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PERFORMANCE EVALUATION OF THE BOTSWANA TECHNOLOGY CENTRE'S PASSIVE SOLAR BUILDINGS

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PREFACE

This report is authored by Blair Hamilton and Beth Sachs, Associates in Rural Development, Inc. (ARD), together with Gabaipone M. Masire of the Botswana Renewable Energy Technology Project (BRET).

Original design of the Botswana Technology Centre building complex was by ARD consultants David Norris (architect) and Peter Temple (engineer). Working drawings and construction supervision were provided by Alister Ritchie of Tswana Design.

Instrumentation and monitoring work was supervised by Mr. Hamilton, with extensive assistance from Ms. Masire, Richard McGowan (ARD), and Neville Wilkinson (BTC). Section 5 of this report was written by Ms. Sachs and Ms. Masire, who designed, conducted and administered the occupant survey reported upon in that section. The computer simulation studies were conducted by Mr. Hamilton.

Special thanks are due ARD consultant Philip Niles for the natural ventilation tests reported in Appendix B, technical assitance in the computer modelling work and his technical review of this report.

The test measurements on the ceiling fans and on lighting levels found in Appendices C and D were conducted by BTC staff under the supervision of Neville Wilkinson and Gerrit Jacobs. Special thanks are due to them for providing this information as well as for all their other assistance in installing the monitoring instrumentation system and keeping it going on a day-to-day basis. Appreciation is also expressed to all the BTC staff for their participation in the occupant survey and general cooperation with this effort.

1.0 EXECUTIVE SUMMARY

The Botswana Renewable Energy Technology project (BRET) designed and built the building complex which now houses the Botswana Technology Centre (BTC) in Gaborone as part of the BRET program of 13 experimental demonstration buildings at eight different locations. The purposes of this program were:

- to experimentally evaluate a number of different building design concepts, materials and components; and
- to provide highly visible demonstration buildings where energy was a prime consideration in design.

The BTC building complex is made up of a main office building, library, workshop and outdoor demonstration and display areas. The main office building and library, which are the subject of this report, were designed to demonstrate the effect of passive solar and energy-conserving design on the two major uses of energy in institutional buildings--cooling and lighting. Both buildings have similar energy design features, including orientation with respect to the sun, high levels of wall and roof insulation, shading louvres on the north and west sides, and distinctive roof "monitors" for daylighting and natural ventilation cooling.

Construction of the buildings began in November of 1983 and was completed in late 1984. Performance evaluation of the buildings had been anticipated from the beginning, and wiring for electronic monitoring of the buildings was installed during construction. In December of 1984, BRET completed installation of a microcomputer monitoring system and began collection of hourly data on temperatures, solar radiation, wind velocity, and electrical power consumption. These monitored data, together with occupant interviews, one-time physical tests, component cost data and computer modelling of the office building served as the basis for the performance evaluation contained in this report.

From the analysis of building performance and cost, a number of conclusions have been reached regarding both the overall success of the design of this facility and the relative merits of the various elements of the design. The results were also the basis for recommendations for future construction of similar institutional buildings in Botswana. The results included the following:

- the thermal performance of the BTC office and library has been essentially consistent with the original predictions of the buildings' designers--the fact that a building of this scale and complexity is performing as expected should give designers greater confidence in using passive heating and cooling techniques for similar buildings in Botswana;
- the occupants are generally pleased with the BTC office and library as work environments--from their perspective,

it would be desirable to improve some aspects of building performance, but the overall level of occupant satisfaction is high;

- as built, the BTC office is thermally far superior to a conventional office building--computer thermal simulation show that if comfort zone limits of 20 to 25 degrees Centigrade are used, the as-built design reduces the cooling load of a conventional design by 77 percent (a savings of 14,144 kWh) and the heating load by 51 percent (4313 kWh);

- several design changes could be made to lower construction costs without significantly affecting the thermal performance of the buildings, including elimination of the wall insulation, redesign of the roof and elimination of the shading louvre system; and

- if the BTC office was heated and cooled to maintain the desired comfort range of 20 to 25 degrees, in the first year alone the operating cost savings attributable to the improved design would be five times greater than the annualized increase in construction costs--over 30 years, the savings would be approximately seven times greater than the cost of the energy design improvements.

A complete "Summary of Significant Findings" from this study is included as Section 8 of this report.

2.0 OVERVIEW OF THE BRET PROJECT

The Botswana Renewable Energy Technology (BRET) project was designed as a pilot project by the Government of Botswana's (GOB) Ministry of Mineral Resources and Water Affairs (MMRWA) and the U. S. Agency for International Development (AID). The project paper was completed in September, 1980. In August, 1981, Associates in Rural Development, Inc. (ARD), of the United States, signed a contract to provide technical assistance and project management, which began in October, 1981 and ended in September, 1985.

ARD fielded two long-term staff and numerous short-term consultants. During the project's first year, most of the 15 Batswana counterparts and administrative personnel were hired. Five U. S. Peace Corps volunteers (PCVs) worked with the BRET project in 1982 and 1983, while two served during the third year.

The project was designed to further the energy policy goals of Botswana's Fifth National Development Plan (NDP-5). As defined in the project paper, the purposes of the BRET project were to:

- introduce village renewable energy technologies (RETs) that are easily reproduced and inexpensive; and

- research, develop and put into use RETs which can reduce Botswana's dependence on vulnerable supplies of increasingly expensive fossil fuels.

To fulfill these purposes, the following "needs-driven" technology development and dissemination process was used:

- needs and resource assessments,

- technology identification, matching and selection,

- prototype development and testing,

- comprehensive field testing and pilot education, and

- widespread dissemination or transfer to the public domain.

At each stage, data were collected and analyses made of the technical, economic, sociocultural, institutional and energy issues related to each technology. This information was used to make decisions about whether to continue with the next step in the process, make adaptations or abandon that particular technology. An important underlying approach used throughout the

technology development and dissemination process was community and entrepreneur involvement.

The work of the BRET project began with the selection of two pilot villages for research on domestic RETs--Ditshegwane in the Kweneng District, with a population of 820 according to the 1981 census, and Shoshong (population of 4,600) in the Central District. To perform the in-depth domestic needs assessment, an energy use and attitude survey was conducted during 1982 in these two pilot villages, and in three towns and three major villages during 1984. It was found that the availability and conservation of firewood for cooking, lighting and heating was the major energy need in Botswana.

To address this need, research and development work was carried out on a variety of stoves and cooking devices. As of the end of the pilot project, both sheet metal stoves and retained heat cookers had been found to be effective and economical and are ready for widespread dissemination. (Separate reports on each of these technologies, as well as all of the others studied by the BRET project, were prepared.)

The BRET project supported solar desalination work carried out by the Rural Industries Innovation Centre (RIIC) in Kanye, as well as the development of two commercial batch solar water heaters by an entrepreneur in Gaborone. In addition the project undertook research and development on several simple batch solar water heating systems.

With regard to community or "institutional" RETs, as they were referred to in the project paper, both the BRET project and other studies determined that the following energy-related needs were of high priority:

- water pumping systems,
- lighting and vaccine refrigeration for health clinics in rural areas, and
- the thermal comfort of buildings in summer and winter.

Thus, as called for in the project paper, the BRET project carried out research, development and field testing of hand, solar and wind pumps (both standard and advanced windmills). During the course of the project, the pumping program was expanded in cooperation with RIIC to include human and animal traction and biogas pumps. Also, due to the clear need for better water pumping information, a comparative pumping assessment was added to the project's activities. At the end of the pilot project, 45 pumping systems of various types had been

installed, including a monitoring and data collection program for the pump comparison effort.

Photovoltaic electrification systems were installed, along with accompanying monitoring equipment, at three rural health centers for lights and refrigeration, and four elementary schoolrooms for lighting. However, because both wind and solar resource data for Botswana are sparse, a program for wind and solar radiation data collection and assessment was developed.

The BRET project carried out a variety of activities related to energy efficiency in building design and increasing the thermal comfort of buildings. Research, development, construction and monitoring were completed on eight houses and three small office buildings. A number of training activities on energy-efficient building design were undertaken, and two solar design workbooks and a thermal performance analysis procedure were also developed.

In connection with all of the activities mentioned here, extensive training activities were conducted for BRET staff (some in the United States) as well as a large number of extension workers, technicians, engineers and architects working for various government and parastatal agencies, and rural people in the districts where the BRET project was active.

3.0 BUILDING DESCRIPTIONS

The BTC complex consists of a main office building, a library, a workshop, and outdoor demonstration and display areas. The buildings were designed by ARD consultants David Norris and Peter Temple in 1982. A full report on their intentions, design concepts and thermal analysis can be found in a report published by ARD (see Reference #1). The main office building and the library, which are the subject of this evaluation, were designed to demonstrate the effect of passive solar and energy-conserving design on the two major uses of energy in institutional buildings - cooling and lighting. The two buildings have similar energy design features for heating and cooling, ventilation, shading and lighting. Figure 3.1 presents the plan of the entire building complex and Figure 3.2 shows the north side of the office and library buildings.

The main office building has 240 square metres of floor area. It has a series of small private offices which surround a large central open space. There is a high roof monitor (see Figure 3.2) which caps the central area. This monitor has 5.1 square metres of operable windows on both the north and south sides, intended to exhaust warm air and provide daylighting. The building is oriented with its long axis running east-west, thus reducing the size of east and west walls. The total area of east and west walls is 62 square metres, compared to the total area for the north and south sides of 122.2 square metres. The window area on the east and west walls in also minimized (total 3.5 square metres), with the majority of the windows facing north and south (total 25.5 square metres). In addition to the doors from the offices into the central open area, there are ventilation openings in the top of these interior walls (see Figure 3.3). The majority of the windows are operable, yielding a total ventilation opening area of 27.8 square metres.

The library, shown in Figure 3.4, is one large room with 88 square metres of floor area and a monitor in the centre of the roof. In most respects it is very similar to the office building. All walls in both buildings are of masonry construction. The ceilings of both buildings are insulated and the space between the ceiling and the roof is ventilated. Insulation was applied to the outside of the walls in both buildings, covered with plaster and painted a neutral colour. Both buildings have a system of shading louvres (see Figure 3.5) on the north and west walls to reduce solar gain in the summer. Vegetation has been planted around the buildings to provide additional shading, but is not yet of a size where there is significant impact.

The thermal design intent for summer operation was that the building would be closed up during the day to keep out the heat and opened at night to cool down. During the day, whenever it was hotter outside than inside, windows were to be kept closed and the insulation was to prevent excessive heat gains through the walls and ceiling. The louvre system would be seasonally

