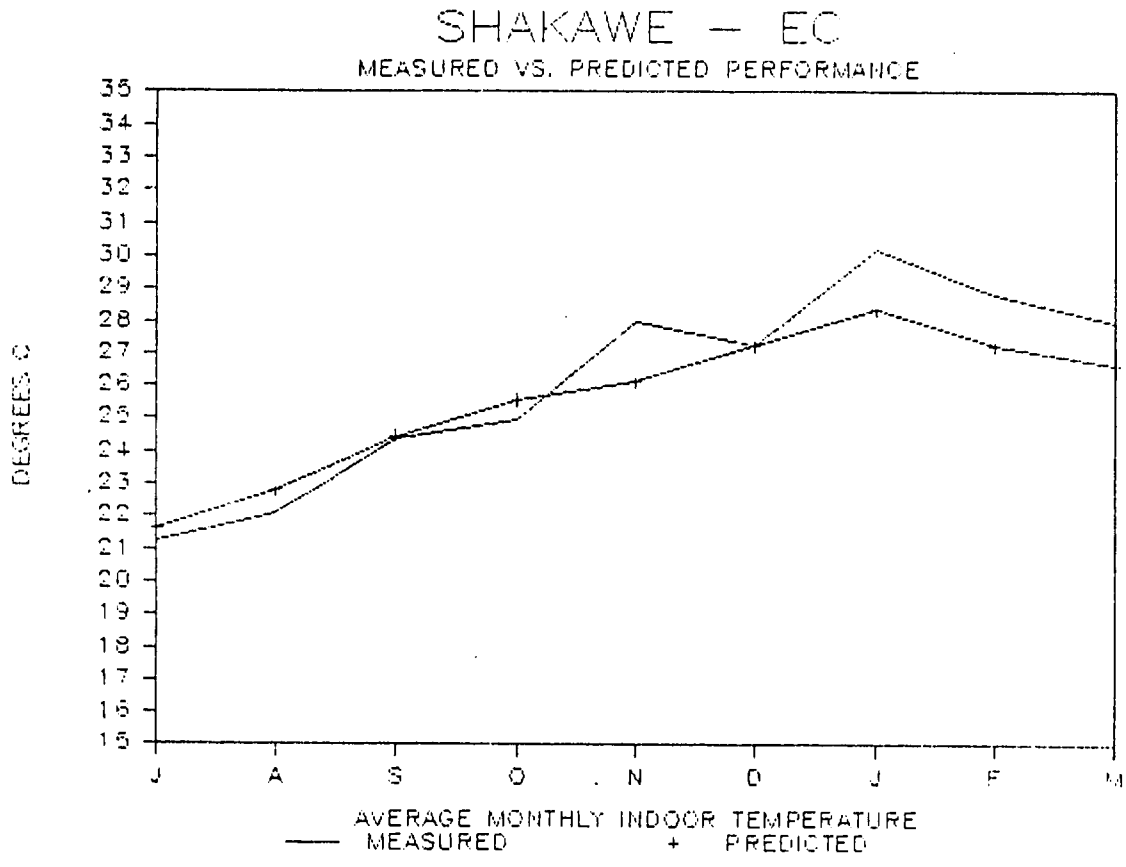
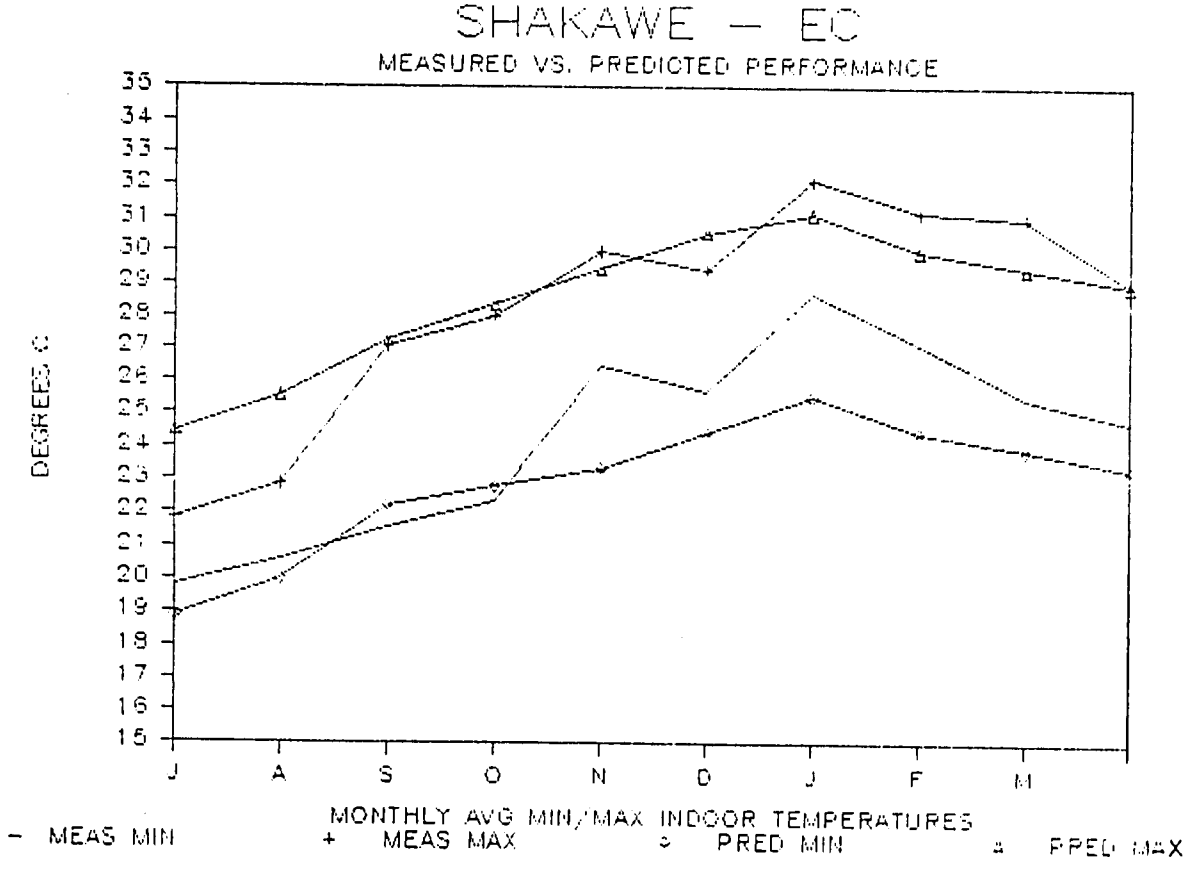


Figure 29.



reference house. In order to make sure that the results reflect only on the passive solar and energy conservation features of the design, the reference house is defined as a house of identical occupancy, operation and internal gains. Only the following changes are made:

1. The reference house has a ceiling, but no insulation (R Value = .53 instead of 3.52 for the SHAKAWE-EC).

2. The walls of the house are hollow-core 230mm concrete block with 15mm cement plaster on the inner and outer surfaces (R Value = .51 instead of 2.36 in the SHAKAWE-EC walls).

3. The Trombe wall is replaced by an equal area of conventional concrete block wall, as described above.

4. Average infiltration is assumed to be 50% greater than the SHAKAWE-EC, estimated from the observation that typical construction appears to have about 50% more cracks and gaps around windows and doors, through the ceiling, air bricks, etc.

5. The reference house has ventilation only through the operable window areas (no outside or inside wall vents as found in the SHAKAWE-EC).

Obviously, this does not give the SHAKAWE-EC credit for building form, orientation and interior layout. While a reference house might not be similar in these respects, it could be, and to define any other reasonable alternatives for the refernce house would be somewhat arbitrary. Accordingly, the performance results should be interpreted as being generous to the reference house, and thus provide a conservative estimate of energy savings. If it had a less favorable shape, layout and orientation, its performance would probably be even worse.

5.2.1 Floating Temperature Comparison

Figure 30 compares the predicted monthly average indoor air temperature for the two houses. As might be expected, the reference house is colder in the winter and warmer in the summer. What is going on is made more clear in Figure 31, where the mean daily minimum and maximum temperatures are compared by month. While, as might be expected, the summer maximum temperatures in the reference house are higher than the solar house, the winter mean daily maximum temperatures are almost the same for the two houses. Evidently, heat gains into the

Figure 30.

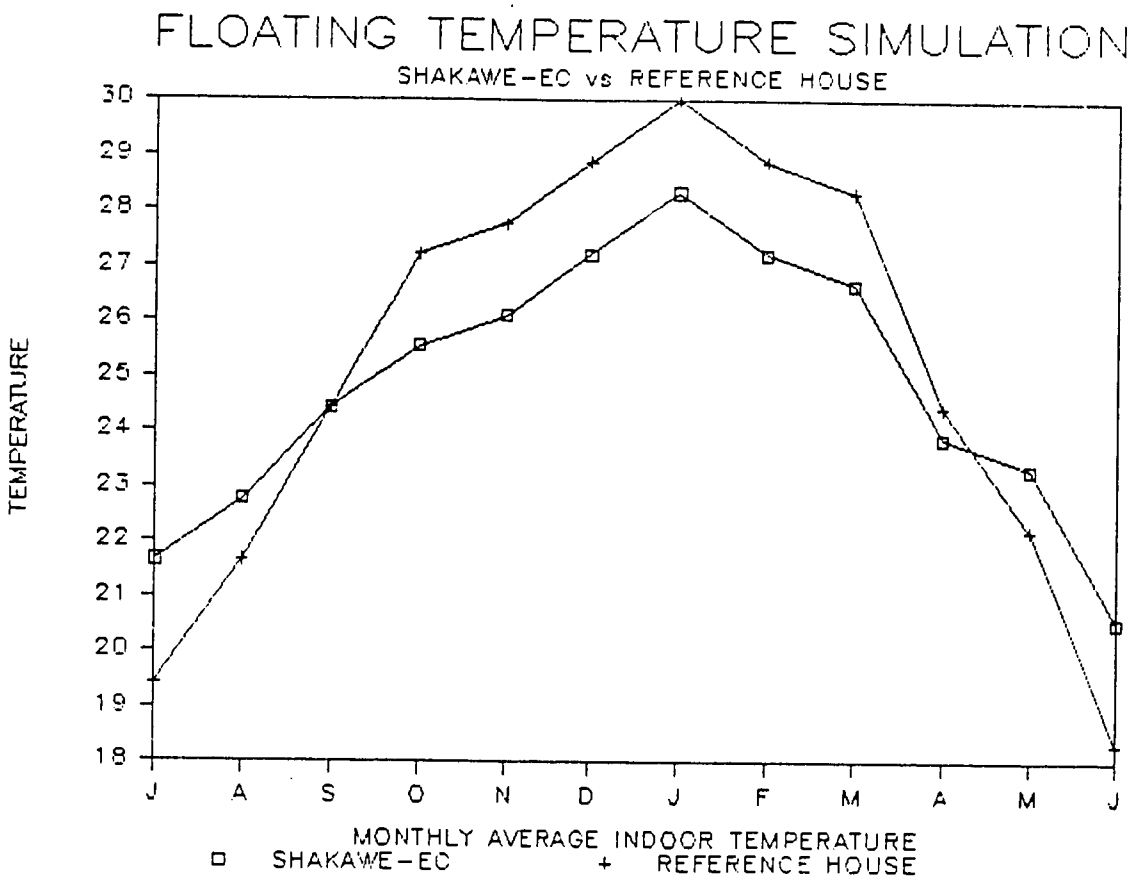
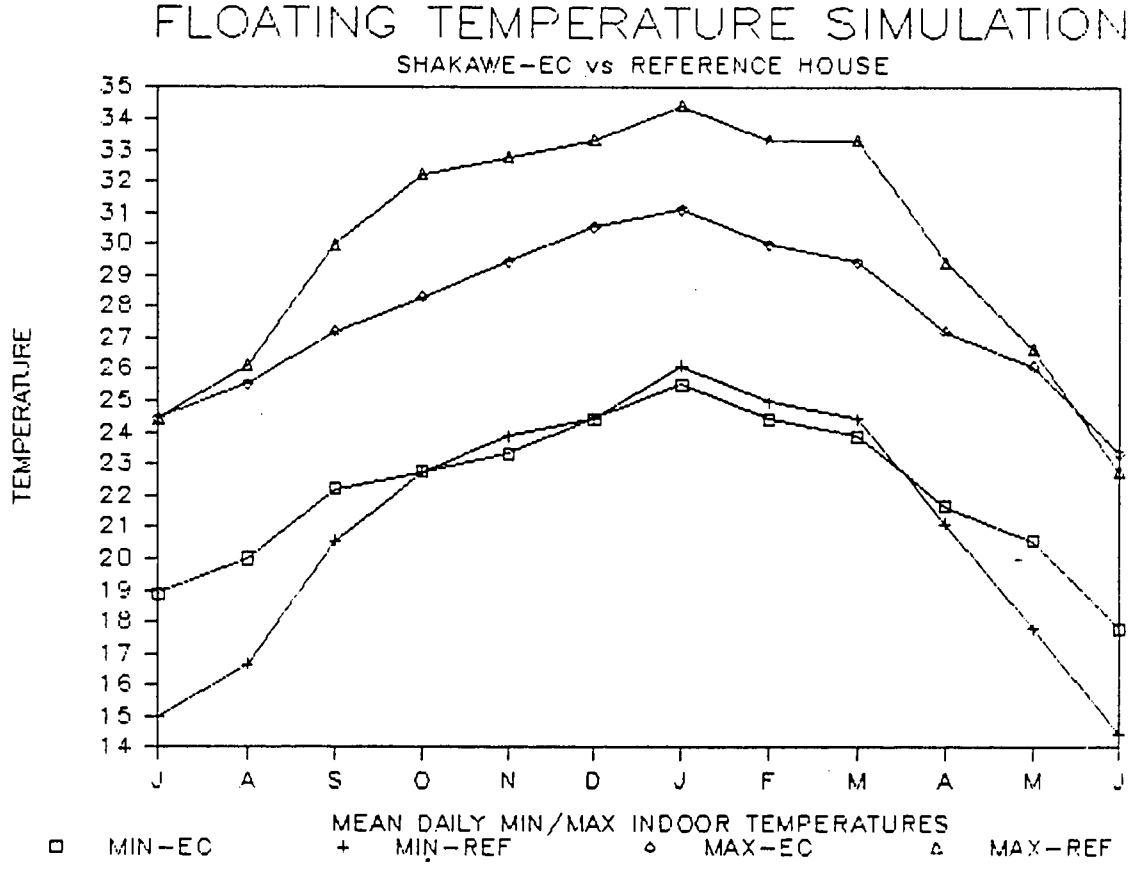


Figure 31.



reference house from the roof, walls and windows heat it up to the same daily maximum temperature during the four months of winter. Of course, at night the lack of insulation and higher infiltration result in the reference house experiencing much lower minimum temperatures. Unexpected, however, is the fact that the summer minimum temperatures in both houses are about the same. This will be explored further below.

Hourly inside temperatures of the two houses under typical August conditions are presented in Figure 32. While the temperature of the SHAKAWE-EC never goes out of the comfort range, the temperature in the reference house is below 20° from about midnight until 10:00 in the morning, with a minimum over four degrees lower than the solar house.

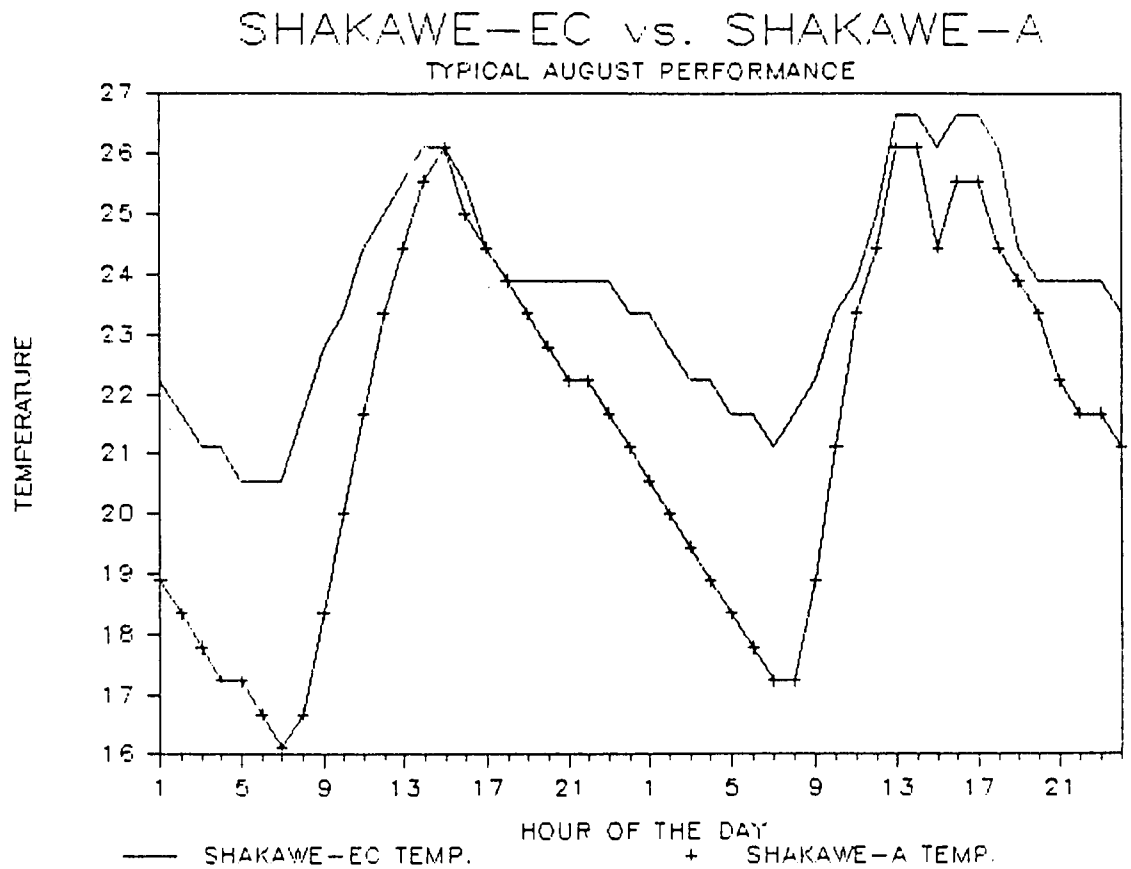
Figure 33 shows a more extreme winter comparison. With outside temperatures dipping below freezing, the minimum temperature in the reference house is under 10°, while the SHAKAWE-EC falls to 14°.

A typical summer temperature comparison is presented in Figure 34. While both houses are quite warm, the reference house is always warmer than the ambient temperature, while the SHAKAWE-EC stays below ambient during the hottest hours of the day. The reference house rise to 36° in late afternoon, a very uncomfortable temperature level. While the overheating of the reference house is clearly a problem, of equal concern here is that both houses appear to be having a problem cooling off at night. The outdoor temperature starts falling rapidly about 17:00, and by 21:00 is 5° lower than the indoor temperature of either house. Ventilation cooling in the SHAKAWE-EC is greater than the reference house and for the SHAKAWE-EC is the primary means of lowering temperature at night. While the reference house does not lose as much heat by ventilation at night, its lack of insulation enables it to lose more heat at night by conduction than the solar house. While this deserves further investigation, it should also be noted that both houses would appear to benefit substantially by being able to lower their nighttime temperatures closer to the ambient conditions by higher ventilation rates. Not only could this make indoor temperatures at night more comfortable, but it might also cool down the mass of the buildings and help to keep them cooler the next day.

5.2.2 Comparison with Use of Auxiliary Heating and Cooling

The next set of simulations run were those where all descriptive inputs were the same for the two houses, except that

Figure 32.


SHAKAWE—EC vs. SHAKAWE—A
TYPICAL AUGUST PERFORMANCE
TEMPERATURE
27
26
25
24
23
22
21
20
19
18
17
16
1 5 9 13 17 21 1 5 9 13 17 21
HOUR OF THE DAY
SHAKAWE—EC TEMP.
+ SHAKAWE—A TEMP.

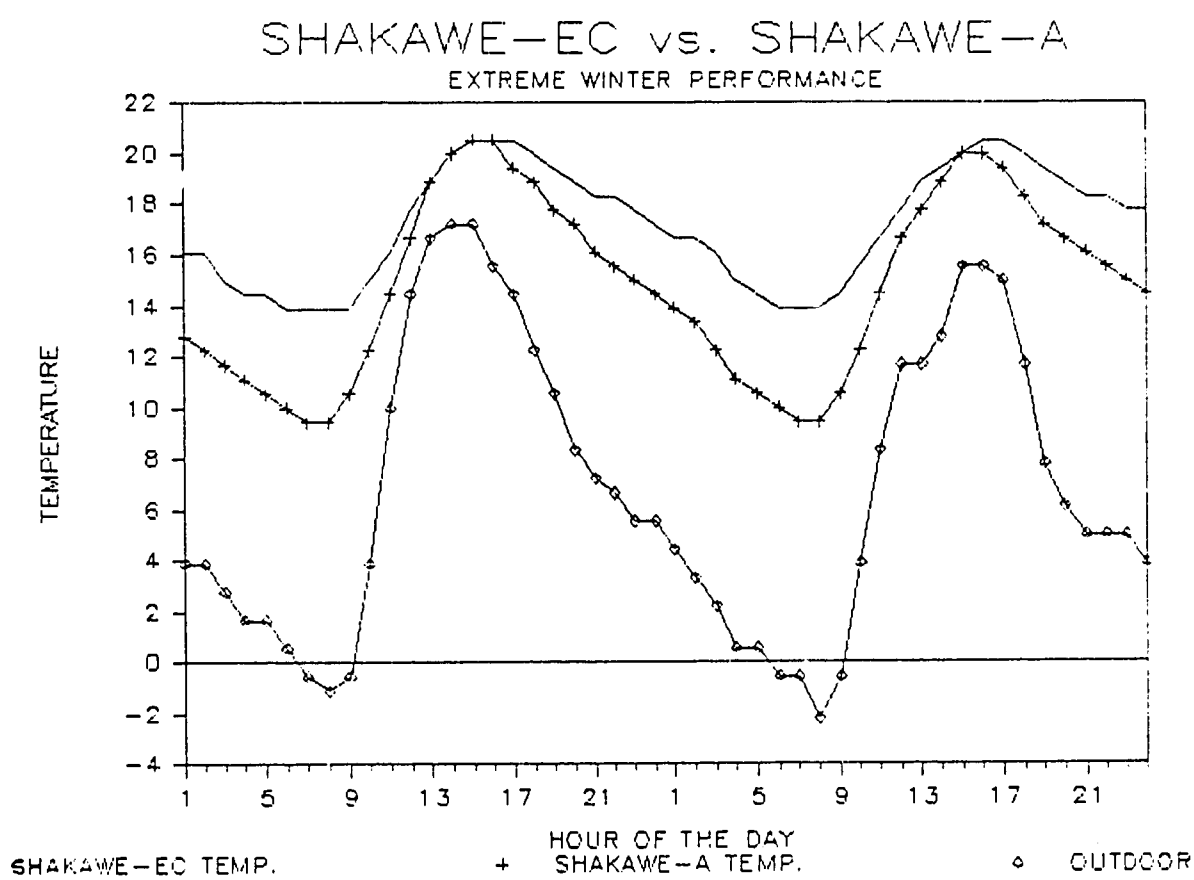
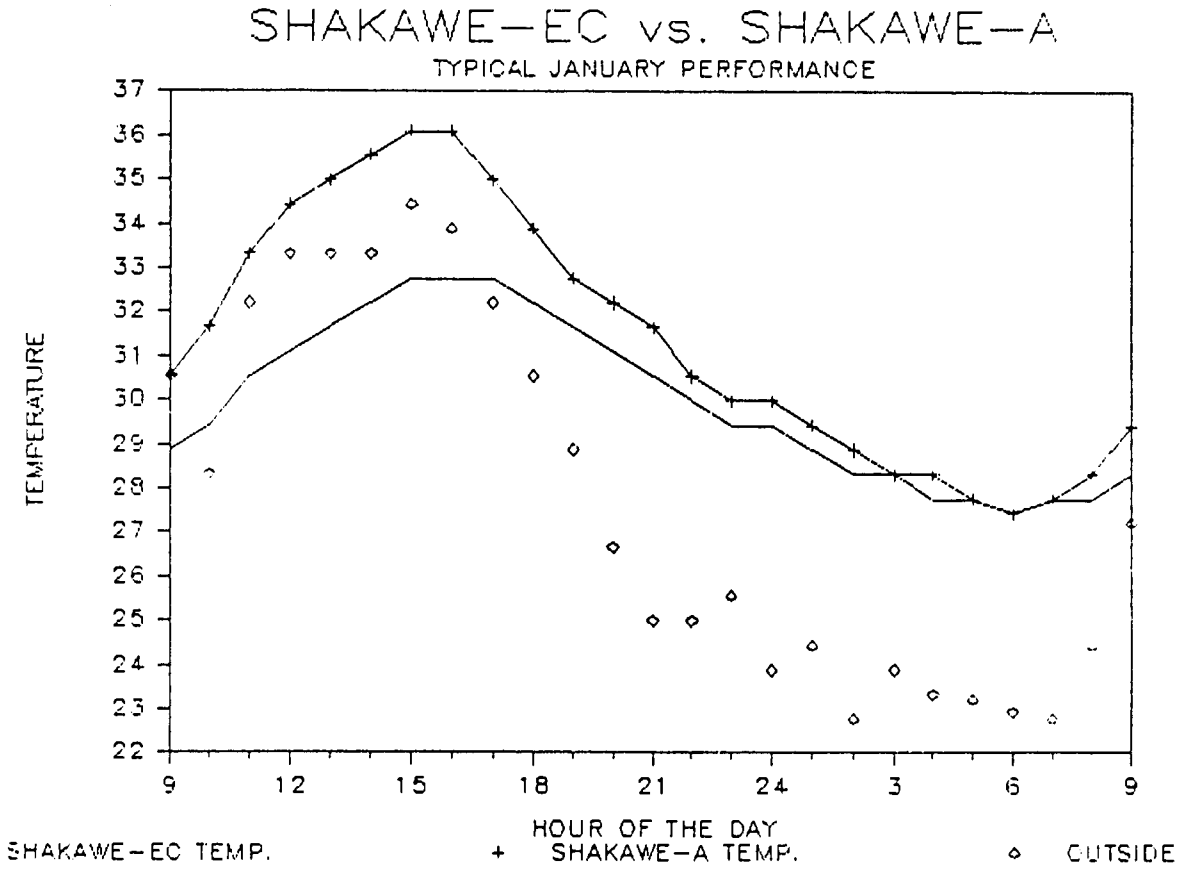

SHAKAWE—EC vs. SHAKAWE—A
EXTREME WINTER PERFORMANCE
TEMPERATURE
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
1 5 9 13 17 21 1 5 9 13 17 21
HOUR OF THE DAY
SHAKAWE—EC TEMP.
+ SHAKAWE—A TEMP.
◇ OUTDOOR

Figure 34.


SHAKAWE-EC vs. SHAKAWE-A
TYPICAL JANUARY PERFORMANCE
TEMPERATURE
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
9
12
15
18
21
24
3
6
9
HOUR OF THE DAY
SHAKAWE-EC TEMP.
+ SHAKAWE-A TEMP.
◇ OUTSIDE

mechanical heating and cooling were assumed to maintain temperatures within the comfort zone. In this case, the relative performance of the two designs is indicated not by the indoor temperatures (they will both be about the same), but rather by the magnitude of the heating and cooling loads for the two houses.

In Figure 35 the space-heating loads for both the solar and the reference house are presented, side-by-side for each month. The solar house has a significant load only for the months of June and July, and in these months is is only about one-third of the load in the reference house. The reference house has some heating requirements for five months of the year and significant loads in four of these months.

The monthly cooling loads for both designs are similarly shown in Figure 36. Again, clearly, the loads in the solar house are substantially less than the reference design, but the reduction is not as great as was achieved for the heating loads. In the winter months, in fact, the differences are not very large at all, while in the summer the SHAKAWE-EC shows a one-third load reduction. It should also be noted that there are cooling loads in <u>both</u> designs every month of the year. Given the low average ambient temperatures in the winter, this suggests that some further passive design improvement could probably make a substantial improvement by reducing winter overheating.