Figure 3.1

Plan of BTC Office, Library and Workshop Buildings

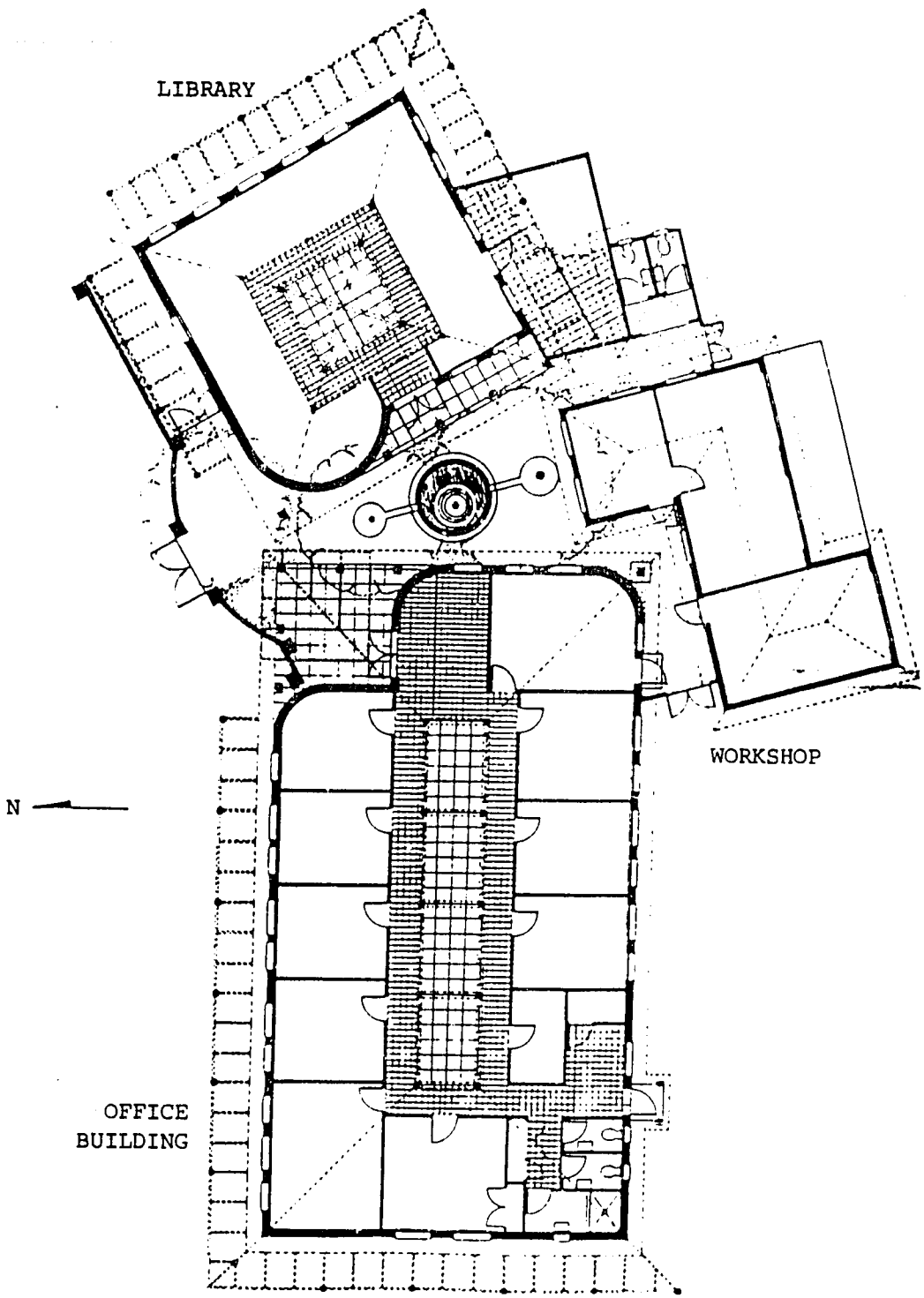


Figure 3.2 - View of Office and Library from Northeast

Figure 3.3 - Ventilation Openings between Individual Offices and Central Office Area

Figure 3.4 - North Side of the Library

Figure 3.5

Shading Louvre System

positioned to be closed and would prevent any direct sun from coming in the low windows. The roof, being what was anticipated to be a light colour, would reflect most of the solar radiation and the ventilated roof design would further reduce solar gains. At night, it was anticipated that the windows in the roof monitor would dump heat through stack ventilation and that the large number of windows would promote ventilation cooling in general. The heavy mass construction, it was hoped, would carry over some of the night cooling to the day and absorb daytime internal gains.

In winter, it was assumed that internal gains (from occupants, lighting and equipment) together with a modest amount of solar gain, would provide most of the heat necessary to keep the building warm. The heavy insulation and low infiltration of the buildings would retain this heat, and the high mass of the building would prevent it from cooling off too much at night. Although the original design of the building anticipated a small heating requirement if the building was to be maintained above 20 degrees in winter, no heating equipment was installed in the building.

Figure 3.6 provides additional views of the office building interior, showing the central open area under the roof monitor. A complete thermal description of building components can be found in Appendix E, where thermal model inputs for the office building are listed.

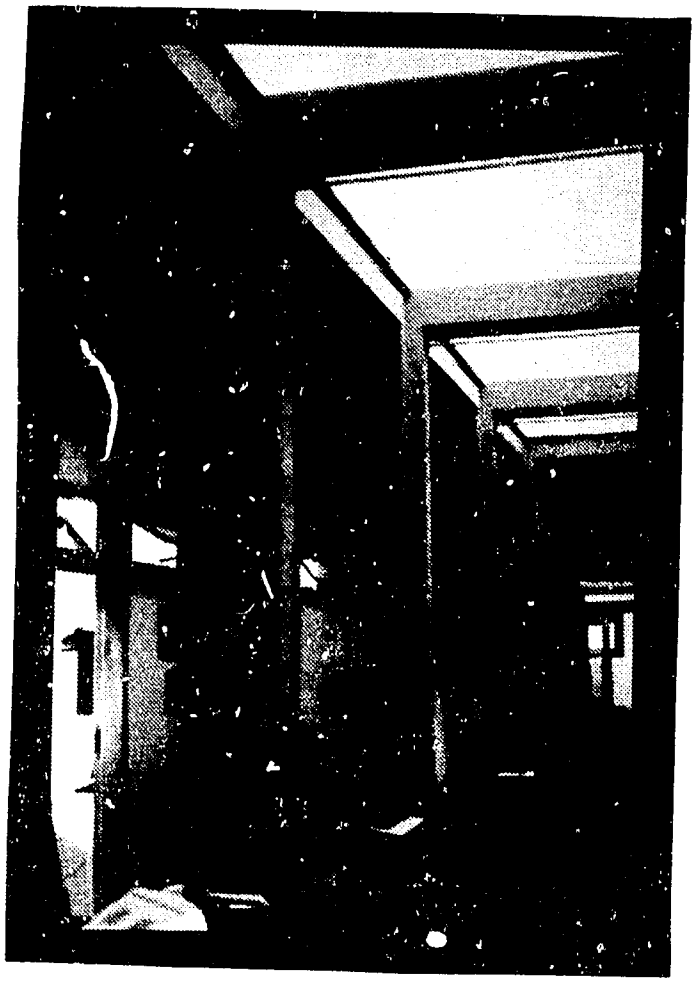


Figure 3.6

Central Area of BTC Office Building

4.0 MEASURED THERMAL PERFORMANCE

Direct measurement of the thermal performance of the BTC office and library has taken place under a variety of conditions since the completion of construction in November, 1984. Most of this measurement was accomplished with an instrumentation package for continuous monitoring of performance provided by BRET. This was supplemented by a number of short-term tests and observations. The monitoring system is described below, followed by presentation and discussion of performance results for both the cooling and heating seasons.

4.1 Description of Monitoring System

In order to quantitatively determine the thermal performance of the BTC office and library buidings, a monitoring system was included in the construction plans from the beginning. Conduit for instrumentation wires was built into the building floor and walls, which made the monitoring system relatively unobtrusive and easy to install. The system consisted of an Aeolian Kinetics PDL-24 microcomputer data acquisition system and 19 sensors used to monitor key performance variables. The variables monitored are as follows:

Channel A - Total Global Horizontal Solar Radiation
Channel B - Total Wind Run
Channel C - Ambient Temperature
Channel D - North Side Office Temperature
Channel E - South Side Office Temperature
Channel F - Central Office Area Temperature - Low
Channel G - Central Office Area Temperature - High
Channel H - Temperature Between Ceiling and Roof
Channel I - Library Temperature
Channel J - Northwest Corner Office Temperature
Channel K - Southeast Corner (Conference Room) Temperature
Channel L - Voltage
Channel M - Office Phase #1 Current - Lights
Channel N - Office Phase #2 Current - Equipment
Channel S1- Status of Windows - Office North Side High
Channel S2- Status of Windows - Office South Side High
Channel S3- Status of Window - Office North Side Low
Channel S4- Status of Windows - Library South Side High
Channel S5- Status of Windows - Library North Side High

All temperatures were measured with AD-590 semiconductor temperature sensors, accurate to 0.5 degrees. All temperature sensors were double-shielded from radiation to give a true indication of air temperature. Solar radiation is measured with a Hollis pyranometer mounted horizontally on the peak of the office building roof. The wind velocity is monitored by a Maximum three-cup anemometer, mounted on a mast above the peak of the office roof. Voltage is monitored by a simple transducer

plugged into an electrical outlet. Current is monitored with clamp-on current transformers inside the main office building electrical service panel, with the different circuits allocated to the two transformers according to the dominant type of load on each circuit (lighting or equipment).

In general, monitoring equipment installation and operation was conducted according to recommendations found in the Canadian National Research Council "Level B Monitoring Manual" (see Reference #2).

The data acquisition system scans all the sensors every 15 seconds. The values are then accumulated by the microcomputer to compute hourly totals or averages for each channel. The resultant hourly values are both printed and stored on magnetic tape.

Routine data collection was initiated in early December, 1984. Problems with electric transients causing the data logger to "crash" and the unavailability of the trained personnel to tend the system made data collection somewhat intermittent, but adequate data for evaluation were acquired. These included most of December through February, strings of data ranging from several days to several weeks from March through May, and virtually continuous data since late May.

4.2 Data Processing

Cassette tapes from all the summer data collection periods were read by microcomputer and reformatted into files for easy analysis. ASCII and packed binary format files were created on IBM-compatible diskettes, both for archiving and further analysis. Then, the packed binary files were again reformatted into a "spreadsheet" format for examination and analysis using the LOTUS-123 program.

Because this report was prepared before the end of the first winter for the building, there was not time to transcribe tapes of winter data. In this case, data from selected periods in May and June were manually entered directly into the spreadsheet format. In this format the data were examined for reasonableness, calibration correction factors were applied, and certain periods selected for detailed examination (typical and extreme summer and winter days). Certain other factors were also computed in this format, such as power consumed (the product of voltage and current), temperature minimums and maximums, and average internal heat gain from lights and equipment. An example of the monitored data in this format is contained in Appendix A to this report.

4.3 Monitored Summer Performance Results

The operational conditions for summer performance of the building were not ideal from a monitoring perspective, as they were

modified by the occupants a number of times. This is due largely to the fact that the building was new at this time, and the occupants were both learning how to best operate the building and having to adapt to unanticipated operational problems. The key passive cooling design aspects of the building were (1) night ventilation and (2) daytime closing and shading of windows to keep out heat. Neither of these was able to operate just as anticipated.

One difficulty with the the night ventilation strategy was due to scheduling problems. It was intended that the windows would be opened only when the outdoor temperature fell below the indoor temperature. This does not typically happen in summer until mid-evening, yet the work day ends at 4:30 P.M. and the windows were usually opened instead at this time. A second operational problem was a breakdown in the cable system used to open one of the top banks of windows in the office, rendering it inoperative for some period of time. Lastly, it was found from experience that the full opening of the upper windows in the office would allow wind-driven rain into the central office area. No resulting provision was made for closing the windows in event of rain, but this difficulty did result in a standard procedure of only opening the upper windows to a tilt of approximately 45 degrees. Overall, the operation of the night ventilation system was somewhat irregular, but efforts were made to operate it as closely to original intent as possible.

With respect to the daytime cooling strategies, it had been intended that windows would be left closed all day, to keep heat out of the inside of the building. This was generally observed, particularly in the case of the lower windows, although the desirability of some air movement made this frustrating at times. The shading of the lower windows and wall, which was accomplished by the louvre system on the north and west sides of the building, was also operated essentially according to intent. The only difficulty was that some louvres would inadvertently get moved out of proper position at times and some were jammed and could not be moved until repaired.

Despite these minor irregularities in operation, performance of the building in summer is well reflected in the monitored data. It is useful to examine both typical and worst-case thermal conditions and see how the building responds.