Figure 37 summarizes the annual heating and cooling loads of the two designs. Overall the SHAKAWE-EC design experiences combined heating and cooling loads of 22.8 Gigajoules, compared to 61.52 Gigajoules for the reference design. This is a reduction of 38.72 Gigajoules; a savings of 63 percent. If the buildings were heated and cooled with electricity (and air-conditioners had the typical coefficient of performance of 2.0) the consumption of the reference house would be 9923 kWh, the solar house would require 3495 kWh and the savings would be 6428 kWh. If the cost of electricity was 11 thebe per kWh, the annual environmental control cost for the reference house would be P 1092 while heating and cooling the SHAKAWE-EC would only cost P 384, a savings of P 708.

Even if the two building designs were not actually heated and air-conditioned to maintain the comfort conditions assumed in this simulation, the simulation results are still useful in quantifying the relative performance of the two designs. Because the heating and cooling loads reported represent the energy necessary to maintain comfort conditions, they reflect the combined effects of magnitude and duration of discomfort which would occur without auxiliary heating and cooling. While the

Figure 35.

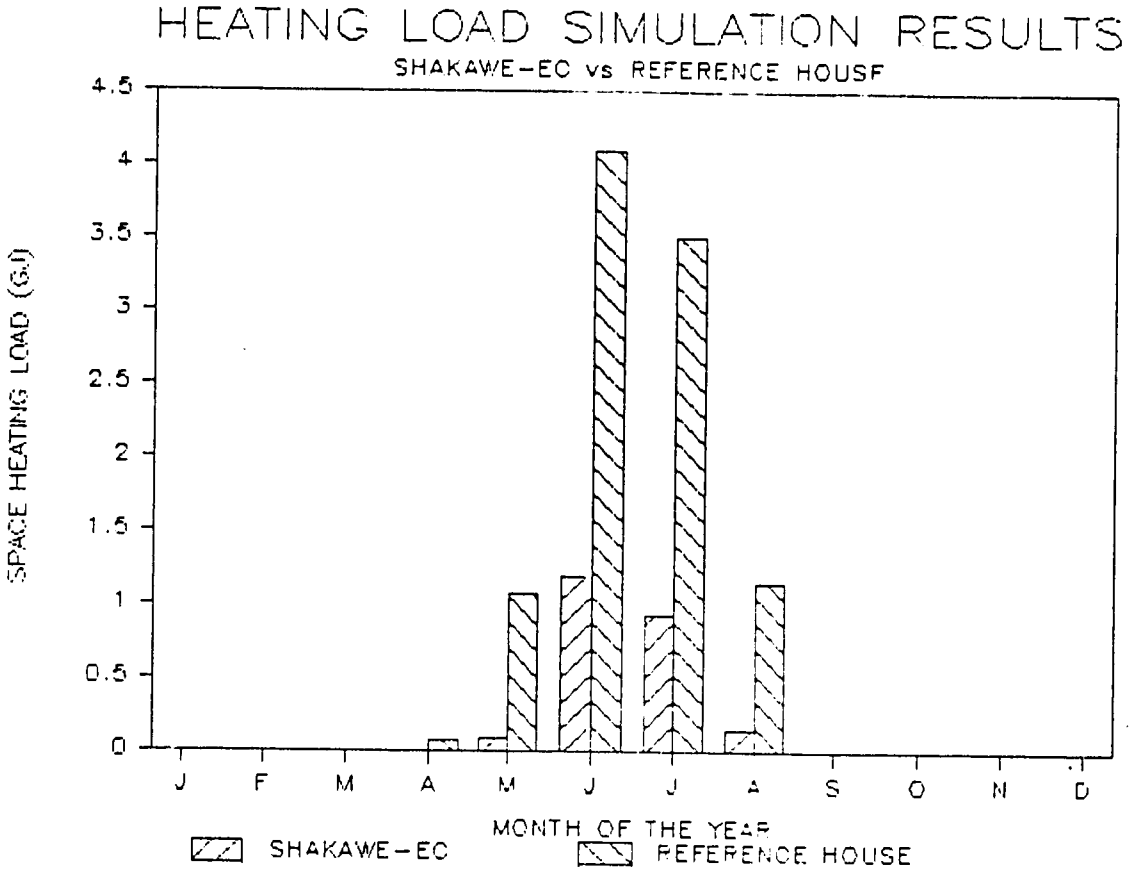


Figure 36.

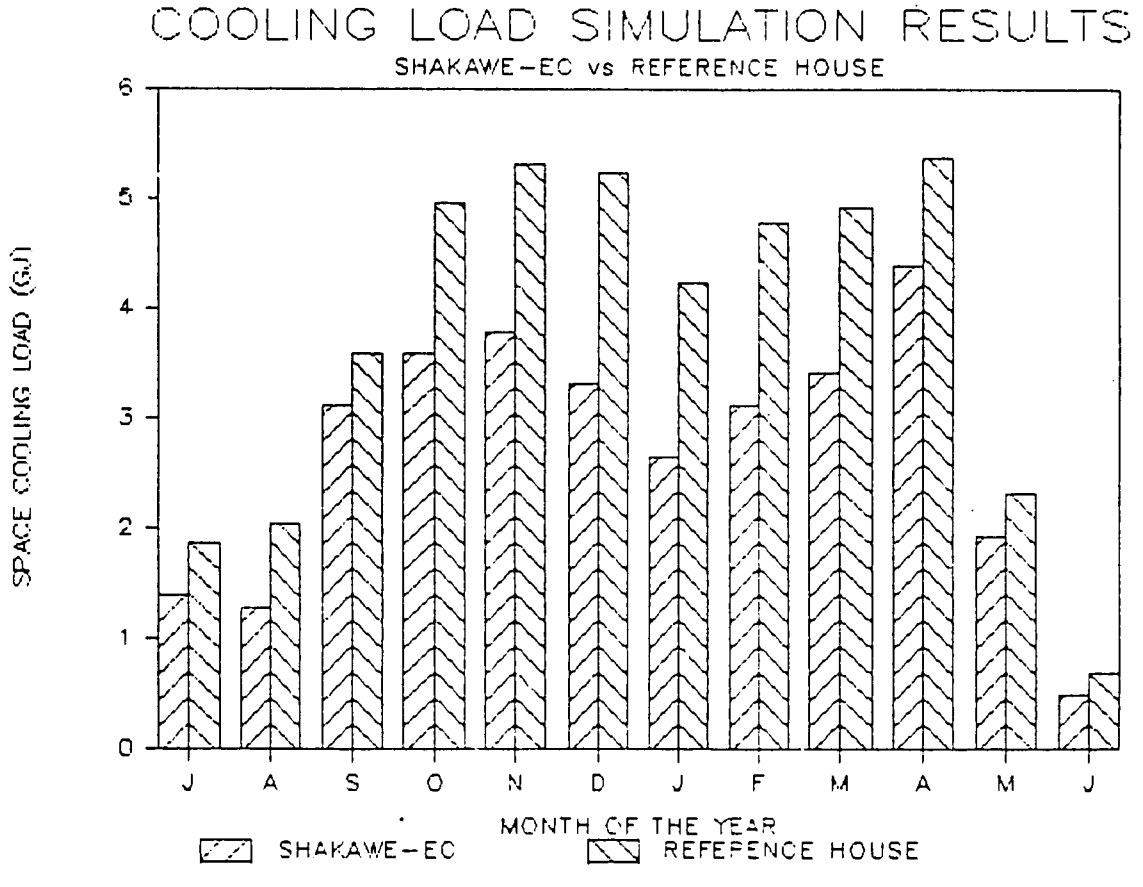
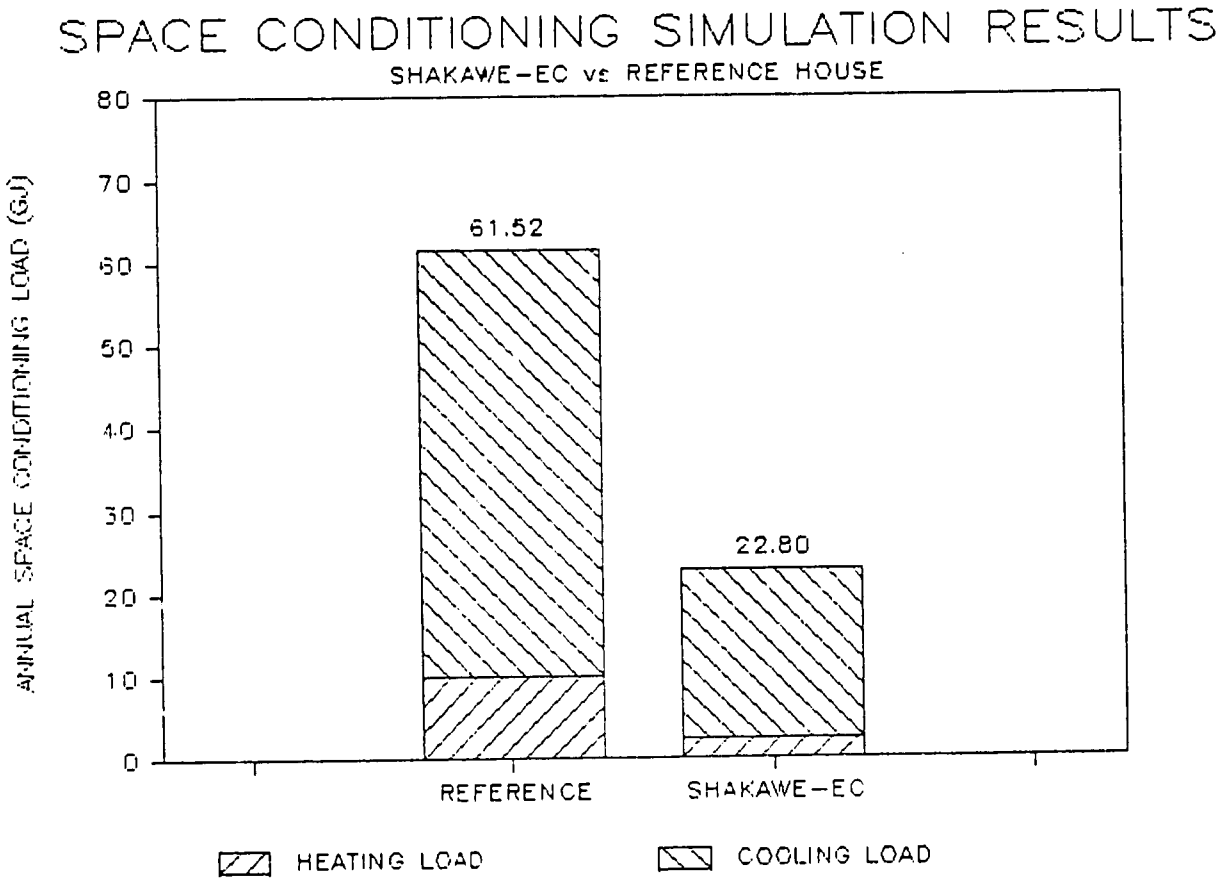


Figure 37.


SPACE CONDITIONING SIMULATION RESULTS
SHAKAWE-EC vs REFERENCE HOUSE
ANNUAL SPACE CONDITIONING LOAD (GJ)
80
70
60
50
40
30
20
10
0
61.52
22.80
REFERENCE
SHAKAWE-EC
HEATING LOAD
COOLING LOAD

correspondence is not exact (it is neither 1:1 nor exactly linear), it is probably reasonable to say that under floating temperature conditions the level of "discomfort over time" in the reference house is reduced by at least half in the SHAKAWE-EC design.

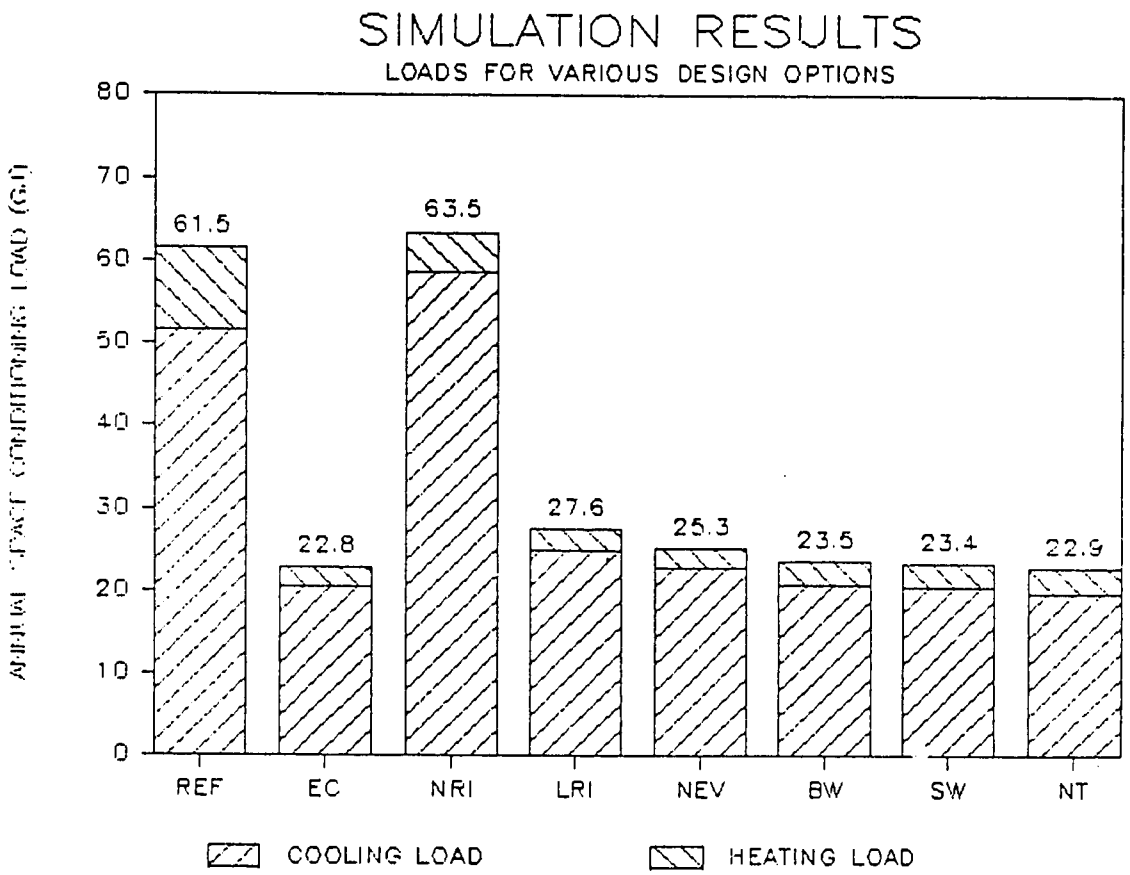
5.3 Component Evaluation

In order to determine which elements of the SHAKAWE-EC design are the most valuable, as well as identify possibilities for improving future designs, additional simulations were conducted and examined. As for the reference house simulations reported above, all inputs were identical to the SHAKAWE-EC except for the component of interest. This makes it possible to isolate the impact of that particular component of the design. The following design variants were simulated:

REF	The reference house described above
EC	The SHAKAWE-EC
NRI	The SHAKAWE-EC with no roof insulation
LRI	The SHAKAWE-EC with less roof insulation (50mm instead of 150mm)
NEV	The SHAKAWE-EC without any of the extra ventilation features that differentiated it from the reference house
BW	The SHAKAWE-EC with the insulated walls replaced by the standard 230mm hollow-core concrete block walls defined above for the reference house
SW	The SHAKAWE-EC with the insulated walls replaced by 230mm solid concrete block walls
NT	The SHAKAWE-EC with the Trombe wall replaced by an equivalent area of insulated wall

The annual space conditioning loads for each of these alternatives are presented in Figure 38. Many interesting things can be seen here. Clearly, the most important aspect of the design is the roof insulation. As can be seen by looking at the bar labelled "NRI" in the chart, the effect of removing the roof insulation from the SHAKAWE-EC is to almost triple the heating

Figure 38.


SIMULATION RESULTS
LOADS FOR VARIOUS DESIGN OPTIONS
ANNUAL PEAK CONDITIONING LOAD (GJ)
80
70
60
50
40
30
20
10
0
61.5
22.8
63.5
27.6
25.3
23.5
23.4
22.9
REF
EC
NRI
LRI
NEV
BW
SW
NT
COOLING LOAD
HEATING LOAD

and cooling loads. The "NRI" option has even a higher total load than the reference house. This is probably because an uninsulated roof provides an enormous heat gain to the house in the summer, which the completely uninsulated reference house can dissipate somewhat better that the "NRI" design with insulated walls. Looking at the next bar to the right, labelled "LRI", it can be seen that reducing the amount of insulation in the roof from 150mm to 50mm increases the load over the SHAKAWE-EC by 21 percent. The 4.77 Gigajoule increase which would occur if less insulation were used would result in a 702 kWh annual increase in energy consumption if the building used auxiliary heating and cooling. At 11 thebe per kWh this would represent a cost for one year of P 77. This would need to be compared against the incremental cost of thicker insulation to determine whether it is a good investment. The one thing that can be said about roof insulation without further analysis is that it is clearly the most important of the improvements to the reference house which was investigated and that even a small amount has a major impact.

Looking at the next bar to the right, labelled "NEV", we see that if the SHAKAWE-EC was built without the extra vents, the total loads would have been 11% higher. If met with electrical air-conditioning, this would require an extra 346 kWh per year (@.11/kWh = P38). While the improved ventilation design of the SHAKAWE-EC appears to have had the second most significant effect (after roof insulation), the effect is not as large as might be expected. As suggested earlier in this report, it appears there is significant room for improvement in this aspect of the design.

The next two bars in the figure shows the space conditioning load if the SHAKAWE-EC had been built without insulated walls. The "BW" bar shows the performance with 230mm hollow-block walls and the "SW" bar the performance with 230mm solid-block walls. It appears that the use of insulated walls in the SHAKAWE-EC may not have made much difference in the performance. With the hollow block walls, loads are only 3.3% greater than the SHAKAWE-EC as built, and with the solid block the loads would only be 2.5% more. While a more detailed component analysis will be necessary to explain this fully, a look at the breakdown of the heating and cooling loads may suggest some of what is going on. As might be expected, the uninsulated walls result in winter heating loads which are higher than the SHAKAWE-EC, but not as much higher as might be expected. Despite the fact that the uninsulated walls have conductivities that are over four times that of the insulated wall, the increases in heating load are only 20% and 22% respectively. This suggests that solar and high daytime temperature effects on the outside of the uninsulated wall significantly affect the heat losses. While the nighttime heat losses through the uninsulated wall will no doubt be great,

the daytime losses may not be significantly more than through the insulated wall. In effect, the entire wall (particularly that on the north side of the building) may be acting like a low-performance solar collector, not unlike the Trombe wall in principle. The cooling loads do not seem to be significantly affected by the wall insulation. Presumably, this is because the average summer temperatures maintained in the house are almost identical to the mean daily outdoor temperatures, so there is very little net heat transfer through the walls to be affected by their thermal resistance. These explanations are consistent with the month-by-month values for total conductive exchange generated in these simulations:

MONTH	SHAKAWE-EC AS BUILT CONDUCTION (MJ)	SHAKAWE-EC W/ BLOCK WALLS CONDUCTION (MJ)
JUL	-8094	-8723
AUG	-5627	-5951
SEP	-3729	-3553
OCT	-332	-162
NOV	161	350
DEC	697	976
JAN	689	937
FEB	78	223
MAR	-211	-87
APR	-3558	-3730
MAY	-6015	-6441
JUN	-7137	-7697

Given that the double-block insulated wall construction is much higher in cost than either of the uninsulated wall options, this suggests that future designs might be more cost-effective without insulated walls. One possibility not explored here is whether a combination of insulated and uninsulated walls might be a better alternative. A combination where the north wall was uninsulated and the other three were insulated could be worth investigating. It is also interesting to note that while the differences are small, the solid-block wall appears to be slightly better than the hollow-block wall. This is contrary to the assumptions made by many and also merits closer investigation.

The last bar in the figure shows the annual space conditioning load for the SHAKAWE-EC with the Trombe wall replaced by an equivalent area of insulated wall. As might be expected, the Trombe wall has a significant impact on the heating load of the building. Without the Trombe wall, the heating load would go up from 2.37 GJ to 3.24 GJ, an increase of 36 percent. However, the heating load was not large to begin with. If

provided by electric heat, this increment would require only 241 kWh. With 80% of the solar radiation blocked by removable shades in the summer, the Trombe wall appears to have little effect on the cooling load. When the Trombe wall was removed, the annual cooling load went down about 0.81 GJ, a 4% change. While the Trombe wall certainly improves the performance of the building, the effect appears to be the smallest of any of the options investigated. This suggests that the Trombe wall is probably not a design element which can be recommended for future buildings unless further analysis of cost relative to benefit produces more positive results.

Copies of the monthly summaries for each of the modelled house configurations reported in this section are contained in Appendix C to this report.

In the discussion above, various options which were included in the SHAKAWE-EC design have been examined by looking at how the building might perform without them. Now, a few of the options which were not built will be examined by looking at how they might improve building performance.

There are endless options which could be considered for incremental improvement of the SHAKAWE-EC design; however, in the scope of this report only a few of them will be examined. These are the options suggested by monitored data analysis and computer simulation studies reported earlier in this report. Figure 39 shows the space conditioning loads which came out of computer simulations for four of these options compared to the the SHAKAWE-EC design.

The labelled bars in the graph represent five different house descriptions used in the simulation model, with all other assumptions as reported earlier in this section:

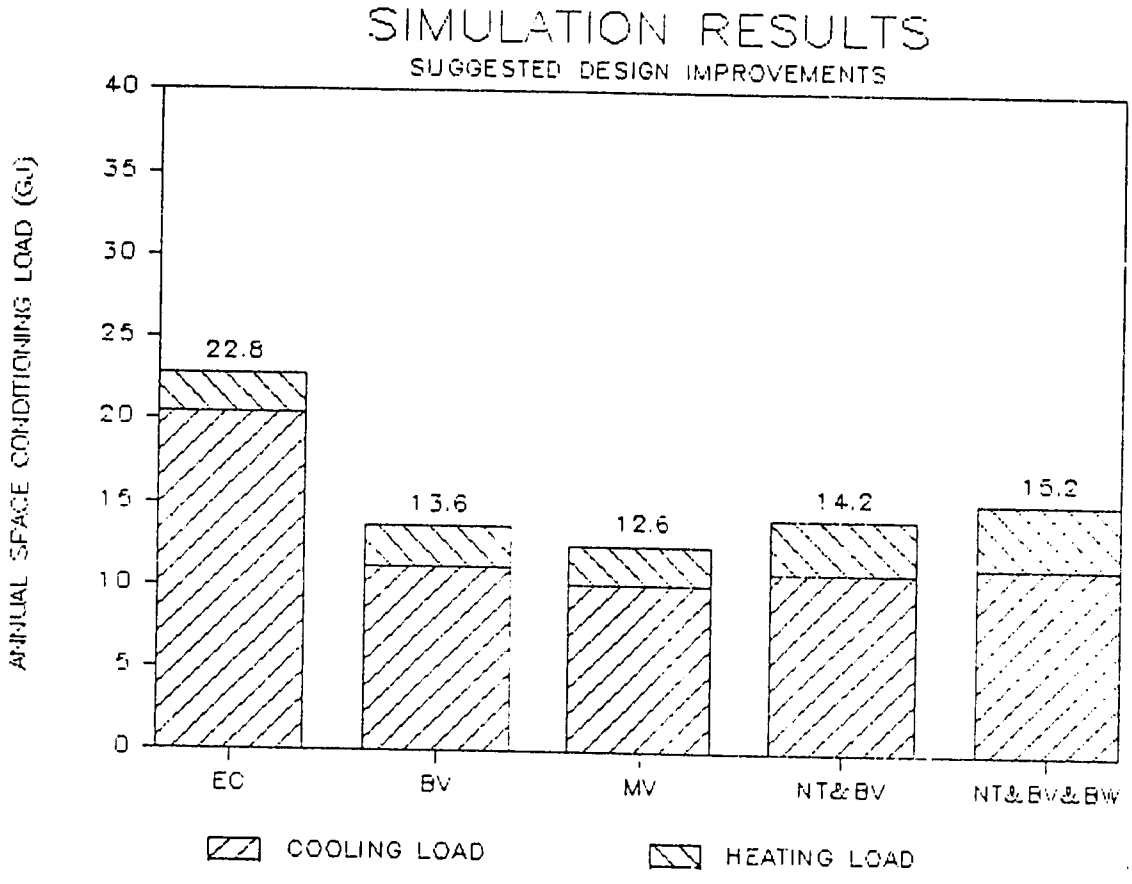
EC — The SHAKAWE-EC as built

BV — The SHAKAWE-EC with bigger vent openings (twice the effective ventilation area), half the vent openings facing in the direction of the prevailing wind, and an average inlet/outlet height difference of about 1.3m)

MV — The SHAKAWE-EC with maximum practical natural ventilation (about four times the effective ventilation area with an inlet/outlet height difference of about 2m)

NT&BV — The SHAKAWE-EC as built, but with the Trombe wall replaced by an insulated wall of the same area and bigger vents, as described in the

Figure 39.


SIMULATION RESULTS
SUGGESTED DESIGN IMPROVEMENTS
ANNUAL SPACE CONDITIONING LOAD (GJ)
40
35
30
25
20
15
10
5
0
22.8
13.6
12.6
14.2
15.2
EC
BV
MV
NT&BV
NT&BV&BW
COOLING LOAD
HEATING LOAD

second option above

NT&BV&BW The SHAKAWE-EC without the Trombe wall, with bigger vents, and with hollow block walls

All the analysis presented earlier in this report suggests that the cooling problem is far more significant than the heating problem. It has also been noted that on most days when there is a cooling load, it still gets cooler outside than inside for a substantial portion of the nighttime hours. This suggests that increased night ventilation might be a promising area for improving performance of the SHAKAWE-EC design. Accordingly, the first options considered in this series of simulations were to increase the area of ventilation openings in the house and locate some of the ventilation openings with respect to the prevailing wind. It is worth noting that the prevailing wind direction in Gaborone is east and that the SHAKAWE-EC, as built, does not have a ventilation design which reflects this situation.

Looking at the bar labelled "BV" in the chart, it can be seen that an improved ventilation design has a significnat effect on the cooling load of the building, dropping it from 20.43 GJ to 11.22 GJ, while having a negligible effect on the heating load. The further savings (above those already achieved by the SHAKAWE-EC design) in annual total load which would result from this improvement are 9.15 GJ, which is the equivalent of 1262 kWh (P 139 worth of air-conditioning at .11/kWh). While the cost of improving the ventilation design of the building to this level is not explored in this report, some improvement could obviously be achieved at little or no cost and it certainly merits investigation.

The second ventilation option simulated was intended to represent the extreme of improved natural ventilation design (fan-forced ventilation could certainly go further). This was intended to provide a target which could be used in assessing the extent to which it might be valuable to pursue improved natural ventilation design. As can be seen in the chart, the difference between the two levels of improved ventilation is only one Gigajoule. While a more detailed investigation will be necessary to optimize the level of ventilation improvements, it can be concluded from these results that going beyond the first level of improvement simulated will probably not be worthwhile.

The next option explored combines the first level of improved ventilation design with the elimination of the Trombe wall. While the loss of the Trombe wall results in a 0.96 GJ increase in the heating load, this is more than offset by the 9.58 GJ decrease in the cooling load attributable to the better ventilation of this combination option. The net effect is a 38% reduction in loads. Assuming that the cost of improved

ventilation design would probably not be much more than the cost of the Trombe wall, this combination probably represents a worthwhile improvement over the as-built SHAKAWE-EC design.