A typical summer day was selected from the monitored data. This was a single day which had levels of solar radiation, wind velocity, and temperatures closest to the average levels over the entire summer data period. Figure 4.1 presents the hour-by-hour ambient temperatures for this day, together with the corresponding average indoor temperatures in the office and library buildings. While the ambient temperature rises over 14 degrees from night to day, the temperature inside the buildings varies by less than three degrees. The library averages about one degree warmer than the office building, and both indoor temperatures are closer to the ambient nightime temperature than the ambient daytime temperature. The overall pattern is as it

FIGURE 4.1 – TYPICAL SUMMER DAY DATA

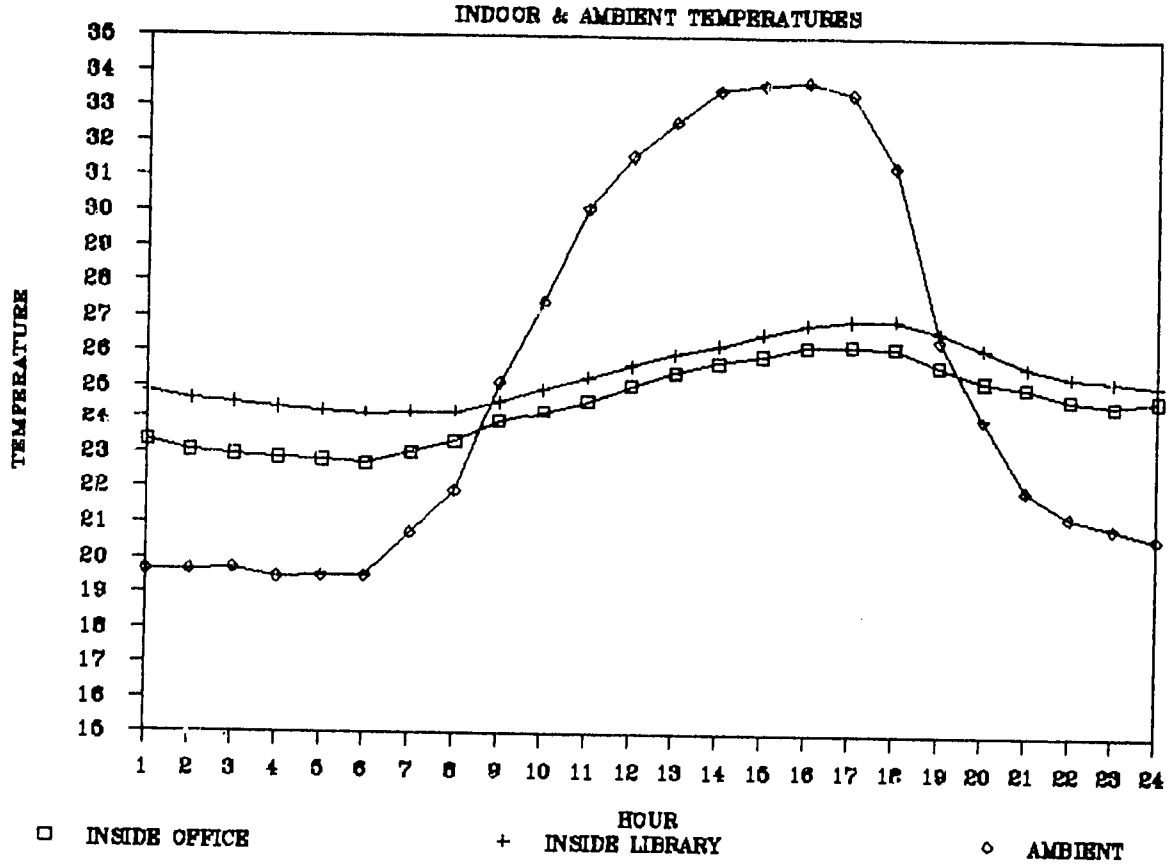
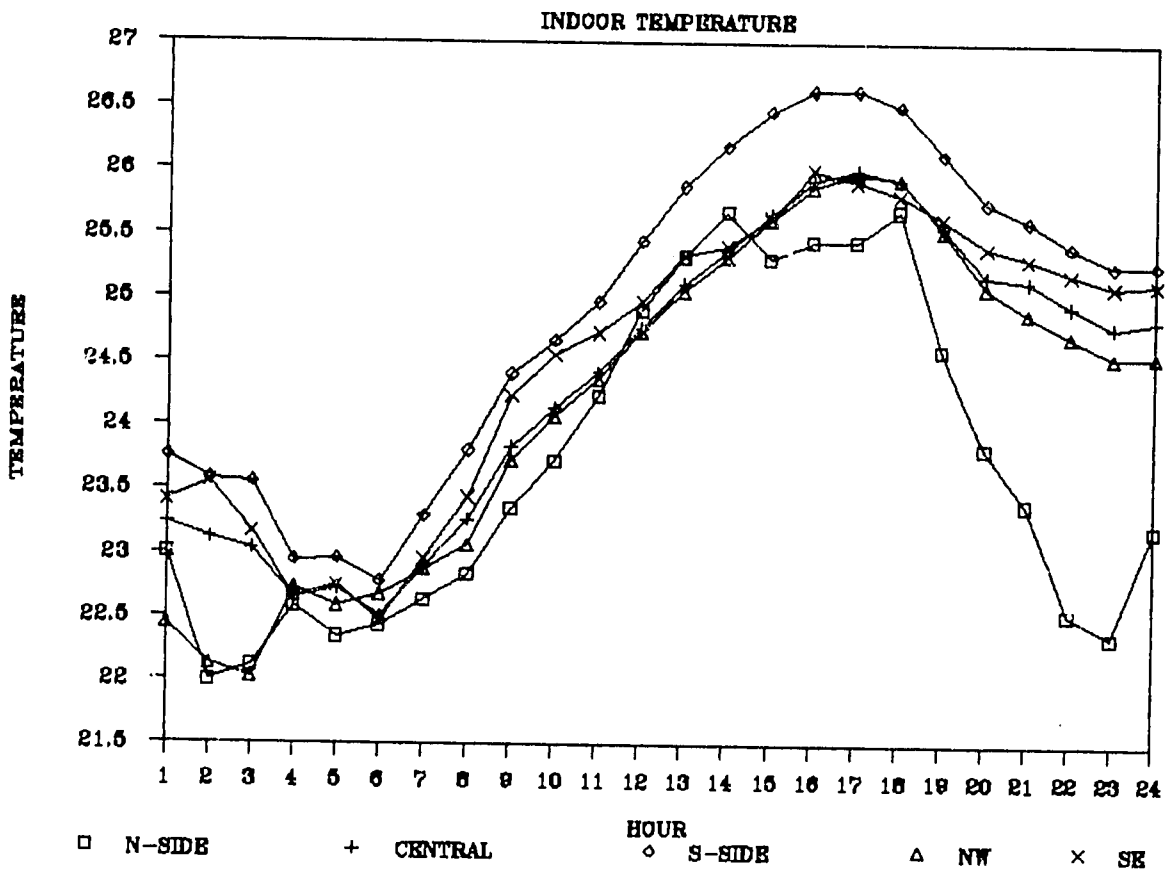


FIGURE 4.2 – TYPICAL SUMMER DAY DATA



was intended, with the indoor temperatures reflecting a pattern that suggests the general effectiveness of the passive cooling systems. During the hottest time of the day, both buildings are over seven degrees cooler than outside. With light clothing, the temperatures experienced inside the buildings are within the comfort zone, even without significant air movement.

Because these are data from a typical day, it can be inferred that on half of the summer days, the building will be cooler than shown here, and on half it will be warmer. The half of the days which are cooler are no problem, but the half which are hotter remain of concern. There are clearly some days where the indoor temperature exceeds reasonable comfort conditions, as indicated in the comments from occupants (summarized in Section 5 of this report). It is also clear that there is some room for improvement in performance. The rate of increase in indoor temperature in the morning, is not much less than the rate of decrease in indoor temperature in the evening. Ideally, the building should be able to cool off much more rapidly (with windows open) than it heats up (with windows closed).

Figure 4.2 takes a closer look at temperatures inside the office builidng on a typical summer day. For most of the day, temperatures in different areas of the building at working level were quite similar. From 4:00 until 18:00, in fact, they were all within 1.7 degrees of each other. In the morning, as the day heated up, all the rooms heated up at about the same rate. The monitoring data indicated that all building windows were closed during this period, as they were intended to be. As might be expected in summer, the rooms on the south side are the warmest and those on the north side the coolest, but these differences are not large. At the end of the day, there was a major change in the pattern. Monitoring of window status shows that the window in the north-side office being monitored was opened, and the temperature in that room then dropped dramatically over the evening, tracking more closely the ambient temperature than the rest of the indoor temperatures. The behavior of these other temperatures is explained by the fact that, according to the monitored data, the other windows were not opened on this evening, so the rest of the building cooled only very slowly.

The performance of these building designs under extreme summer conditions is shown in Figures 4.3 and 4.4, which present hour-by-hour temperatures for the hottest day of summer for which there was complete monitored data. As seen in Figure 6.3, on this day the ambient temperature rose 17.2 degrees, from a low the night before of 22.2 degrees to a high of 39.4 degrees. At the same time, the library and office had average indoor temperatures which only rose by 5.8 and 6.2 degrees respectively. Both buildings had peak temperatures of 30.3 degrees, a full 9.1 degrees below the ambient maximum.

In relative terms, these buildings work even better on the worst days of summer than they do on the average days. The indoor temperatures are relatively closer to the ambient minimum than they were for the average day. Being almost 10 degrees cooler

FIGURE 4.3 – HOTTEST SUMMER DAY DATA

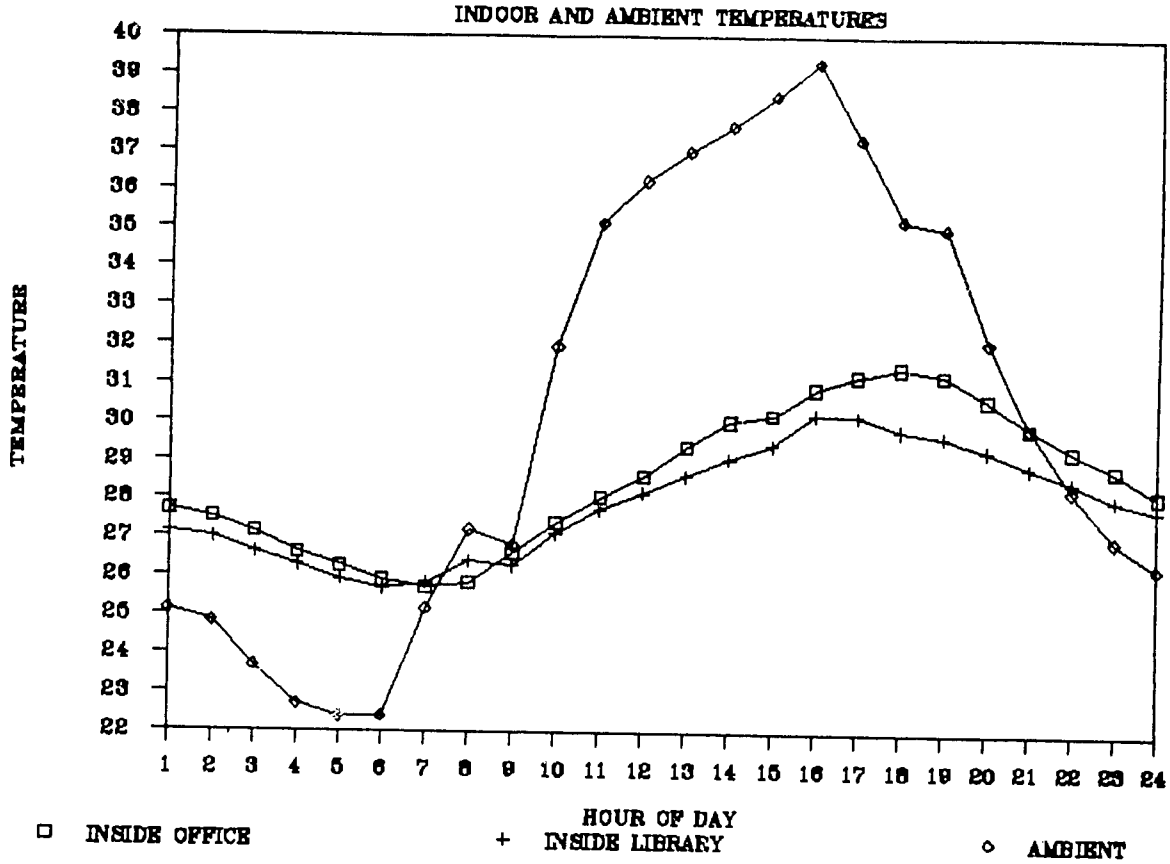
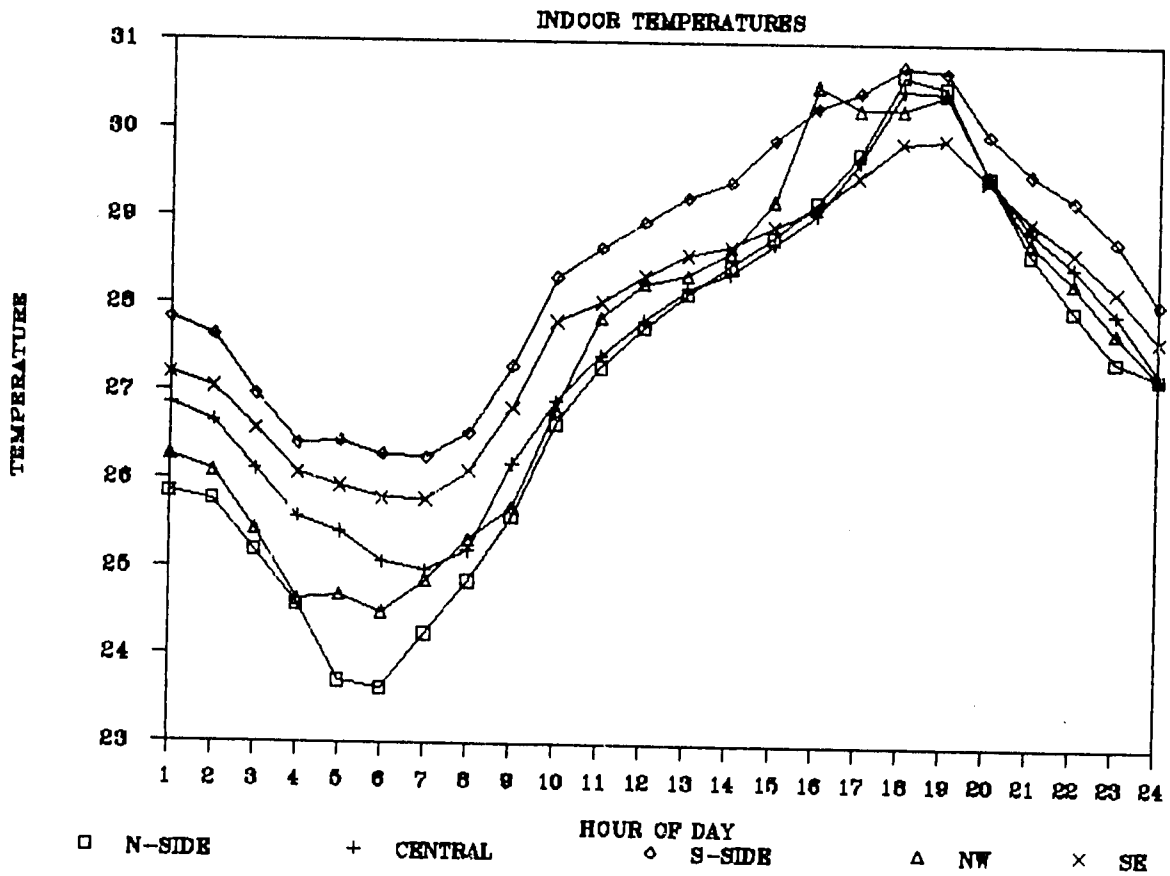


FIGURE 4.4 – HOTTEST SUMMER DAY DATA



than outside when it is close to 40 degrees outdoors is very desirable performance. It is also worth noting that the maximum indoor temperature does not occur until the end of the work day. At the beginning of the work day, the indoor temperature is under 26 degrees and it does not rise over 28 until noon. With no significant air movement, this suggests the temperatures might be only slightly uncomfortable up until noon, but that the afternoon could be quite uncomfortable. Again, this is consistent with the observations of building occupants reported in Section 5 of this report.

The limited amount of time, and magnitude, that it is cooler outside than inside, as shown in Figure 4.3, suggests that there is limited potential for greater passive cooling of these buildings on the hottest summer days. The indoor daytime peak might still be lowered a few degrees if the building mass were cooled lower the night before and/or if daytime heat gains were reduced (this will be explored further in Section 6), but on the whole this must be viewed as good passive cooling performance.

In Figure 4.4, the temperatures in different areas of the office building on the hottest day of summer are presented. Again, there is a pattern of the north side being the coolest and the south side the warmest, although the spread between the two is somewhat greater than it was for the average summer day. In contrast with the average summer day, the different temperatures which are shown all drop at about the same rate as the evening goes on. This is because the ambient temperature remained above the indoor temperature well into the evening and (as indicated by the monitored data) none of the windows were opened.

Greater understanding of the summer performance of the building was provided by supplemental testing of the ventilation cooling of the building. This involved the measurement of natural ventilation flow rates and directions in the office building on March 9, 1985, between 5:30 and 6:30 A.M. While conditions were not ideal and only these conditions were evaluated, the following conclusions were reached:

- At the low-level windows, flow was into the building on the two windward sides of the building and out of the building on the two leeward sides. With wind coming from the southwest, flows were greatest through the south- and north-side room windows. The windows in the center room on the west side of the building had about 30% less flow than the center north-side office and the windows in the conference room (southeast corner) had about 75% less.

- Even with a small breeze (about 3 m/s), any stack-driven ventilation appears to have been totally overcome by wind-driven ventilation. With this wind speed coming from the southwest, air was flowing in through the south high windows and out through the north high windows. Flow in the stack area below the high windows was small, and while upward along the north wall, it was downward along the south wall.

- The upper windows are not particularly effective as ventilation openings. With an outside wind of about 3.0 m/s, the flow measured in the openings was about 1.5 m/s on the windward side and 0.5 m/s on the leeward side. This situation is aggravated by the direction the windows open and the degree to which they are opened.

- Overall, the effectiveness of the windows in the building to wind-driven ventilation is quite low. It is calculated that for a given wind speed at a height of 10 meters, the actual airflow through the windows in the office building is on the order of 20% of what would be expected for an equivalent set of unobstructed openings struck directly by that wind.

These wind-driven ventilation patterns are schematically illustrated below in Figure 4.5. A more complete report on the test conducted is included with this report as Appendix B.

Another element of performance which was monitored was electricity consumption of the building. Figure 4.6 presents the hour-by-hour electricity consumption of the office building for the same typical summer day as discussed previously. It can be seen that the total electrical load is very light. The daily total electrical use is only 17.9 kWh, compared to a typical load for an office of this size of over 40 kWh/day. There is a base lighting load of about 100 Watts which is on all the time (a spotlight in the reception area which is left on at night for security). In addition a small amount of additional lighting is used in the morning and evening. The equipment circuit shows a continuous intermittent load, with a high spike around noon. The background usage here is due to a refrigerator and a water heater, and the peak loads around noon have to do with lunch preparation.

4.4 Monitored Winter Performance Results

Operational variables which might affect performance are much less of an issue in winter than in summer. Windows were left closed most of the time, unless there was a particularly warm day where the outdoor temperature rose substantially above the indoor temperature. The louvre system on the north and west walls was usually in the proper position to allow maximum sunlight transmission due to careful attention, though on a few occasions there may have been unanticipated shading.

From the data recorded to date, a typical winter day was selected in a manner similar to that used for summer. Figure 4.7 presents the hour-by-hour ambient conditions for this day, together with the corresponding average indoor temperatures for the library and office building. On this day, the ambient temperature started from a low of 4.8 degrees just before sunrise, and rose to a high of 21.0 degrees in late afternoon. The average temperature in the office started the day with a low of 17.9 and rose only 3.3