The last option takes the additional step of replacing the insulated walls with uninsulated concrete block walls. This results in an increased load (mostly heating) of only one Gigajoule. This does not appear to be much of a penalty compared to the greatly reduced cost that would result from using uninsulated walls. Of the various design options which were simulated, this is not the one resulting in the lowest overall load, but it may be the most attractive combination of options when cost and difficulty are considered. If operated with electrical heating and air-conditioning, this combination would consume 2652 kWh, which at P .11/kWh would cost P 291. This is 24% less than the as-built SHAKAWE-EC and 73% less than the reference design.

6 Recommendations for Design Modifications and Further Investigation

Based on the examination of monitored performance data from the SHAKAWE-EC and computer simulation of design modifications, the following recommendations for future building energy designs are made:

1. Building Form and Orientation

   - The building form and orientation may merit modification to take better advantage of wind-driven ventilation. The prevailing direction of wind when night ventilation cooling is desired should be considered.

   - The pitched-roof, high-ceiling design of the SHAKAWE-EC should be reconsidered. It is not clear that stack-driven ventilation in the design, as built, was significant; therefore a lower-cost roof design may be preferable.

   - The performance of separate bedroom (#4) in the SHAKAWE-EC design was much poorer than that of the rest of the house. This could be corrected in future designs by any number of techniques, possibly including less exposed surface to ambient conditions, better insulation, and/or better ventilation.

2. Ceiling/Roof Construction

   - While the need for insulation in the ceiling/roof is very clear, the amount which is worthwhile needs to be more closely evaluated. The optimum amount is probably less than the 150mm used in the SHAKAWE-EC.

   - While it was not investigated in these studies, it has been previously determined that roof absorptivity to solar radiation is a key determinant of ceiling/roof performance in the Botswana climate. The data and simulations which were done in this study showed the most critical heat transfers through the roof to be

those which contribute to the cooling load of the building. Accordingly, a less absorptive roof surface than that used in the SHAKAWE-EC would improve performance. Such use of a less absoptive roof, such a white-colored roof, would also lower the thickness of the optimum amount of insulation in the ceiling/roof.

3. Wall Construction

- The double-block, insulated wall construction used in the SHAKAWE-EC is probably not cost-effective and should be modified in future designs. Replacement by either solid or hollow-core concrete block walls would be more economical without significant detrimental impact on performance.

- A combination approach, which uses solid concrete for the north wall and a wall construction with a higher thermal resistance for the east, west and south walls may be worth some investigation.

- The relative performance of hollow-block and solid-concrete block walls needs to be examined more closely, either through detailed experimental testing or more detailed simulation studies. In such studies, the properties of materials should be determined much more accurately than was done in the studies reported here, where textbook values were used. It would be useful to determine the thermal and physical properties of the actual materials used locally by direct measurement, as well as those of other potential masonry construction materials (local fired brick, mud brick, rammed earth, etc.).

- While exterior wall absorptivity to solar radiation was not studied in this investigation, it could have a significant impact, particularly if high-conductivity walls are used. This should be further analyzed, either through experimental measurement or simulation.

4. The Trombe Wall

- Analysis of the Trombe wall suggests that while it works well, it may not be an economical element of the design and should not be used in future designs without careful cost/benefit analysis.

- The use in summer of removable shades and/or insulating panels to cover winter-only heating devices like the Trombe wall can be effective and is important to prevent aggravation of the summer cooling problem.

5. Windows and Vents

Total natural ventilation design of the SHAKAWE-EC design should be improved so that rates are significantly higher (about twice as great?) than they are at present. Improved performance could be affected by any of the following elements:

- Larger operable window areas, particularly where they will improve wind-driven ventilation

- Window shape and placement to make best use of wind-driven ventilation

- Window opening designs to improve wind-driven ventilation by creating ventilation-enhancing projections on the outside of the building when windows are opened (similar to "wing walls")

- Use of much larger non-window vents in the ouside walls, preferably high and low on the walls

- Ventilation design to maximize air flow at appropriate areas and heights of habitation (daytime activities and nighttime sleeping)

- Less obstruction of air flow between rooms

- It may be worthwhile investigating forced-air ventilation, particularly if this could be specifically directed at cooling the mass of the building

JULY MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	21.22	20.02	21.74	19.25	14.75	29.15	33.50			0.37	229.19	218.19	
MINIMUM	18.85	18.52	19.34	14.03	4.52	19.01	17.25			0.13			
MAXIMUM	24.31	22.17	24.76	23.85	25.97	37.42	49.30			2.16			
STD	1.14	0.76	1.18	2.03	4.93	4.36	8.39			0.22			

AUGUST MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	22.06	21.07	22.57	20.07	15.24	30.29	34.15	37.67		0.42	235.38	261.54	1.13
MIN	19.17	18.85	19.83	14.87	4.05	23.27	23.46	22.25		0.00			0.02
MAX	24.98	23.51	25.37	24.81	28.76	36.88	47.20	60.90		2.20			4.27
STD	1.26	0.89	1.26	2.37	6.31	3.60	6.66	9.46		0.24			0.97

SEPTEMBER MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	24.41	24.10	25.04	24.56	22.06	30.33	32.95	40.99		0.45	157.69	312.68	1.78
MIN	17.89	17.06	18.31	17.31	9.42	21.99	21.16	20.81		0.00			0.00
MAX	33.81	31.73	34.02	32.39	37.52	36.05	44.83	60.22		2.53			7.46
STD	2.82	2.58	2.70	2.98	6.38	3.08	5.61	9.06		0.26			1.55

OCTOBER MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	24.96	25.58	25.59	25.98	25.09	27.14	28.46	44.15		0.51	67.53	305.74	2.43
MIN	19.38	21.37	20.29	20.07	-2.75	20.88	20.12	24.53		0			0
MAX	34.71	32.48	34.84	36.65	39.96	34.47	38.95	64.76		2.32			6.98
STD	3.13	2.21	2.95	2.89	5.95	2.8	3.64	8.87		0.27			1.54

NOVEMBER MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	27.98	28.70	28.67	29.38	29.22	29.60	30.48	53.44	34.83	0.50	62.19	332.93	2.40
MIN	21.52	23.58	21.66	23.64	16.45	25.49	24.36	34.10	0.00	0.00	0.00	0.00	0.00
MAX	31.48	31.47	31.80	33.77	39.69	32.72	35.90	66.89	358.68	2.29	278.06	1229.42	6.33
STD	2.03	1.27	1.82	1.82	5.64	1.56	2.60	6.11	58.86	0.23	72.84	418.06	1.49

DECEMBER MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	27.25	28.18	27.97	28.46	28.34	29.93	30.87	50.00	39.59	0.53	66.15	295.20	1.90
MIN	22.59	24.67	23.18	23.79	14.54	25.86	25.18	33.93	0.00	0.00	0.00	0.00	0.00
MAX	32.33	31.51	32.78	33.07	40.48	33.20	36.26	66.91	387.42	2.30	266.72	1236.88	5.21
STD	2.07	1.42	1.95	2.02	5.36	1.65	2.53	7.53	65.77	0.27	78.74	382.20	1.23

JANUARY MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	30.19	30.86	30.94	31.60	31.71	31.73	32.62	59.72	36.77	0.55	63.72	365.30	1.76
MIN	25.89	28.05	26.45	27.77	22.66	29.27	29.02	43.56	0.00	0.00	0.00	0.00	0.00
MAX	34.43	34.36	34.47	36.51	43.12	34.58	37.73	71.50	389.33	2.30	275.31	1237.59	5.03
STD	1.91	1.35	1.72	2.00	5.29	1.29	2.05	4.86	51.28	0.31	72.30	437.34	1.17

FEBRUARY MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	28.85	29.77	29.53	30.09	29.60	29.84	30.14	38.78	51.40	0.53	63.83	340.57	1.95
MIN	22.70	25.65	23.58	24.36	18.69	26.03	26.21	25.83	0.00	0.00	0.00	0.00	0.00
MAX	34.35	33.67	34.54	36.80	41.22	33.26	33.81	54.34	1880.75	2.24	276.57	1224.10	5.44
STD	2.25	1.55	2.12	2.40	5.12	1.46	1.60	5.89	116.82	0.28	73.89	418.41	1.25

MARCH MONITORED HOURLY DATA SUMMARY

	TEMP LR	TEMP BR#3	GTEMP LR	TEMP BR#4	TEMP AMBIENT	WALLTEMP INSIDE	WALLTEMP OUTSIDE	SOLARDHW TEMP	SOLARDHW FLOW	ELEC. CONSUMP.	VERTICAL SOLAR	HORIZ. SOLAR	WIND
AVERAGE	27.95	28.81	28.57	28.78	27.89	29.24	29.48	35.04	53.74	0.58	66.78	286.67	1.94
MIN	22.20	24.05	22.29	22.67	17.99	24.17	23.98	22.29	0.00	0.00	0.00	0.00	0.00
MAX	34.74	35.29	34.72	36.91	40.56	33.10	34.00	49.51	480.15	2.30	267.32	1182.22	6.45
STD	2.92	2.45	2.83	3.18	5.56	2.36	2.53	6.33	87.03	0.33	80.93	371.50	1.37

APPENDIX B

TYPICAL LISTING OF COMPUTER SIMULATION INPUTS

SHAKAWE-EC AS BUILT

Gabarone

Weather: GABARONE.BA (Gabarone BA MOD)

S U M M A R Y

Run period: JAN-01 - DEC-31 Conditioned floor area: 1078 sf

SPACE CONDITIONING LOADS	Run totals kBtu	Run totals kBtu/sf	Peaks kBtuh
House			
Cooling	0	0	
Heating	0	0.000	0.270

ENERGY CONSUMPTION	Run totals kWh; kBtu	Run totals Prop line kBtu/sf	Run totals Source kBtu/sf	Peaks kW; kBtuh
Electricity				
House cooling	0	0	0	
Total	0	0	0	
Fuel				
House heating	0	0.000	0.000	0.450
Building total		0.000	0.000	

Note: CALPAS3 is the property of and is licensed by Berkeley Solar Group, 3140 Grove St., Berkeley, CA 94703 (415 843-7600). Correct application and operation of CALPAS3 is the responsibility of the user. Actual building performance may deviate from CALPAS3 predictions due to differences between actual and assumed weather, construction, or occupancy. CALPAS3 is certified for California energy code compliance when used in accordance with the BSG publication "Using CALPAS3 with the California Residential Building Standards."

M O N T H L Y H O U S E E N E R G Y B A L A N C E

(kBtu; + into house)

	GAINS & LOSSES						TRANSFERS			
MON	COND	SHCND	INFIL	SLR	INT	STRG	RB+SS	VENT	COOL	HEAT
JAN	-7311.7		-3581.0	9640.6	2391.1	64.3		-1210.7	0	0.270
FEB	-5337.9		-2472.8	7078.3	2159.7	-116		-1298.8	0	0
MAR	-3398.0		-1445.4	5904.0	2391.1	-25.7		-3425.2	0	0
APR	-773.03		-718.15	3568.8	2314.0	-168		-4201.7	0	0
MAY	-592.27		-761.00	3795.4	2391.1	64.6		-4906.3	0	0
JUN	-326.83		-716.33	3744.3	2314.0	-31.7		-4979.5	0	0
JUL	-673.43		-644.16	3635.7	2391.1	20.4		-4731.4	0	0
AUG	-770.46		-642.07	3450.9	2391.1	78.5		-4517.0	0	0
SEP	-908.60		-667.03	3694.0	2314.0	33.1		-4469.2	0	0
OCT	-3568.1		-1439.1	7202.3	2391.1	67.1		-4660.6	0	0
NOV	-5761.5		-2654.1	8144.0	2314.0	28.9		-2074.4	0	0
DEC	-6285.8		-3507.7	7641.2	2391.1	141		-397.03	0	0
TOT	-35707		-19249	67500	28154	157		-40872	0	0.270

M O N T H L Y C O N D I T I O N S

(Units as shown)

	TEMPERATURES (F)						WTHR (F; Btu/sf)				PEAKS (kBtuh)			
MON	THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	SGL	HSCL/DY	HSHT/DY	SSCL/DY	SSHT/DY
JAN	66	76	71				39	72	53	1581	0	0.27 25		
FEB	68	78	73				44	78	59	1673	0	0		
MAR	72	81	76				53	85	66	1915	0	0		
APR	73	83	78				60	87	73	2384	0	0		
MAY	74	85	79				63	88	74	2502	0	0		
JUN	76	87	81				65	90	77	2483	0	0		
JUL	78	88	83				67	90	78	2266	0	0		
AUG	76	86	81				66	88	76	2262	0	0		
SEP	75	85	80				64	88	74	2112	0	0		
OCT	71	81	75				55	81	66	1780	0	0		
NOV	69	79	74				46	76	59	1489	0	0		
DEC	64	74	69				39	72	54	1214	0	0		
TOT	72	82	77				55	83	67	1973	0	0.27		

Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

D A I L Y H O U S E E N E R G Y B A L A N C E

(kBtu; + into house)

	TEMPS (F)			GAINS & LOSSES						TRANSFERS				
DAY	THL	THH	THM	COND	SHCND	INFIL	SLR	INT	STRG	RB	SS	VENT	COOL	HEAT
JAN														
1	69	79	74	-215		-80.3	317	77.1	-20.7			-75.3	0	0
2	68	80	74	-237		-105	328	77.1	0.44			-63.7	0	0
3	71	81	75	-231		-39.2	328	77.1	-26.4			-105	0	0
4	72	78	74	-214		-82.1	162	77.1	74.2			-25.4	0	0
5	67	76	72	-225		-124	297	77.1	-2.98			-21.9	0	0
6	67	78	73	-239		-95.3	318	77.1	-14.3			-45.6	0	0
7	68	77	73	-191		-118	304	77.1	-9.62			-61.5	0	0
8	70	77	73	-185		-101	196	77.1	38.3			-29.6	0	0
9	66	75	71	-227		-140	329	77.1	-10.3			-27.0	0	0
10	64	75	70	-260		-210	334	77.1	52.2			-1.24	0	0
11	61	71	66	-226		-198	278	77.1	62.9			0	0	0
12	60	71	66	-211		-126	294	77.1	-29.2			0	0	0
13	64	75	70	-259		-76.3	336	77.1	-62.1			-9.44	0	0
14	66	77	72	-259		-77.8	337	77.1	-37.7			-35.9	0	0
15	68	79	74	-258		-51.5	338	77.1	-35.1			-66.3	0	0
16	69	78	74	-255		-114	337	77.1	16.0			-63.2	0	0
17	70	79	74	-248		-57.0	328	77.1	-22.5			-74.7	0	0
18	70	80	75	-256		-55.0	341	77.1	-3.99			-104	0	0
19	68	80	74	-274		-94.3	342	77.1	13.4			-66.1	0	0
20	71	80	75	-261		-85.1	343	77.1	3.59			-78.1	0	0
21	69	79	74	-229		-87.6	312	77.1	-10.4			-59.6	0	0
22	70	80	75	-242		-63.5	336	77.1	-17.4			-88.6	0	0
23	71	79	75	-210		-82.8	277	77.1	25.2			-89.4	0	0
24	63	72	67	-197		-213	80.3	77.1	226			0	0	0
25	55	68	62	-213		-218	348	77.1	3.94			0	0	0.27
26	57	69	63	-211		-188	348	77.1	-23.2			0	0	0
27	57	69	63	-243		-182	350	77.1	-1.10			0	0	0
28	56	70	64	-251		-135	351	77.1	-37.5			0	0	0
29	62	75	68	-268		-78.5	351	77.1	-72.9			0	0	0
30	65	77	71	-251		-125	347	77.1	-26.6			-18.8	0	0
31	62	75	69	-266		-177	354	77.1	11.6			-0.28	0	0

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D A I L Y C O N D I T I O N S

(Units as shown)

DAY	TEMPERATURES (F) THL	THH	THM	TSL	TSH	TSM	WTHR (F, Btu/sf) DBL	DBH	DBM	DBB	SGL	PEAKS (kBtuh) HSCL	HSHT	SSCL	SSHT
JAN															
1	69	79	74				45	78	58	57	1621	0	0		
2	68	80	74				41	79	56	57	1660	0	0		
3	71	81	75				45	76	59	57	1662	0	0		
4	72	78	74				46	79	58	57	943	0	0		
5	67	76	72				41	71	54	57	1498	0	0		
6	67	78	73				42	72	54	57	1600	0	0		
7	68	77	73				49	75	60	57	1542	0	0		
8	70	77	73				49	74	60	57	1085	0	0		
9	66	75	71				42	70	53	57	1662	0	0		
10	64	75	70				36	65	49	57	1684	0	0		
11	61	71	66				34	65	48	55	1388	0	0		
12	60	71	66				35	68	49	54	1482	0	0		
13	64	75	70				36	69	49	53	1693	0	0		
14	66	77	72				38	72	52	53	1696	0	0		
15	68	79	74				39	72	55	51	1700	0	0		
16	69	78	74				40	76	55	51	1691	0	0		
17	70	79	74				43	73	57	51	1662	0	0		
18	70	80	75				39	75	57	52	1713	0	0		
19	68	80	74				38	76	54	53	1717	0	0		
20	71	80	75				42	74	55	54	1721	0	0		
21	69	79	74				46	72	57	55	1555	0	0		
22	70	80	75				41	78	57	56	1708	0	0		
23	71	79	75				46	82	60	56	1493	0	0		
24	63	72	67				42	63	51	57	546	0	0		
25	55	68	62				28	62	43	56	1744	0	0.27		
26	57	69	63				30	63	45	54	1748	0	0		
27	57	69	63				28	60	43	53	1750	0	0		
28	56	70	64				24	66	43	51	1756	0	0		
29	62	75	68				30	74	47	49	1757	0	0		
30	65	77	71				40	76	52	48	1754	0	0		
31	62	75	69				32	68	50	46	1770	0	0		

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Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

D A I L Y H O U S E E N E R G Y B A L A N C E

(kBtu; + into house)

	TEMPS (F)			GAINS & LOSSES						TRANSFERS				
DAY	THL	THH	THM	COND	SHCND	INFIL	SLR	INT	STRG	RB	SS	VENT	COOL	HEAT
JUL														
1	79	89	84	-30.6		-36.6	122	77.1	45.4			-183	0	0
2	75	85	80	-28.0		-22.0	93.8	77.1	36.5			-161	0	0
3	74	87	81	-5.61		-6.49	119	77.1	-38.7			-141	0	0
4	78	88	83	-15.7		-15.3	119	77.1	-37.8			-123	0	0
5	78	89	83	-24.9		-25.0	119	77.1	15.7			-165	0	0
6	76	87	82	-20.8		-18.7	119	77.1	7.20			-164	0	0
7	77	86	81	-15.2		-35.0	119	77.1	51.4			-204	0	0
8	76	87	81	-8.48		-22.8	119	77.1	-7.86			-156	0	0
9	73	85	80	-20.3		-19.7	119	77.1	15.4			-172	0	0
10	74	85	80	-14.9		-11.5	120	77.1	-27.6			-140	0	0
11	75	87	81	-33.7		-12.9	129	77.1	-17.9			-139	0	0
12	77	85	81	-32.7		-20.1	119	77.1	21.5			-167	0	0
13	77	87	83	-25.6		-20.5	130	77.1	-45.7			-111	0	0
14	79	90	84	-22.0		-19.0	119	77.1	-28.3			-123	0	0
15	81	88	84	-47.1		-25.4	96.6	77.1	17.7			-121	0	0
16	79	88	84	-34.2		-19.6	118	77.1	5.96			-149	0	0
17	77	89	83	-18.6		-18.8	118	77.1	4.42			-163	0	0
18	77	88	83	-22.7		-21.4	118	77.1	-19.8			-129	0	0
19	79	90	85	-17.2		-16.6	116	77.1	-26.3			-130	0	0
20	81	91	86	-19.2		-16.2	118	77.1	-11.0			-148	0	0
21	80	91	86	-11.3		-20.5	118	77.1	-3.89			-158	0	0
22	82	89	85	-20.4		-33.3	119	77.1	41.6			-189	0	0
23	79	87	83	-17.5		-29.7	114	77.1	-3.77			-139	0	0
24	78	86	83	-16.3		-40.8	117	77.1	81.1			-229	0	0
25	76	87	82	-4.50		-11.2	117	77.1	-54.5			-117	0	0
26	77	89	83	-11.6		-14.3	117	77.1	0.21			-169	0	0
27	77	88	83	-18.0		-15.9	117	77.1	-8.85			-150	0	0
28	77	88	83	-20.9		-18.4	117	77.1	-9.59			-144	0	0
29	79	88	84	-30.4		-20.8	117	77.1	0.79			-144	0	0
30	78	88	83	-31.2		-16.5	117	77.1	-0.38			-145	0	0
31	78	87	83	-33.8		-19.3	116	77.1	17.5			-160	0	0

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D A I L Y C O N D I T I O N S

(Units as shown)

	TEMPERATURES (F)						WTHR (F, Btu/sf)					PEAKS (kBtuh)			
DAY	THL	THH	THM	TSL	TSH	TSM	DBL	DBH	DBM	DBB	SGL	HSCL	HSHT	SSCL	SSHT
JUL															
1	79	89	84				66	90	78	80	2226	0	0		
2	75	85	80				64	89	75	80	1218	0	0		
3	74	87	81				62	94	76	79	2465	0	0		
4	78	88	83				68	90	78	78	2458	0	0		
5	78	89	83				67	95	78	78	2457	0	0		
6	76	87	82				65	96	77	78	2457	0	0		
7	77	86	81				65	85	76	77	2464	0	0		
8	76	87	81				66	88	77	77	2454	0	0		
9	73	85	80				61	87	74	77	2454	0	0		
10	74	85	80				63	89	75	76	2483	0	0		
11	75	87	81				64	87	75	76	1940	0	0		
12	77	85	81				66	83	75	76	2453	0	0		
13	77	87	83				68	90	78	76	1846	0	0		
14	79	90	84				68	95	80	76	2199	0	0		
15	81	88	84				73	92	79	76	1217	0	0		
16	79	88	84				67	89	78	77	2450	0	0		
17	77	89	83				66	99	78	77	2446	0	0		
18	77	88	83				67	91	78	78	2443	0	0		
19	79	90	85				70	94	81	78	2351	0	0		
20	81	91	86				71	93	82	79	2446	0	0		
21	80	91	86				69	94	82	79	2441	0	0		
22	82	89	85				73	88	80	80	2362	0	0		
23	79	87	83				74	88	81	80	1195	0	0		
24	78	86	83				69	85	78	80	2436	0	0		
25	76	87	82				67	90	78	80	2290	0	0		
26	77	89	83				67	94	78	80	2446	0	0		
27	77	88	83				64	92	77	80	2435	0	0		
28	77	88	83				64	91	77	79	2432	0	0		
29	79	88	84				68	87	78	78	2431	0	0		
30	78	88	83				67	90	77	78	2429	0	0		
31	78	87	83				65	87	76	78	2431	0	0		

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Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

H O U R L Y H O U S E E N E R G Y B A L A N C E

(kBtu; + into house)

			GAINS & LOSSES				STORAGE						TRANSFERS		
D	H	THS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
J	1	72	-14.0	-8.49	0	1.85	2.40	4.46	4.91	3.08	3.66			0	-
A	2	71	-12.8	-6.46	0	1.70	1.28	4.00	4.73	2.64	3.27			0	-
N	3	71	-12.3	-7.30	0	1.62	1.69	3.67	4.79	2.63	3.31			0	-
	4	70	-11.9	-6.09	0	1.62	1.33	3.36	4.67	2.38	3.16			0	-
2	5	70	-11.6	-5.93	0	1.62	1.30	3.08	4.57	2.24	3.07			0	-
1	6	69	-11.2	-6.72	0	2.01	1.55	2.84	4.58	2.27	3.08			0	-
	7	69	-10.8	-6.57	0.70	2.93	1.04	2.37	4.26	2.01	2.82			0	-
	8	69	-9.34	-4.81	14.5	4.55	-1.97	-2.24	0.58	0.19	0.49			0	-
	9	71	-8.20	-4.61	27.1	4.32	-3.47	-6.29	-2.77	-1.70	-1.55			0	-
	10	73	-5.54	-2.07	35.7	4.63	-5.44	-8.79	-5.93	-4.02	-3.99			0	-
	11	74	-3.68	-1.10	29.3	4.55	-4.56	-6.31	-5.82	-4.95	-4.81			0	-
	12	76	-2.54	-1.60	39.3	3.55	-2.99	-9.52	-7.91	-4.78	-5.42			-3.75	V
	13	77	-3.74	-1.96	42.2	3.47	-3.11	-9.63	-8.41	-4.73	-5.56			-5.01	V
	14	78	-4.02	-0.91	43.5	2.31	-3.51	-9.02	-9.04	-4.93	-5.98			-4.57	V
	15	79	-5.72	-1.53	38.2	2.16	-2.10	-6.54	-7.79	-4.25	-5.23			-5.18	V
	16	79	-7.18	-1.20	28.7	2.39	0.18	-2.95	-5.21	-2.63	-3.70			-7.92	V
	17	78	-9.29	-2.45	12.8	4.40	1.47	2.36	-1.36	-0.91	-1.71			-6.79	V
	18	76	-11.2	-3.17	0	4.94	5.52	6.09	3.21	2.41	1.40			-13.2	V
	19	75	-10.6	-2.82	0	4.94	2.51	5.88	3.54	2.75	1.81			-9.40	V
	20	75	-11.7	-2.58	0	4.01	0	5.63	3.04	1.80	1.70			-3.15	V
	21	75	-12.1	-2.95	0	3.86	0	5.29	2.62	1.15	1.58			-0.21	V
	22	75	-11.8	-2.06	0	4.24	0	4.86	2.27	0.76	1.36			-0.50	V
	23	75	-13.8	-2.93	0	3.39	1.39	4.72	2.56	1.25	2.07			0	-
	24	74	-14.2	-1.35	0	2.08	1.31	4.41	2.74	1.48	2.28			0	-
J	1	74	-12.0	-3.44	0	1.85	1.48	3.91	2.88	1.75	2.14			0	-
A	2	73	-13.2	-4.12	0	1.70	2.00	3.76	3.31	2.20	2.69			0	-
N	3	72	-13.7	-1.38	0	1.62	1.00	3.51	3.23	1.92	2.65			0	-
	4	72	-15.0	-1.77	0	1.62	1.52	3.38	3.44	2.08	3.03			0	-
2	5	71	-14.6	-1.70	0	1.62	1.48	3.11	3.56	2.10	3.01			0	-
2	6	71	-13.3	-4.50	0	2.01	1.91	2.80	3.87	2.39	3.03			0	-
	7	70	-14.3	-1.68	0.25	2.93	0.79	2.60	3.59	1.92	2.88			0	-
	8	71	-13.3	-1.68	7.62	4.55	-0.87	0.25	1.51	0.77	1.52			0	-
	9	72	-9.48	-1.25	29.9	4.32	-4.06	-7.38	-3.89	-1.71	-1.98			0	-
	10	74	-7.36	-0.72	38.4	4.63	-5.67	-9.80	-6.80	-4.09	-4.31			0	-
	11	75	-2.43	-1.60	43.9	4.55	-2.28	-11.3	-7.54	-3.77	-5.21			-11.1	V
	12	77	-1.18	-0.63	46.2	3.55	-5.36	-11.6	-9.08	-5.39	-6.70			-4.67	V
	13	80	-1.65	-0.25	46.0	3.47	-5.92	-10.8	-10.2	-6.55	-7.56			-1.87	V
	14	80	-4.2[illegible]	-1.50	43.7	2.31	-1.81	-8.82	-9.17	-5.13	-6.31			-6.28	V
	15	79	-7.56	-2.98	38.2	2.16	3.39	-5.87	-5.65	-1.44	-3.24			-17.5	V
	16	80	-6.30	-1.13	28.9	2.39	-2.77	-2.76	-4.83	-2.61	-3.95			-4.62	V
	17	80	-8.26	-1.52	12.9	4.40	-0.78	2.47	-1.86	-1.91	-2.52			-4.36	V
	18	79	-9.64	-1.65	0	4.94	3.16	6.10	1.82	0.41	-0.20			-7.08	V
	19	76	-12.7	-1.88	0	4.94	7.31	6.46	4.51	4.24	3.08			-20.5	V
	20	75	-12.5	-4.49	0	4.01	2.79	6.16	4.89	4.01	3.26			-9.77	V
	21	75	-12.8	-7.37	0	3.86	0	5.75	4.18	2.65	2.79			-0.82	V
	22	75	-12.4	-6.40	0	4.24	0.28	5.29	3.74	1.83	2.46			0	-
	23	75	-12.0	-4.96	0	3.39	0.38	4.84	3.39	1.42	2.21			0	-
	24	74	-12.4	-4.89	0	2.08	1.49	4.53	3.57	1.71	2.53			0	-