Figure 4.5

Air Flow Patterns Under

Wind-Driven Ventilation

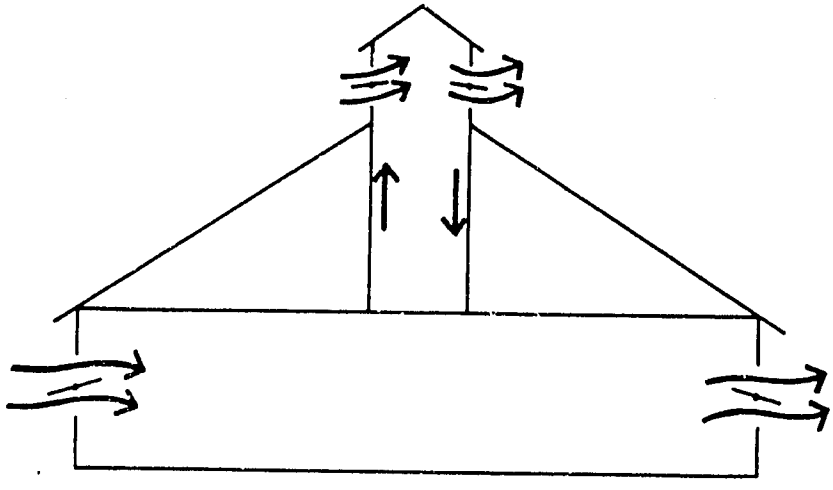


FIGURE 4.6 – TYPICAL SUMMER DAY DATA

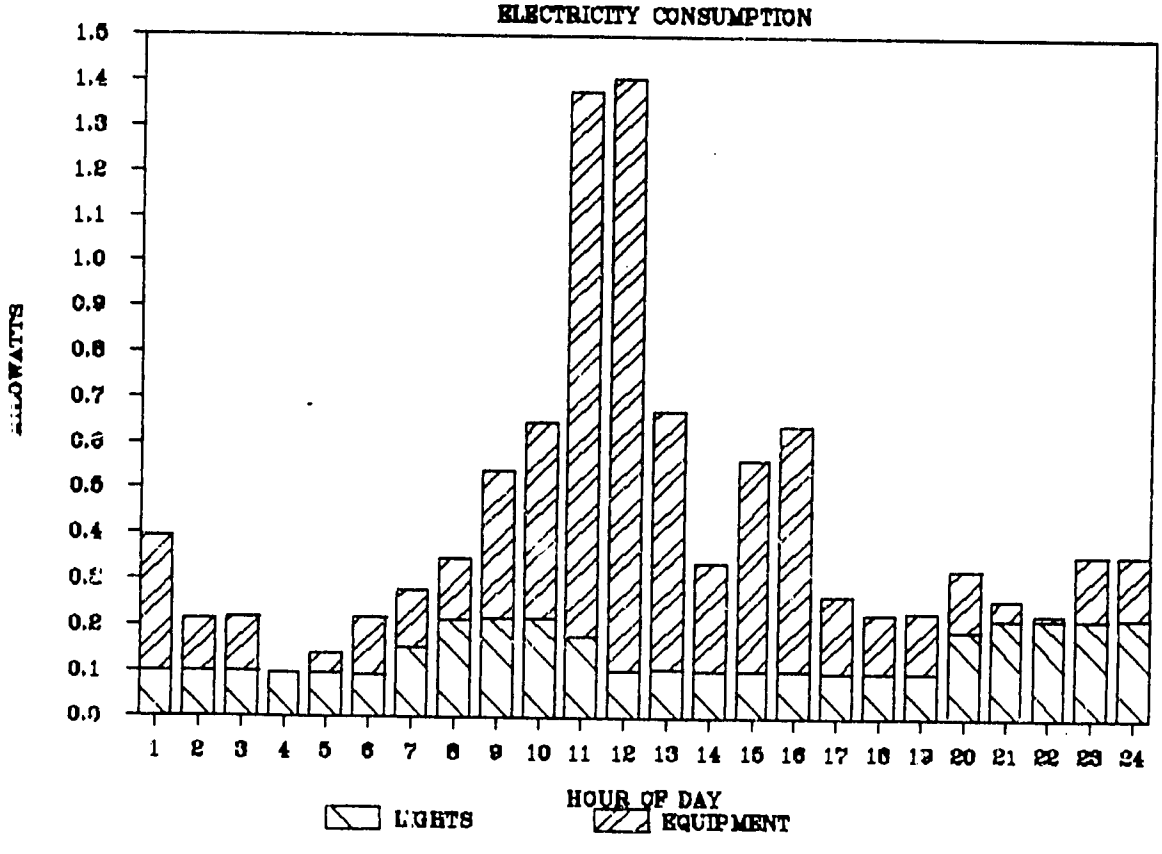


FIGURE 4.7 – TYPICAL WINTER DAY DATA

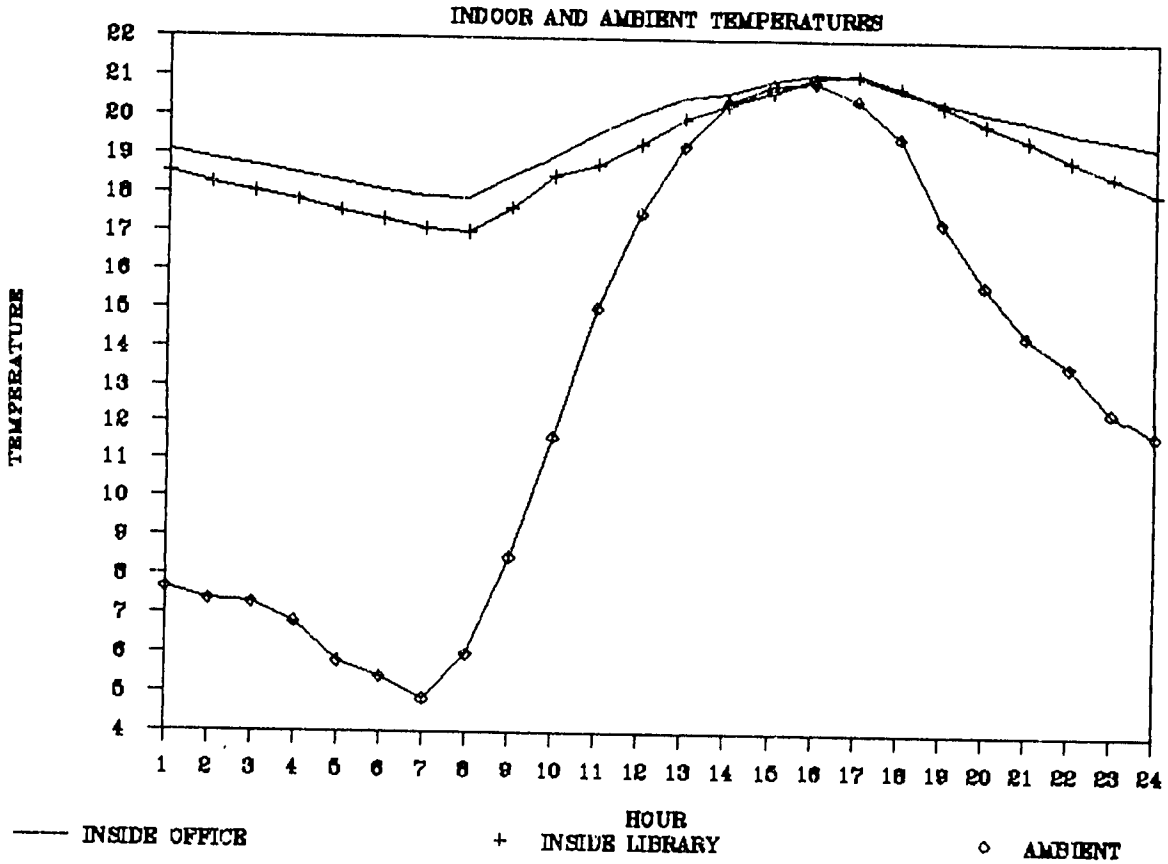
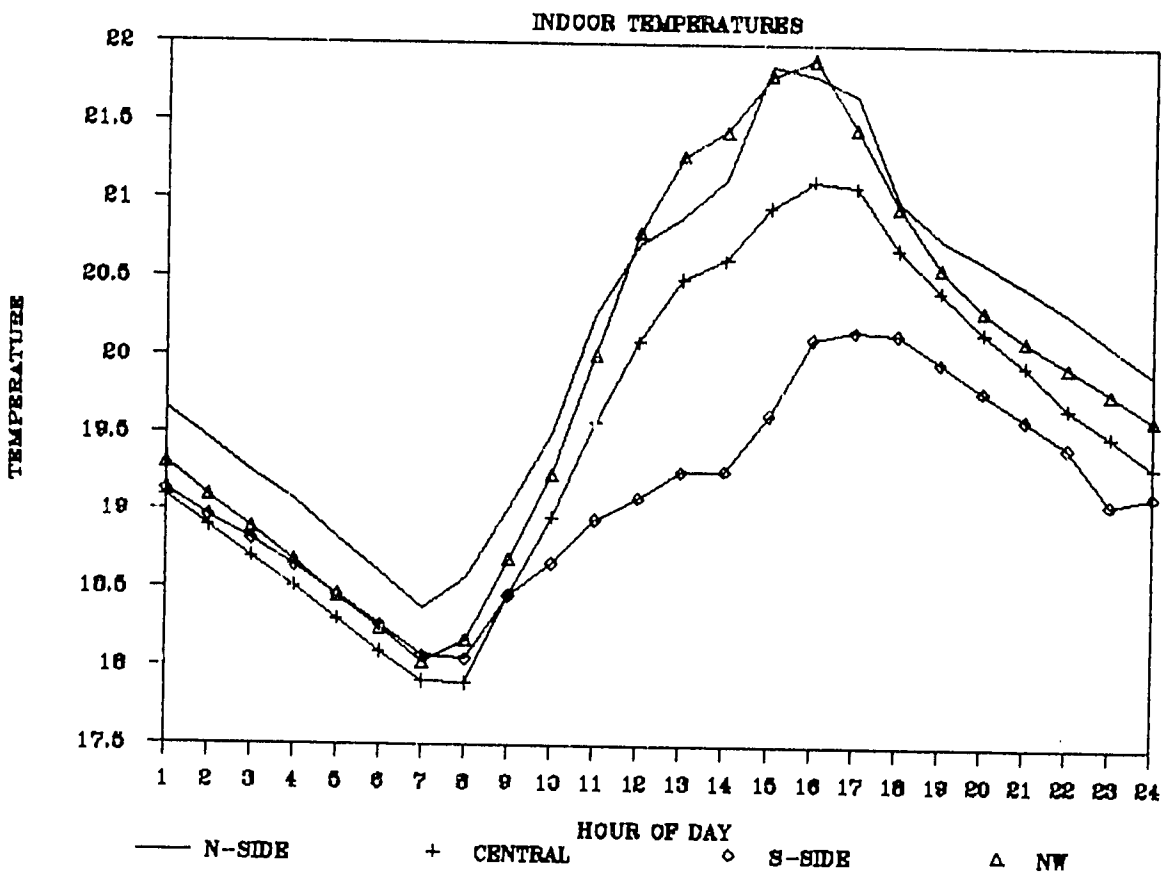


FIGURE 4.8 – TYPICAL WINTER DAY DATA



degrees during the day to a maximum of 21.2 at the end of the work day. The library, which stayed slightly cooler than the office most of the time, started at 17.0 degrees but rose to the same 21.2 degrees by 17:00.

While both buildings are not cooling off too much at night, neither are they heating up too much in the day. Both have average temperatures above 20 degrees for only about half of the work day. This is clearly not comfortable for most people engaged in office activities, as is confirmed by occupant comments reported in Section 5 of this report.

Given that Figure 4.7 presents average day performance, half the winter days can be expected to be colder inside and half can be expected to be warmer. The half that are warmer should be marginal to acceptable, but the colder ones will be well below the range of comfort for much of the day. Comparing just this aspect of performance to the summer, it is a reasonable conclusion to say that the building design works better in summer than it does in winter.

Figure 4.8 presents the distribution of indoor temperatures on this same typical winter day. Again, there is clearly a difference from summer. The temperatures in all the areas of the office fall at the same rate at night, and are within one degree of each other. But in the day, the temperatures on the south side of the building are as much as 2.2 degrees cooler than on the north side. This shows the impact of winter solar gains in the north rooms to be significant. This pattern also suggests, as might be expected, that heat transfer of warmer air from the north side into other areas towards the south is very limited.

In Figure 4.9, data from the coldest day in July, 1985 are presented. Here, the building is seen under very unfavorable winter conditions. The ambient temperature fell to a low of 2.1 degrees at 8:00 and only rose to 16 degrees by mid-afternoon. Although the sun was bright, accounting for both the indoor and outdoor daytime temperature rises, there were high winds all day long. Under these conditions, both buildings fell to around 15 degrees at 8:00 and never rose above 18 degrees the entire day. In Figure 4.10, the distribution of temperatures in the office building is shown for this same day. The offices on the north side are showing the benefits of solar gain by noon, and would appear to be marginally comfortable in the afternoon. The remaining areas, however, never rise above 17 degrees. Most office workers would not find these to be acceptable working conditions and on a day such as this, some auxiliary heating is obviously desirable.

As was noted earlier, the temperature between the ceiling and roof (above the ceiling insulation) was monitored continuously. It had been noted that the temperature of this space was close to ambient at night, but usually warmer than either ambient or indoor temperature during the day. As cold winter experiences made clear that some additional heat would be useful in the office, it was suggested that the attic space be examined as a

FIGURE 4.9 – COLDEST WINTER DAY DATA

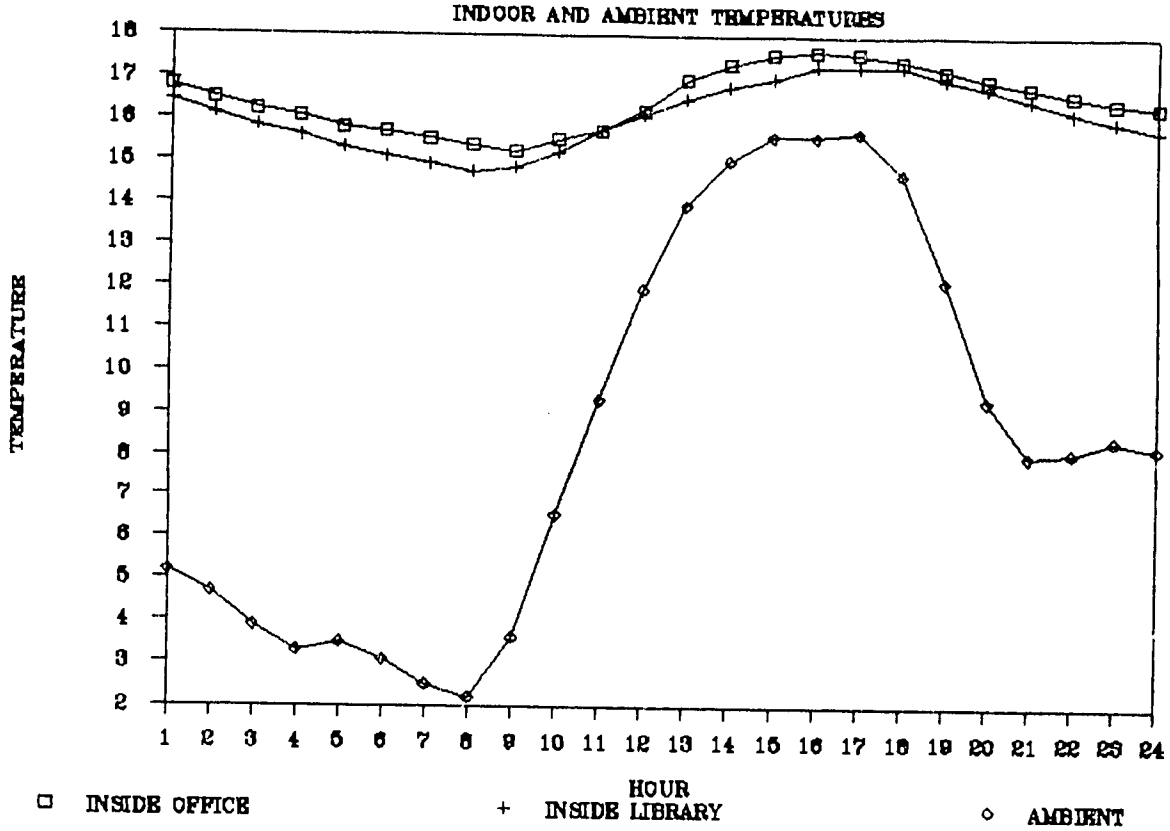
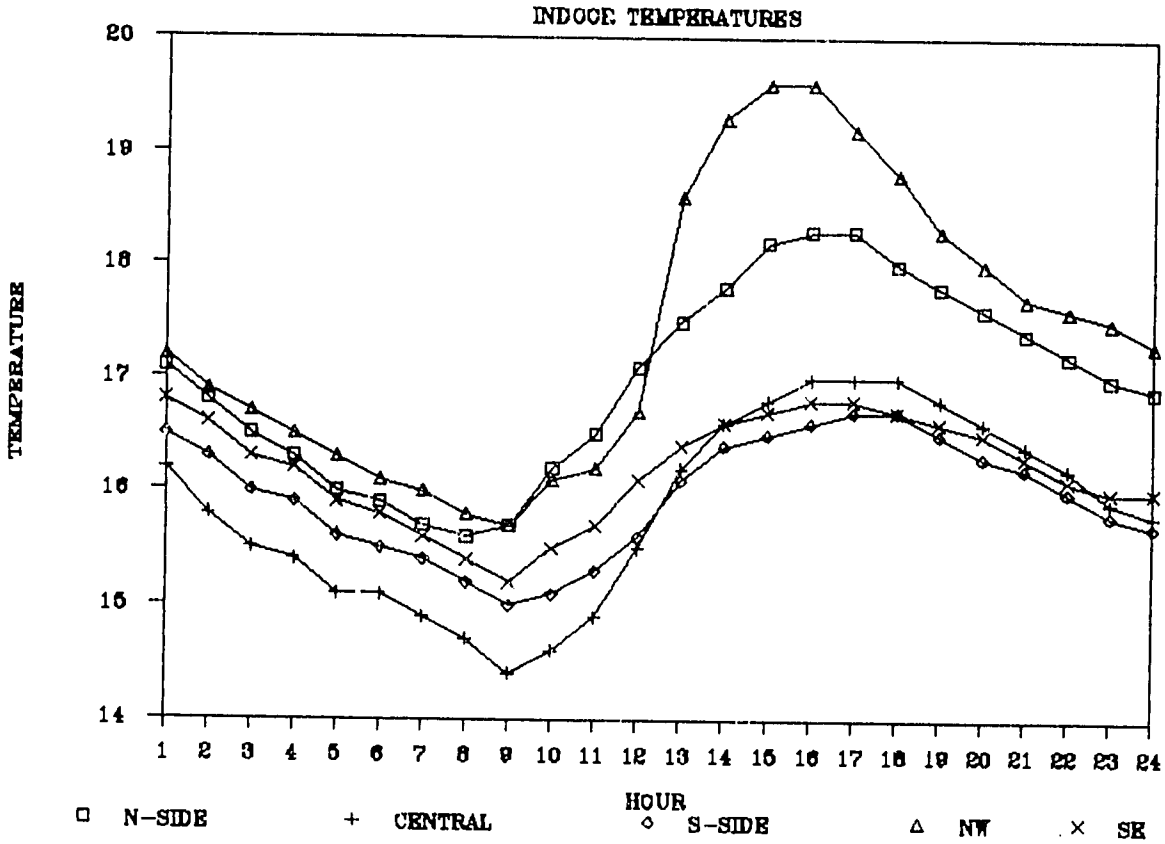


FIGURE 4.10 – COLDEST WINTER DAY DATA



potential source for some heat. Figure 4.11 shows the monitored attic space temperature for the coldest day in July, compared to the ambient and average indoor temperature. Even on a day this cold outside, it appears that the attic space could be a source of heat for the building. On more typical winter days the attic space temperature achieves a maximum of close to 30 degrees. Significantly higher temperatures would be expected if the intentionally large ventilation openings in and out of this space were closed up, possibly on a seasonal basis. While the magnitude of this resource has not yet been quantified, it appears to be worth pursuing in both this building and similar future designs in Botswana.

In Figure 4.12, the electrical consumption for a typical winter day is plotted. Compared to the summer daily total of 17.9 kWh, the winter use averages 25.8 kWh, but this is still quite low compared to most similar office buildings. The base lighting load appears to be much higher, suggesting that more lights were left on at night and electric lights were necessary all day for work (this was confirmed in later interviews). The higher equipment load present for most of the work day is explained partly by the increased staff level which occurred in winter and by the increased use of kitchen equipment (again, according to staff interviews).

While more monitored data would be useful, the key aspects of performance have been well identified by the results presented here. Further characterization and understanding of performance are more productively pursued by other means. One of these is examination of the experience and impressions of the buildings' occupants. A second is the use of analytical models which can help to isolate more of the cause and effect of building performance. These two approaches are the subjects of the next two sections of this report.

FIGURE 4.11 – COLDEST WINTER DAY DATA

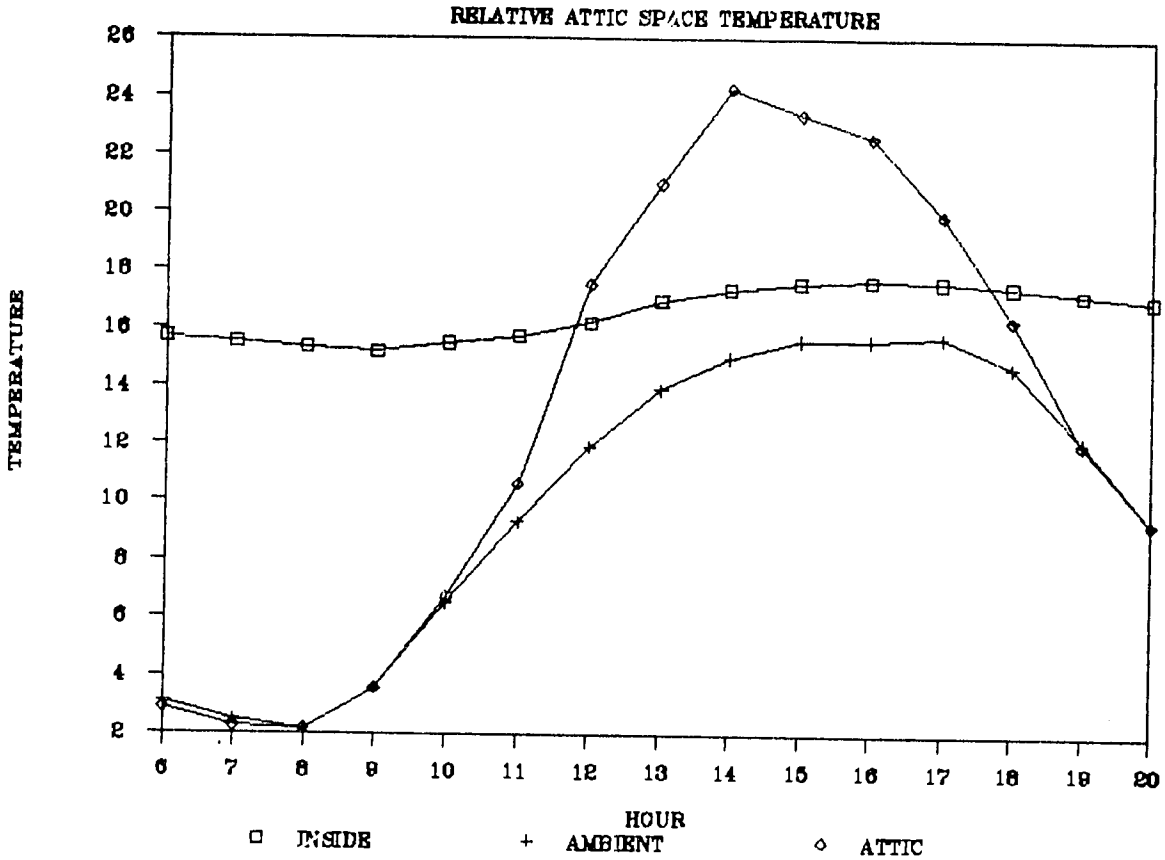
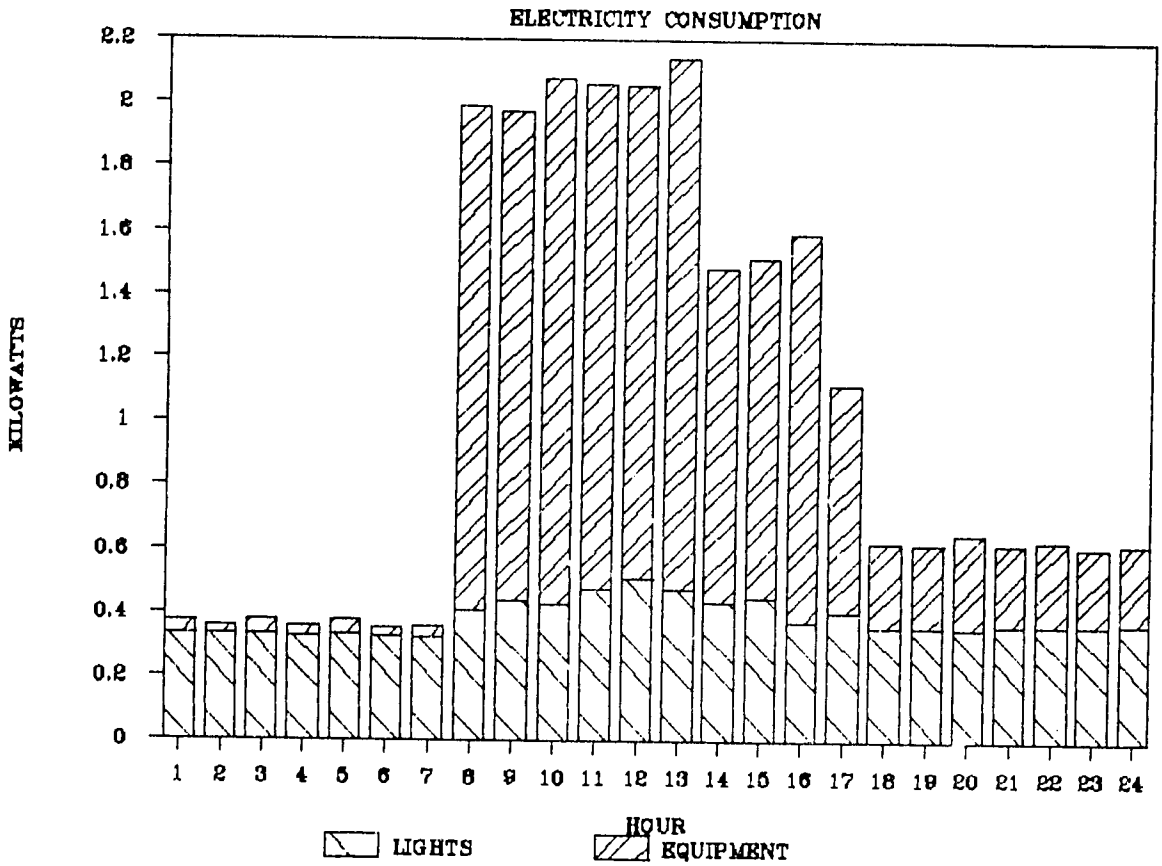


FIGURE 4.12 – TYPICAL WINTER DAY DATA



5.0 QUALITATIVE PERFORMANCE EVALUATION BY BUILDING OCCUPANTS

Performance of a building can be measured in many different ways. The previous section of this report focussed on an evaluation of the BTC building based on monitored, measured data about its thermal performance. This section, however, presents an evaluation of the building from the perspective of the people who work in it. The data are not measured by instruments. Rather, the information presented here is based on conversations with the building's users. Thermal comfort was the primary focus of the quantitative evaluation. This qualitative evaluation further examines the thermal comfort performance of the buildings, and examines other aspects which affect its users as well.

5.1 Methodology

The information for this study was gathered through in-depth interviews with 18 people who work in the main office building and the library at the BTC. A questionnaire was developed to help structure the interviews. It was used, however, only as a "guide" for the interviewers, as interviews were conducted in a relatively informal manner. Most of the questions were open-ended and were intended to encourage comments from the occupants about many aspects of their physical work environment. A copy of the questionnaire is presented on the next two pages as Figure 5.1. The interviewees were told that the purpose of the study was to get their personal perceptions about how the building was working. Two people conducted all of the interviews, some jointly and some individually. Each person was interviewed privately and the average interview lasted 20 minutes. The interviews were conducted almost completely in English during the second half of June, 1985.