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SHAKAWE-EC AS BUILT

CALPAS3 V3.11 License: PC0156

Gabarone

Weather: GABARONE.BA (Gabarone BA MOD)

H O U R L Y C O N D I T I O N S

(Various units)

D	H	S	THS	TSS	WEATHER DATA DB	WB	SBM	SDF	SGL	WS	WDR	CNTRLS TF	SH	FLOWS SS	VHS	VSS	RBC	SUPPLY TMPS VHS	VSS	RBC
J	1	W	72		46	45	0	0	0	5	337	1.0			0			46		
A	2	W	71		48	48	0	0	0	4	0	1.0			0			48		
N	3	W	71		48	48	0	0	0	5	337	1.0			0			48		
	4	W	70		48	48	0	0	0	4	337	1.0			0			48		
2	5	W	70		48	48	0	0	0	4	0	1.0			0			48		
1	6	W	69		48	48	0	0	0	5	337	1.0			0			48		
	7	W	69		48	48	10	1	1	5	337	1.0			0			48		
	8	W	69		48	48	158	21	52	3	337	1.0			0			48		
	9	W	71		50	50	242	31	123	3	337	1.0			0			50		
	10	W	73		58	58	258	51	187	2	0	1.0			0			58		
	11	W	74		68	65	164	67	170	3	45	1.0			0			68		
	12	W	76		70	65	252	55	225	5	90	1.0			624			70		
	13	W	77		70	65	270	59	239	5	90	0.9			687			70		
	14	W	78		72	66	282	64	233	2	67	0.5			694			72		
	15	W	79		72	66	278	48	182	4	90	0.0			695			72		
	16	W	79		72	66	250	29	110	3	22	0			1074			72		
	17	W	78		70	65	132	14	31	5	90	0			761			70		
	18	W	76		64	64	0	0	0	4	67	0			1002			64		
	19	W	75		62	62	0	0	0	3	67	0.7			660			62		
	20	W	75		58	58	0	0	0	2	90	1.0			169			58		
	21	W	75		56	56	0	0	0	2	45	1.0			10.1			56		
	22	W	75		56	56	0	0	0	1	90	1.0			24.0			56		
	23	W	75		50	50	0	0	0	1	112	1.0			0			50		
	24	W	74		48	48	0	0	0	0	0	1.0			0			48		
J	1	W	74		52	52	0	0	0	2	180	1.0			0			52		
A	2	W	73		48	48	0	0	0	2	180	1.0			0			48		
N	3	W	72		46	46	0	0	0	0	0	1.0			0			46		
	4	W	72		42	42	0	0	0	0	0	1.0			0			42		
2	5	W	71		42	42	0	0	0	0	0	1.0			0			42		
2	6	W	71		44	44	0	0	0	2	225	1.0			0			44		
	7	W	70		41	40	2	1	1	0	0	1.0			0			41		
	8	W	71		41	40	56	25	36	0	0	1.0			0			41		
	9	W	72		46	46	268	33	135	0	0	1.0			0			46		
	10	W	74		54	54	280	53	201	0	0	1.0			0			54		
	11	W	75		68	59	284	68	247	4	180	1.0			1432			68		
	12	W	77		75	59	284	75	267	5	180	1.0			1921			75		
	13	W	80		78	61	284	74	263	3	180	0.3			1144			78		
	14	W	80		75	60	282	65	234	5	135	0			1117			75		
	15	W	79		69	59	278	48	182	5	157	0			1638			69		
	16	W	80		76	60	252	29	110	5	135	0			1078			76		
	17	W	80		75	59	134	14	31	5	112	0			768			75		
	18	W	79		71	58	0	0	0	3	112	0			814			71		
	19	W	76		59	57	0	0	0	1	90	0			1099			59		
	20	W	75		57	57	0	0	0	4	90	0.6			497			57		
	21	W	75		55	55	0	0	0	6	90	1.0			37.5			55		
	22	W	75		55	55	0	0	0	5	112	1.0			0			55		
	23	W	75		55	55	0	0	0	4	135	1.0			0			55		
	24	W	74		53	53	0	0	0	3	135	1.0			0			53		

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Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

H O U R L Y T E M P E R A T U R E S

(Degrees F)

		HOUSE									SUNSPACE					ROCKBED		
D	H	THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
J	1	72	90	94	73	74	73	73	73	72								
A	2	71	87	91	73	73	72	73	72	72								
N	3	71	85	88	72	72	71	72	71	71								
	4	70	83	85	72	72	71	71	71	71								
2	5	70	81	82	71	71	70	71	70	70								
1	6	69	80	80	71	71	70	70	70	70								
	7	69	78	79	70	70	69	70	69	69								
	8	69	77	97	71	70	70	69	70	69								
	9	71	77	120	72	70	70	70	71	69								
	10	73	78	143	73	70	72	71	72	70								
	11	74	80	146	73	71	73	72	73	71								
	12	76	83	168	75	72	74	73	74	72								
	13	77	86	182	76	73	75	74	75	73								
	14	78	90	192	77	74	77	75	76	74								
	15	79	94	193	78	75	77	77	77	75								
	16	79	97	184	78	75	78	77	77	75								
	17	78	99	161	77	76	78	78	77	76								
	18	76	100	138	76	76	77	77	76	76								
	19	75	100	126	76	76	76	77	76	75								
	20	75	99	118	76	75	76	76	75	75								
	21	75	98	111	75	75	76	76	75	75								
	22	75	96	106	75	75	75	76	75	74								
	23	75	94	101	75	74	75	75	75	74								
	24	74	92	97	74	74	75	75	74	73								
J	1	74	90	94	74	74	74	75	74	73								
A	2	73	87	90	74	73	74	74	73	73								
N	3	72	86	87	73	73	73	73	73	72								
	4	72	84	83	73	73	73	73	72	71								
2	5	71	82	80	72	72	72	72	72	71								
2	6	71	80	78	72	72	71	72	71	71								
	7	70	79	76	71	71	71	71	71	70								
	8	71	78	83	72	71	71	71	71	70								
	9	72	77	118	73	71	72	71	72	70								
	10	74	78	143	74	72	73	72	73	71								
	11	75	80	166	75	72	74	73	74	72								
	12	77	84	184	77	73	76	74	76	73								
	13	80	88	196	78	74	77	76	77	74								
	14	80	92	201	79	75	78	77	78	75								
	15	79	96	199	79	76	78	78	78	76								
	16	80	100	190	79	77	79	79	79	77								
	17	80	103	167	79	77	79	79	79	77								
	18	79	104	143	78	78	79	79	78	77								
	19	76	103	130	77	77	77	79	77	77								
	20	75	102	122	77	77	77	77	76	77								
	21	75	100	115	76	76	76	77	76	76								
	22	75	98	109	76	76	76	76	76	75								
	23	75	96	105	76	75	75	76	75	75								
	24	74	93	100	75	75	75	75	75	74								

Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

H O U R L Y H O U S E E N E R G Y B A L A N C E

(kBtu; + into house)

		GAINS & LOSSES				STORAGE						TRANSFERS		
D H	THS	TCOND	INFIL	SLR	INT	AIR	MW	SLB	IW	XW	RBSLB	RB+SS	MECH	M
J 1	83	-4.86	-2.25	0	1.85	2.83	0.85	4.88	3.71	4.05			-13.6	V
U 2	82	-4.47	-2.03	0	1.70	2.11	0.83	5.03	3.45	3.97			-12.2	V
L 3	81	-4.11	-2.17	0	1.62	1.95	0.80	5.15	3.30	3.96			-12.6	V
4	80	-5.48	-3.19	0	1.62	4.83	1.07	6.49	4.73	5.31			-18.7	V
2 5	80	-2.24	-0.94	0	1.62	-2.12	0.56	4.53	1.74	2.84			-5.35	V
1 6	80	-3.28	-2.02	1.64	2.01	1.20	0.65	4.24	1.97	3.06			-11.6	V
7	80	-1.02	-1.58	5.97	2.93	-1.63	0.25	2.00	0.21	0.92			-6.67	V
8	82	1.71	-0.49	7.26	4.55	-4.79	-0.26	-0.58	-2.34	-1.41			-2.03	V
9	84	4.83	0.55	9.37	4.32	-4.90	-0.77	-2.92	-4.13	-3.26			0	-
10	85	3.30	-0.44	11.3	4.63	-2.94	-0.74	-4.03	-4.15	-3.25			-1.86	V
11	87	6.02	0.95	12.8	4.55	-4.30	-1.15	-5.58	-5.04	-4.61			0	-
12	88	6.26	1.20	13.3	3.55	-3.83	-1.26	-6.44	-5.21	-5.02			0	-
13	89	5.71	0.84	13.1	3.47	-2.73	-1.21	-6.61	-4.83	-4.95			0	-
14	90	4.98	0.67	12.0	2.31	-2.00	-1.10	-6.27	-4.15	-4.61			0	-
15	91	4.89	0.90	10.3	2.16	-1.62	-1.02	-5.72	-3.56	-4.35			0	-
16	91	3.44	0.73	8.30	2.39	-1.14	-0.80	-4.98	-2.88	-3.84			0	-
17	91	1.10	-0.46	6.82	4.40	0.50	-0.45	-3.77	-1.58	-2.67			-3.34	V
18	90	-1.32	-1.39	5.10	4.94	2.22	-0.04	-1.91	0.18	-0.96			-7.60	V
19	89	-3.11	-1.76	0.32	4.94	3.57	0.34	0.78	2.01	0.98			-9.78	V
20	88	-4.42	-1.41	0	4.01	2.75	0.56	1.76	2.73	1.88			-9.35	V
21	87	-5.21	-1.33	0	3.86	2.98	0.72	2.76	3.36	2.73			-11.9	V
22	86	-4.77	-2.17	0	4.24	2.81	0.74	3.51	3.64	3.13			-13.1	V
23	85	-4.15	-1.46	0	3.39	0.89	0.65	3.35	2.79	2.72			-9.26	V
24	85	-5.09	-1.31	0	2.08	1.74	0.75	3.63	2.77	3.09			-9.43	V
J 1	84	-4.33	-1.63	0	1.85	1.49	0.69	3.67	2.54	2.97			-8.48	V
U 2	83	-5.18	-1.86	0	1.70	2.51	0.81	4.23	3.02	3.55			-10.9	V
L 3	83	-4.09	-1.72	0	1.62	1.17	0.69	4.08	2.50	3.11			-8.37	V
4	82	-4.25	-1.66	0	1.62	1.23	0.69	4.04	2.31	3.10			-8.66	V
2 5	82	-2.12	-1.32	0	1.62	-0.34	0.42	3.30	1.25	2.06			-5.03	V
2 6	83	-1.81	-1.03	1.53	2.01	-0.86	0.29	2.21	0.39	1.21			-4.17	V
7	82	-2.43	-3.00	5.97	2.93	2.36	0.37	2.07	1.56	1.55			-12.7	V
8	82	0.06	-2.21	7.26	4.55	-0.09	0.07	1.35	0.86	0.60			-12.3	V
9	83	2.53	-0.91	9.37	4.32	-4.01	-0.39	-0.99	-1.60	-1.35			-5.03	V
10	84	3.16	-1.20	11.3	4.63	-2.72	-0.58	-2.28	-2.41	-1.94			-6.58	V
11	86	4.59	-0.10	12.8	4.55	-4.82	-0.92	-4.30	-4.19	-3.53			-0.73	V
12	87	4.24	-0.55	13.3	3.55	-2.34	-0.92	-4.66	-3.83	-3.37			-3.97	V
13	88	4.42	-0.12	13.2	3.47	-2.98	-1.00	-5.26	-4.14	-3.90			-0.85	V
14	89	3.46	-0.41	12.6	2.31	-1.33	-0.91	-4.89	-3.28	-3.47			-3.01	V
15	88	2.40	-0.86	11.2	2.16	0.64	-0.67	-3.64	-1.80	-2.45			-6.22	V
16	89	2.01	-0.71	8.28	2.39	-0.12	-0.45	-2.60	-1.24	-2.00			-5.15	V
17	88	0.57	-0.95	6.82	4.40	0.35	-0.23	-1.83	-0.61	-1.37			-6.92	V
18	88	-1.11	-1.23	5.10	4.94	1.26	0.05	-0.63	0.29	-0.33			-8.94	V
19	87	-2.95	-1.49	0.32	4.94	3.03	0.41	1.68	1.82	1.38			-10.8	V
20	85	-4.47	-2.42	0	4.01	4.26	0.71	3.20	3.44	2.87			-14.0	V
21	84	-4.04	-2.27	0	3.86	2.58	0.72	3.77	3.53	3.10			-12.9	V
22	83	-3.71	-2.33	0	4.24	1.87	0.70	4.01	3.29	3.15			-13.0	V
23	83	-4.16	-2.24	0	3.39	2.22	0.78	4.38	3.29	3.47			-13.0	V
24	83	-3.23	-1.11	0	2.08	-0.20	0.61	3.62	1.97	2.58			-6.88	V

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H O U R L Y C O N D I T I O N S (Various units)