5.2 Study Participants

The study participants included all members of the junior and senior staff at BTC, with the exception of one person who was not available at the time the interviews were done. Of the 18 people interviewed, 14 work in the main office building and four work in the library. Ten of the group are women; 11 of the 18 are Batswana. The length of time of employment at BTC ranged from less than one month to five years, but only one person had not worked there long enough to have experienced at least part of a cooling season.

5.3 Study Findings

Due to the nature of the data gathering process and the necessary interpretation of responses by the interviewers, the study findings must be viewed as very subjective. The findings are supplemented by observations made by the interviewers, and those observations are noted as such.

FIGURE 5.1 - QUESTIONNAIRE FOR QUALITATIVE EVALUATION OF THE BTC OFFICE BUILDING

1. Overall Impression of Building:
   - do you like working in the building?
   - what do you like best?
   - what do you like least?
   - what does the building look like to you?
   - does it remind you of any other buildings? which other(s)?
   - what do your family, friends and others say about it?
   - what have you heard visitors say about it?

2. Open Space Design:
   - do you like the "open" design?
   - are there "traffic" problems in the open space?
   - is privacy a concern for you? if so, do you have enough?

3. Sound:
   - is it noisy?
   - what kinds of noise are bothersome? (phone, typewriters, people talking, people walking by, etc.)
   - is it hard to have conversations, in person or on the phone?

4. Light/Color:
   - does it ever feel too bright? when? where?
   - does it ever feel too dark? when? where?
   - if it is too dark, do you put on the lights?
   - then is it bright enough?
   - is glare ever a problem? when? where?
   - do you like the colors inside?
   - do they make you feel warm, cool?

5. Thermal Comfort:
   - does it ever feel too hot? when? what do you do?
   - does it ever feel sticky?
   - do the fans help when it is hot?
   - do you turn them on? if not, why not? who decides?
   - do you like the fans? are they noisy? do they make it too windy (disturb papers)?
   - does it ever feel too cold? when? what do you do?
   - do you feel cold all over?
   - do your hands, feet, nose feel cold?
   - what is the most comfortable space(s)?
   - what is the most uncomfortable space(s)?

6. Air Quality:
   - does it ever feel stuffy? do you open windows then?
   - what makes it feel stuffy (too many people, afternoon)?
   - does it get too smokey?

FIGURE 5.1 (Continued)

7. Exterior/Outdoors:
   - what do you think of the color of the building?
   - have you heard comments about the colour?
   - do you use the outside for meetings? comments...
   - if you stay around office, where do you have your lunch?
   - comments about parking
   - comments about landscaping

8. Night Use
   - do you ever work in the building at night?
   - if so, are there any different comments?

9. Maintenance:
   - are there any unusual problems with maintenance? (access to parts of building, length of time for repairs, etc.)
   - maintenance of louvres
   - maintenance of landscaping

10. Demographics:
   - name
   - job
   - age
   - sex

*** In general, break down discussion between WINTER and SUMMER.

Some of the interviews did not cover every question, for reasons of time and difficulty in communication. Where statistics are presented, it should be noted that they only include those who answered the question.

The contents covered in the interviews were divided into distinct subject areas for discussion purposes and are presented in a similar manner. The primary subject areas addressed were building appearance and setting, the open space design, noise, light and thermal comfort. General comments were also solicited, and demographic information was gathered as well.

Interior Design

Almost everyone felt that the buildings provided pleasant spaces in which to work. When asked specifically about the "open space" design of the central area, two-thirds of the total 18 liked it. It is interesting to look separately at those who presently work in that area and those who have private offices. Of the 14 people who work in the main building, five work in the central area. Only two of those five are satisfied with the open space design of the central area. The main problems cited were a lack of privacy, noise and a general feeling of being exposed. While many of the nine who work in the main building in private offices say they like the open design, very few indicated that they would want to work in it.

The open space plan is an important feature of the passive solar design of the BTC buildings, but it obviously creates some problems. The interviewers feel that the noise in that area is the most serious concern, and that there may be possible ways to improve the situation without affecting thermal performance. All of them, of course, cost money. One possible solution would be to install low space dividers, which could be covered with sound-absorbing material. The addition of carpet would also help absorb sound.

Noise

Noise was felt to be a problem in the building by many occupants. Ten of the 14 people in the office building feel that it is at least a moderate problem, primarily in the central area. Most people cited voices as the most bothersome, although a few said that all noises were disturbing, including people talking, people walking by, machines, etc. A few people specifically mentioned the problem of echoes. Noise from the road on the north-side offices and noise from the workshop on the south-side offices were cited as disturbing.

Because the passive solar design requires heat to be stored in the mass of the building, it was seen as necessary to have a lot of exposed hard surfaces. But the hard surfaces in combination with the open space design create an environment where sounds are

amplified and bounce around a lot. Again, adding carpet or dividers would probably help the situation. In addition, the decision to locate the office building in such close proximity to the workshop was unfortunate, but may have been necessary due to constraints of the site.

Light

It is very clear that the work areas in both the office building and the library do not get enough daylighting. Sixteen of the total 18 people interviewed felt that it was too dark to work, for at least part of the day, without having the lights on. Five of those felt that it was too dark all or most of the time. Others said it was too dark during a particular time of day, such as when the shading louvres must be closed, or when it was cloudy. The location of the individual's work space determines when it is too dark, and this of course changes with the seasons. Almost everyone felt that there was adequate light with the artificial lights on, although some would prefer more natural light rather than having to depend so heavily on artificial lighting. Only two people felt that it was sometimes still dim (one in a north-side office, one in the library) with the artificial lights on.

Glare was not seen as a serious problem, even though half of the people said that it occurred sometimes. When it occurs, people try to remedy the situation by changing their positions.

Again, the passive solar design has some negative effect on the human work environment. The need for the shading louvres and the placement of the windows to alleviate overheating prevent the interior from getting enough daylighting. It would be useful to look at the effect of variations in the louvre schedule on thermal performance. Perhaps having the louvres open more of the day to allow more daylighting would have negligible effect on overheating. Similarly, perhaps closing the louvres during the short periods of time when glare is a problem would have little effect on heat delivered through the windows.

Air Quality

People were questioned about air quality and the responses indicate that it is not much of a problem. The occasions when it is "stuffy" seem to occur primarily on summer afternoons or winter mornings when the windows are closed. People do not smoke in the buildings, but when they have in the past, it was noticed that the build-up was bad. Similarly, it was mentioned that when the building is being cleaned, the smells of the cleaning agents used are quite bad. The only locations singled out as a problem by more than one person were the conference room, which seems to get quite uncomfortable when it is used by a lot of people for an extended period of time, and the cooking area. Exhaust fans have been installed in both the cooking area and the conference room to help clear the air.

Thermal Comfort

The discussion of thermal comfort was broken down separately by winter and summer. The interviews took place during the winter, so it may have influenced the perceptions somewhat. (When you are cold, it may be harder to remember what it was like five months ago when it was hot.)

Sixteen of the 18 people said it is sometimes too cold in the buildings. Most people felt that is was only the mornings that were uncomfortable; two felt it was cold all day. In response to the cold, a number of people mentioned that they wore extra clothes to keep warm; other said drinking hot drinks or moving around helped. While the level of discomfort varied from person to person, the interviewers got the sense that many of the staff felt it to be a fairly serious problem.

Thinking back to the summer, 13 of the 17 people who were there during last summer felt it was sometimes too hot, although two of those said it was hot very rarely. Five people said that it was only uncomfortably hot on those few days in the summer when it was humid as well as very hot outside. A number of people mentioned that when they came inside the building from outdoors, it was always noticeably cooler inside. Only when one was stationary for a long time did it then begin to feel uncomfortable.

Because the design of the buildings requires that the windows be closed in summer when the outside temperature is higher than the indoor temperature, fans were put in to help cool the buildings. The fans were only installed at the end of the summer, so some people felt that they would have to wait until this summer to say whether they thought the fans helped. About two-thirds of those who had an opinion now about the fans felt that they did help. Those who felt they did not help were generally in private offices without fans and were therefore not affected by them. When asked if they liked the fans, the opinions were split. Of the 10 people who responded, six like them. The four who did not particularly like them gave a variety of reasons - they were noisy, they blow papers around, the breeze across the face is annoying, etc.

When asked to compare the discomfort in the buildings of the cold in winter to the heat in summer, 10 of 16 people felt the heat to be more uncomfortable and six felt the cold was worse. It is interpreted that the general sentiment is that there are things one can do to stay warm, but there is not much you can do to get cooler when it is hot.

Building Appearance

In general, people were very enthusiastic about the appearance of the building. The most frequent description was that the

buildings are "beautiful." When asked what it reminded them of, responses were varied; the most common was that it reminded them of a church (six responses). Others said it reminded them of traditional Botswana architecture (four), and one or two were reminded of a bank, a school or a Chinese pagoda. Six people said that it was unique and reminded them of no other building. When asked what kinds of comments they had heard from friends, family and visitors, there were three responses cited often. Those were (1) questions about the roof (why is it so high?, what is up there?), (2) general comments about the uniqueness (that crazy-looking building, strange, unusual) and (3) general comments about the beauty of the building.

Opinions about the colour of the buildings were very mixed, ranging from "great" to "okay" to "horrible". Roughly one-third of the people liked it; the rest felt that it was passable or that they had gotten used to it, or really did not like it at all. The buildings' interior colours were more acceptable. One-third of the group did not like them and their attitude can be summarized by saying that they think the interior colours were dull. Although the choice of exterior colours was made because of their impact on thermal performance, the interior colours were chosen for purely aesthetic reasons. The choice seems poor in the interviewers' opinions, not only because they are drab, but they also create a dim interior in combination with the inadequate daylighting.

Attitudes about the landscaping in its early stages of growth were split fairly evenly. A little less than half did not like it for a variety of reasons, the rest feel it is was "okay" or "nice" or "will improve over time." The few people who commented on the parking were not pleased with its size or layout.

Operation and Maintenance

In order for buildings such as this to perform as they were intended, a strict and rigorous schedule of opening and closing windows and shading louvres must be maintained. These operations require more time than in a standard building, but those responsible usually accept the routine as necessary. When the schedule is not followed closely, however, it can cause problems. For example, if the windows are inadvertently left open at night in winter, the building is, of course, quite cold the next morning. This is no different from the case of a conventional building, but the location of the high windows in the monitor makes it easier to forget to close them. There have also been problems noted of rain entering the building through monitor windows which were left open too far.

Other effects of the window and louvre operations are not physical in nature. While the staff understood that, for instance, the windows must be closed on summer afternoons, it seems "contrary" to common practice and somewhat complex. Additionally, the strict adherence to the schedule to insure the maximum thermal comfort leads to a feeling of lack of flexibility

and personal control over the environment. The louvre schedule,in particular, contributes to the problems of glare and poor daylighting.

5.4 Conclusions

When the BTC staff were asked to comment in general about what they liked least about the building, the extremes of heat and cold were indicated as the most serious problems, followed by noise and inadequate daylighting. Nine people answered the question about what they liked least about the buildings, giving multiple answers in some cases. Five people cited overheating in this context, five cited noise, four cited cold and two cited lack of light.

When asked what they liked best about the buildings, people had a more difficult time being specific. This, in itself, is probably a positive response. If a building works well, there is not necessarily anything which can be pointed to about why it works well - it just works. One of the comments repeated several times was an appreciation for the feeling of "gentle" climate control which is experienced working in these buildings. The building appears to temper the environment in a positive way without changing it drastically, particularly in summer. The building provides relief from the outside heat without producing the cold sensation associated with air conditioning.

Most of the other comments about the outstanding features of the building related to the appearance and general atmosphere. Overall, the BTC staff are very impressed with the appearance of the building and are proud to be working in it. While some problems have been noted and suggest potential design improvements, people are generally pleased and happy with these buildings as work environments.

6.0 ANALYSIS THROUGH SIMULATION MODELLING

6.1 Use of Simulation Modelling

In the previous section of this report, the basic quantitative evaluation based on monitoring (reported in Section 4.0) was expanded upon with a qualitative evaluation based on the occupants' experiences and impressions of performance. It is also desirable to return to and pursue qualitative evaluation further. Among the quantitative questions it would be useful to answer are:

- What is the annual performance of the building in quantitative terms, not just the performance for the monitoring period?