					WEATHER DATA							CNTRLS	FLOWS					SUPPLY TMPS		
D	H	S	THS	TSS	DB	WB	SBM	SDF	SGL	WS	WDR	TF	SH	SS	VHS	VSS	RBC	VHS	VSS	RBC
J	1	S	83		74	72	0	0	0	4	337	0			1416			74		
U	2	S	82		74	72	0	0	0	4	337	0			1396			74		
L	3	S	81		74	68	0	0	0	5	337	0			1582			74		
	4	S	80		69	65	0	0	0	5	337	0			1650			69		
2	5	S	80		77	64	0	0	0	5	337	0			1490			77		
1	6	S	80		73	63	32	9	12	5	337	0			1571			73		
	7	S	80		75	64	138	33	78	5	315	0			1126			75		
	8	S	82		80	67	200	42	148	4	315	0			812			80		
	9	S	84		87	67	222	52	210	3	315	0			0			87		
	10	S	85		83	67	228	62	257	3	315	0			745			83		
	11	S	87		90	66	232	70	291	5	0	0			0			90		
	12	S	88		92	66	232	73	303	6	45	0			0			92		
	13	S	89		92	67	232	72	299	6	0	0			0			92		
	14	S	90		92	66	230	66	274	6	45	0			0			92		
	15	S	91		94	67	226	57	234	5	0	0			0			94		
	16	S	91		93	67	214	47	180	7	22	0			0			93		
	17	S	91		90	68	174	38	112	7	0	0			2833			90		
	18	S	90		87	71	88	21	40	7	22	0			2168			87		
	19	S	89		84	72	2	2	2	6	22	0			1857			84		
	20	S	88		80	72	0	0	0	3	22	0			1106			80		
	21	S	87		77	71	0	0	0	2	0	0			1136			77		
	22	S	86		77	70	0	0	0	4	337	0			1408			77		
	23	S	85		78	69	0	0	0	3	337	0			1180			78		
	24	S	85		75	68	0	0	0	2	315	0			909			75		
J	1	S	84		76	65	0	0	0	3	315	0			977			76		
U	2	S	83		73	63	0	0	0	3	315	0			1003			73		
L	3	S	83		75	63	0	0	0	4	315	0			1015			75		
	4	S	82		74	67	0	0	0	3	315	0			982			74		
2	5	S	82		79	67	0	0	0	7	315	0			1415			79		
2	6	S	83		79	60	32	8	11	5	315	0			1066			79		
	7	S	82		73	58	138	33	78	6	315	0			1346			73		
	8	S	82		76	68	200	42	148	6	337	0			1984			76		
	9	S	83		81	71	222	52	210	7	337	0			2037			81		
	10	S	84		82	74	228	62	257	9	337	0			2616			82		
	11	S	86		86	72	232	70	291	10	0	0			3918			86		
	12	S	87		86	71	232	73	303	9	0	0			3457			86		
	13	S	88		88	70	220	75	290	10	0	0			3918			88		
	14	S	89		88	70	176	81	240	10	0	0			3923			88		
	15	S	88		87	70	160	75	201	10	0	0			3929			87		
	16	S	89		87	71	212	47	179	8	0	0			3150			87		
	17	S	88		86	72	174	38	112	7	0	0			2694			86		
	18	S	88		85	71	88	21	40	7	0	0			2856			85		
	19	S	87		82	72	2	2	2	5	0	0			2116			82		
	20	S	85		77	74	0	0	0	5	337	0			1599			77		
	21	S	84		77	72	0	0	0	5	337	0			1683			77		
	22	S	83		77	72	0	0	0	6	337	0			1885			77		
	23	S	83		75	69	0	0	0	5	337	0			1587			75		
	24	S	83		77	66	0	0	0	3	337	0			1131			77		

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Gabarone Weather: GABARONE.BA (Gabarone BA MOD)

H O U R L Y T E M P E R A T U R E S

(Degrees F)

	HOUSE									SUNSPACE					ROCKBED		
D H	THS	MWI	MWO	SLI	SLO	IWI	IWO	XWI	XWO	TSS	MWI	MWO	SLI	SLO	TRB	SLI	SLO
J 1	83	86	85	85	86	84	85	85	86								
U 2	82	85	84	85	86	83	84	84	86								
L 3	81	84	83	84	85	82	83	83	85								
4	80	83	82	83	85	81	82	82	84								
2 5	80	83	83	83	84	81	81	82	84								
1 6	80	82	82	82	83	80	81	81	83								
7	80	82	83	83	83	81	81	82	83								
8	82	83	84	83	83	82	81	83	83								
9	84	83	86	84	83	83	82	84	84								
10	85	84	87	85	83	84	83	84	84								
11	87	85	89	86	84	86	84	86	85								
12	88	86	91	86	84	87	86	87	85								
13	89	87	92	87	85	88	87	88	86								
14	90	88	93	88	86	89	88	89	87								
15	91	89	93	88	87	90	89	89	88								
16	91	89	93	89	87	90	90	90	88								
17	91	90	92	89	88	91	90	90	89								
18	90	90	91	89	88	90	90	90	89								
19	89	89	90	89	88	89	90	89	89								
20	88	89	89	88	88	89	89	88	89								
21	87	88	87	88	88	88	88	88	88								
22	86	88	87	87	88	87	88	87	88								
23	85	87	86	87	87	86	87	87	88								
24	85	87	85	86	87	85	86	86	87								
J 1	84	86	85	86	86	85	85	85	86								
U 2	83	85	84	85	86	84	85	85	86								
L 3	83	85	84	85	86	84	84	84	85								
4	82	84	83	84	85	83	83	84	85								
2 5	82	84	83	84	85	83	83	83	84								
2 6	83	84	83	84	84	83	83	83	84								
7	82	83	83	84	84	82	83	83	84								
8	82	83	84	84	84	82	82	83	84								
9	83	84	86	84	84	83	82	84	84								
10	84	84	87	85	84	84	83	84	84								
11	86	85	89	86	84	85	84	86	85								
12	87	86	90	86	85	86	85	86	85								
13	88	86	91	87	85	87	86	87	86								
14	89	87	91	87	86	87	87	88	87								
15	88	87	92	88	86	88	88	88	87								
16	89	88	91	88	87	88	88	88	87								
17	88	88	91	88	87	88	88	88	88								
18	88	88	90	88	87	88	88	88	88								
19	87	88	88	87	87	87	88	87	87								
20	85	87	87	87	87	86	87	86	87								
21	84	86	86	86	87	85	86	86	87								
22	83	86	85	85	86	84	85	85	86								
23	83	85	85	85	86	84	84	84	86								
24	83	85	84	85	85	83	84	84	85								

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Line
----    ------------------------------------------------------------------------
   1
   2    *TITLE SHAKAWE-EC AS BUILT
   3    SITE TZN= 21 LOCATION=Gabarone
   4    GREFLECT JANGR=.25 FEBGR=.25 MARGR=.25 APRGR=.25 MAYGR=.25 JUNGR=.25 &
   5    JULGR=.25 AUGGR=.25 SEPGR=.25 OCTGR=.25 NOVGR=.25 DECGR=.25
   6
   7    *HOUSE *FLRAREA=1077.7
   8
   9    ROOF AREA=1082 TILT=5.1 UVAL=.05 ABSRP=.65
  10    WALL NAME=WESTWALL  *AREA=18.65 *AZM=90 UVAL=.075 ABSRP=.45 INSIDE=EXWAL
      C L
  11    WALL NAME=NORTHWALL1 *AREA=437.2 *AZM=180 UVAL=.075 ABSRP=.45 INSIDE=EXW
      C ALL
  12    WALL NAME=EASTWALL1  *AREA=245 *AZM=270 UVAL=.075 ABSRP=.45 INSIDE=EXWAL
      C L
  13    WALL NAME=SOUTHWALL1 *AREA=227.8 *AZM=0 UVAL=.075 ABSRP=.45 INSIDE=EXWAL
      C L
  14    WALL NAME=DOOR1 *AREA=18.3 *AZM=90 UVAL=.30 ABSRP=.5 INSIDE=AIR
  15    WALL NAME=DOOR2 *AREA=19.8 *AZM=90 UVAL=.30 ABSRP=.5 INSIDE=AIR
  16
  17    MATERIAL *MATERIAL=HBLK95 *VHCAP=16 *COND=.275
  18
  19    MASSWALL *AREA=80.05 *THKNS=8 *MATERIAL=CONC100 HOGLS=1.21 HOTAHS=0 HGTA
      C HS=0
  20     MWGLASS *AZM=0 NGLZ=1 UGLASS=1.06 GLSTYP=2 XRFLCT=.06
  21      SGFACTORS JANSGF=1 FEBSGF=1 MARSGF=1 APRSGF=.2 MAYSGF=.2 JUNSGF=.2 &
  22      JULSGF=.2 AUGSGF=.2 SEPSGF=.2 OCTSGF=1 NOVSGF=1 DECSGF=1
  23      SHADING *WHEIGHT=6.23 *WWIDTH=12.81 OHDEPTH=1.38 OHWD=1.65 OHLX=8 OHRX
      C =35
  24
  25    SLAB *AREA=1077.7 *THKNS=4 *MATERIAL=CONC120 UGRND=.1
  26
  27    INTWALL *AREA=1467 *THKNS=2 *MATERIAL=HBLK95
  28
  29    EXWALL *THKNS=4.5 *MATERIAL=HBLK95
  30
  31    GLASS NAME=SGLASS1 *AREA=33 *AZM=0 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.05
  32      SGDISTWNTR AIR=.5 SLB=.4 XW=.1
  33      SGDISTSMR AIR=.5 SLB=.4 XW=.1
  34      SHADING *WHEIGHT=5.3 *WWIDTH=6.2 OHDEPTH=1.64 OHWD=1.4 OHLX=30 OHRX=18
  35    GLASS NAME=SGLASS2 *AREA=26.9 *AZM=0 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.0
      C 5
  36      SGDISTWNTR AIR=.5 SLB=.5
  37      SGDISTSMR AIR=.6 SLB=.4
  38      SHADING *WHEIGHT=6.6 *WWIDTH=4.1 OHDEPTH=1.64 OHWD=1.8 OHLX=24 OHRX=24
  39    GLASS NAME=SGLASS3 *AREA=13.45 *AZM=0 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.
      C 05
  40      SGDISTWNTR AIR=.8 SLB=.2
  41      SGDISTSMR AIR=.7 SLB=.3
  42      SHADING *WHEIGHT=3.3 *WWIDTH=4.1 OHDEPTH=1.64 OHWD=1.4 OHLX=18 OHRX=36
  43    GLASS NAME=SGLASS4 *AREA=33 *AZM=0 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.05
  44      SGDISTWNTR AIR=.7 SLB=.2 XW=.1
  45      SGDISTSMR AIR=.6 SLB=.3 XW=.1
  46      SHADING *WHEIGHT=3.3 *WWIDTH=4.1 OHDEPTH=1.64 OHWD=1.4 OHLX=6 OHRX=45
  47    GLASS NAME=WGLASS1 *AREA=19.5 *AZM=90 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.
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Line
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0001001000
  48        SGDISTWNTR AIR=.7 SLB=.3
  49        SGDISTSMR AIR=.7 SLB=.3
  50        SHADING *WHEIGHT=4.96 *WWIDTH=3.94 OHDEPTH=50 OHWD=1.6 OHLX=18 OHRX=1
  51      GLASS NAME=WGLASS2 *AREA=19.5 *AZM=90 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.
        C 05
  52        SGDISTWNTR AIR=.7 SLB=.3
  53        SGDISTSMR AIR=.7 SLB=.3
  54        SHADING *WHEIGHT=4.96 *WWIDTH=3.94 OHDEPTH=50 OHWD=1.6 OHLX=1 OHRX=18
  55      GLASS NAME=NGLASS1 *AREA=19.5 *AZM=180 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=
        C .05
  56        SGDISTWNTR AIR=.5 SLB=.4 XW=.1
  57        SGDISTSMR AIR=.5 SLB=.4 XW=.1
  58        SHADING *WHEIGHT=3.94 *WWIDTH=4.96 OHDEPTH=3.3 OHWD=4.3 OHLX=1 OHRX=42
  59      GLASS NAME=NGLASS2 *AREA=20.2 *AZM=180 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=
        C .05
  60        SGDISTWNTR AIR=.9 SLB=.1
  61        SGDISTSMR AIR=.9 SLB=.1
  62        SHADING *WHEIGHT=3.08 *WWIDTH=6.56 OHDEPTH=3.3 OHWD=4.3 OHLX=13 OHRX=3
        C 0
  63      GLASS NAME=NGLASS3 *AREA=7.1 *AZM=180 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=.
        C 05
  64        SGDISTWNTR AIR=1
  65        SGDISTSMR AIR=1
  66        SHADING *WHEIGHT=2.13 *WWIDTH=3.35 OHDEPTH=3.3 OHWD=4.3 OHLX=23 OHRX=2
        C 1
  67      GLASS NAME=NGLASS4 *AREA=10.5 *AZM=180 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=
        C .05
  68        SGDISTWNTR AIR=1
  69        SGDISTSMR AIR=1
  70        SHADING *WHEIGHT=2.13 *WWIDTH=4.96 OHDEPTH=3.3 OHWD=4.3 OHLX=31 OHRX=1
        C 2
  71      GLASS NAME=NGLASS5 *AREA=19.5 *AZM=180 NGLZ=1 UVAL=1.06 GLSTYP=2 XRFLCT=
        C .05
  72        SGDISTWNTR AIR=.7 SLB=.2 XW=.1
  73        SGDISTSMR AIR=.7 SLB=.2 XW=.1
  74        SHADING *WHEIGHT=3.94 *WWIDTH=4.96 OHDEPTH=3.3 OHWD=4.3 OHLX=40 OHRX=3
        C .1
  75
  76      INFIL ACBASE=0 ACTD=0.0125 ACWIND=.375
  77
  78      INTGAIN INTGAIN=22.6 SCHED=RES
  79
  80      VENT *TYPE=NATURAL AINLET=34.6 AOUTLET=6.5 HDIFF=9.8 DDEFF=.9 DIEFF=0
  81
  82      TSTATSWNTR THEAT=55.4 TDSRD=75.2 TCOOL=120 THEATNIGHT=55.4
  83      TSTATSSMR THEAT=55.4 TDSRD=71.6 TCOOL=120
  84
  85      GROUNDTEMP *GROUNDTEMP=DBBAR
  86
  87      WINDFACTOR .4
  88
  89      PRINTDAILY JAN-1 JAN-31
  90      PRINTDAILY JUL-1 JUL-31
  91      PRINTHOURLY JAN-21 JAN-22
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Line
----    ------------------------------------------------------------------------
  92    PRINTHOURLY JUL-21 JUL-22
  93
  94    *END

    *** No input errors.

    *** Beginning simulation    04-OCT-84    09:57:44
House energy imbalance for APR Net=22.066 kBtu (0.0019)

    *** Run complete.
```


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