- What cause and effect relationships can be identified which will explain some of the more unusual aspects of the monitored performance?

- How well does the BTC office perform, in quantitative terms, in comparison to a similar conventional building?

- What is the relative effectiveness of the different elements of the passive solar design of the building, and were some of them mostly responsible for the improved performance of the building and others relatively unimportant?

- What design changes could have resulted in even better performance of the building?

One approach to answering these questions would be to do more monitoring, in greater detail, for a longer period of time. Then, to answer questions regarding relative thermal performance, it would be necessary to measure the performance of a similar conventional building, if one existed, and build and measure other experimental buildings with variations on the passive design of the BTC office. This is obviously impractical, both due to cost and the fact that building performance is greatly affected by the way it is occupied and used. Opening and closing of shutters, the number of occupants, the use of lighting and other equipment, and personal preferences for comfort conditions all affect the thermal performance of a building. Unless these were all measured or controlled to be the same, results would not be comparable.

An alternative approach is to develop and compare thermal models of both the actual structure which was built and various alternative designs. This is relatively inexpensive and makes possible both more detailed, dynamic analysis and the evaluation of a large number of design alternatives in a very short period of time.

This second approach was used to evaluate long-term performance, subsystem interactions and comparative performance of the BTC office building, using the CALPAS3 computer simulation model. This is the same approach which was used in the previous evaluation of a passive solar house design conducted as part of the BRET project (see Reference #3). In this approach, a thermal-network model of the building is developed and then the thermal response of the building modelled, on an hour-by-hour basis, for a full year using typical hour-by-hour weather (solar radiation, temperature and wind) for Gaborone. The output of the model is a series of tabular reports which present 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 SYMPHONY program. More details on the computer model and the development of the Gaborone weather file are contained in the report referenced above.

6.2 Modelling the BTC Office Building

The first step in this analysis was the development and checking of a thermal model of the BTC office building, as it was actually built and operated. Dimensions and geometry of the building were taken from construction drawings. Additional information was provided by the occupants and the designers of the buildings. A complete listing of the computer program inputs used to model the building is presented in Appendix E. Some critical assumptions had to be made in developing these inputs. While these represent the best of the analyst, they are listed below for the purpose of documentation:

1. The shading louvres on the north and west sides of the building are assumed to be closed for the entire summer and properly adjusted in an open position for the entire winter.

2. The windows are assumed to be opened for ventilation cooling of the building whenever (a) the ouside temperature is cooler than the inside, and (b) the inside temperature is above 22 degrees in summer or 24 degrees in winter.

3. All electrical energy consumed inside the building is assumed to result in a heat gain to the building. The daily total of this heat gain is based on the monitored average daily consumption of 17 kWh.

4. The average heat gain from occupants of the building is assumed to be 11.8 kWh/day (14 people x 7 hours x 120 Watts).

5. Infiltration in the building is assumed to be .0225 air changes per hour per degree of inside-outside temperature difference plus .168 air changes per hour per metre/second wind speed. This results in an average infiltration rate

in summer of .24 air changes per hour and in winter of .27 air changes per hour.

6. Ventilation of the roof space was modelled by adjusting the actual roof absorptivity of 65% to a component model-based equivalent absorptivity of 20% for a roof with no air space.

7. Shading of the north and west low walls by the overhanging louvres during the summer was similarly modelled by adjusting the absorptivity of these walls from the assumed actual of 65% to an equivalent 20% on the north and 30% on the west. Shading of the east wall by the library was similarly modelled by using an equivalent absorptivity of 55%.

8. Insulation is assumed to be installed as specified, giving reasonably complete coverage of walls and ceiling.

Obviously, these assumptions are not accurate at all times. Occupancy is not the same every day and operating strategies are not always as assumed. This should be kept in mind when comparing short-term differences between modelled and actual performance.

Checking the Model Against Monitored Data

One of the primary concerns with using a model is that it may not accurately reflect how the building performs in reality. A model is necessarily a simplification and it will be useful only so long as these simplifications do not introduce unreasonable errors into the results. While the CALPAS3 model has been widely used and has been the subject of numerous studies where measured and predicted performance were compared, there are enough unusual aspects to this application that it was felt important to check the model against monitored data from the building.

The means for checking the model against measured data was to compare predicted vs. measured hourly temperatures for typical winter and summer days. First, days with typical weather for January and July were identified and the performance of the building modelled for those days. Then, the monitored data were searched for days with the same weather conditions, and the indoor average temperatures on these days were compared to the model results. Figure 6.1 presents the comparison for a typical summer day, and Figure 6.2 for a typical winter day. The agreement for the summer condition is extremely good. The only time over the 24-hour period when the difference between the modelled and measured temperatures exceeds 0.7 degrees is after 20:00 hours. An examination of the monitored data showed that most of the windows in the office were not opened on this evening, as they should have been for ventilation cooling and as was assumed in the model. Accordingly, the model was judged to be a good predictor of summer indoor temperatures, when the basic

FIGURE 6.1 -- TYPICAL SUMMER DAY

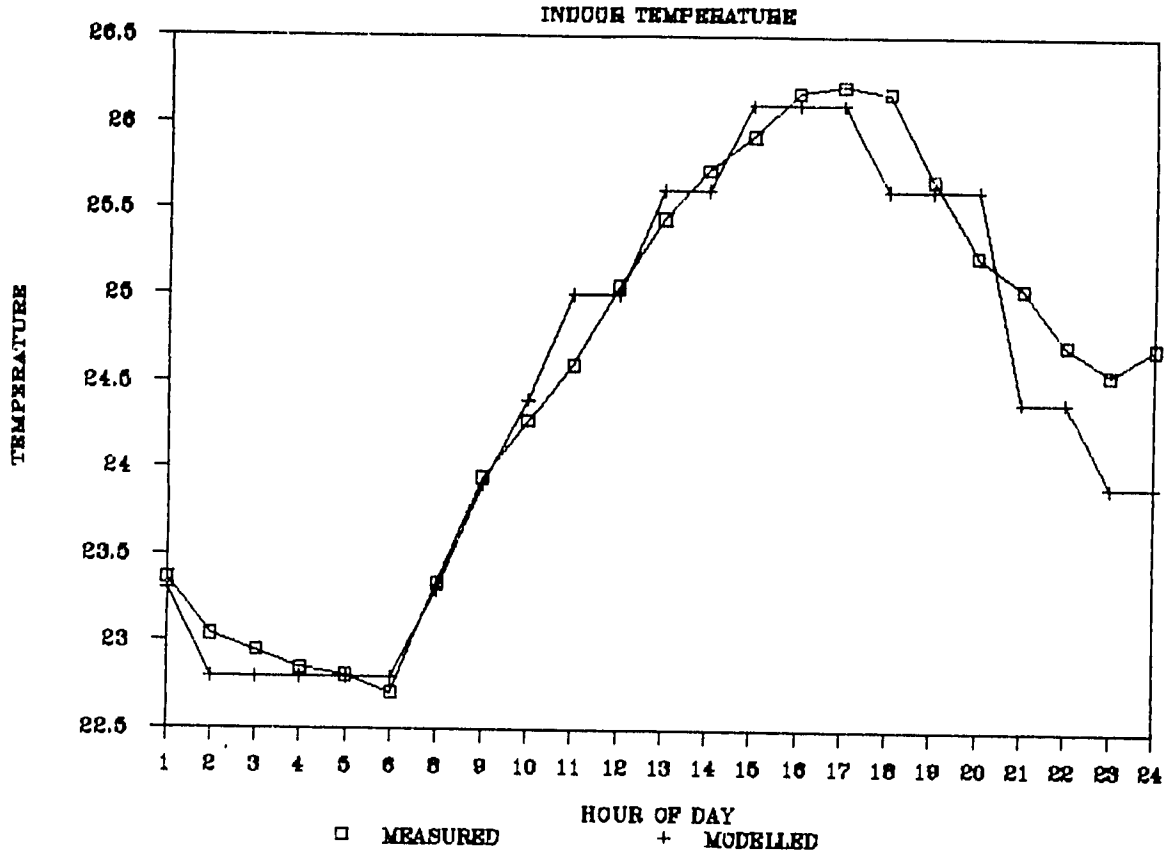
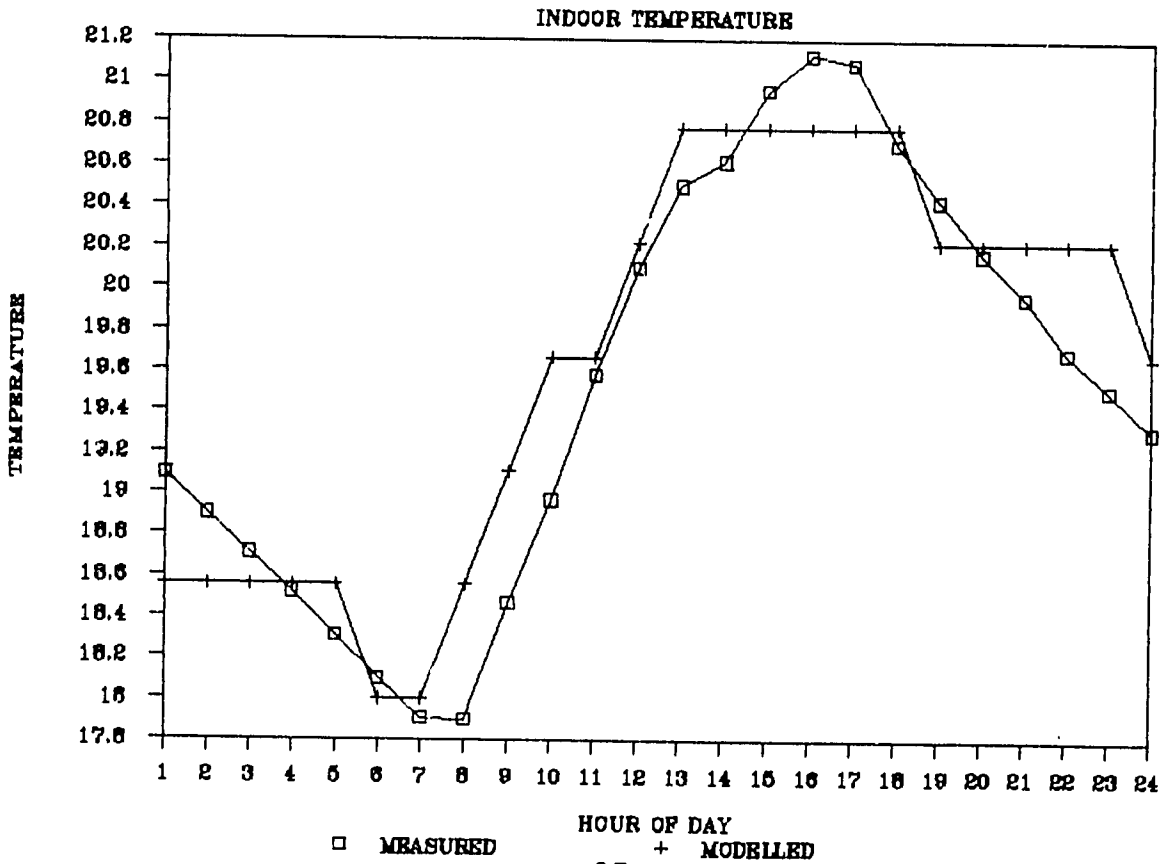


FIGURE 6.2 TYPICAL WINTER DAY



assumptions are correct. The comparisons for winter conditions, as shown in Figure 6.2, are just as good. The model predicts temperatures within one degree for every hour. Overall, the model appears to do well in both winter and summer and was judged to be adequate for further analysis.

6.3 Simulated Performance of the BTC Office Building (As Built)

It is useful to use the model developed above to characterize the long-term and average performance of the building. Figure 6.3 presents the mean low and high temperatures for each month of the year, together with the mean high and low monthly ambient temperatures. Obviously, the building does a good job at modifying the ambient conditions to create a more comfortable indoor environment. It can also be seen that it responds appropriately to the season, with indoor temperature being closer to the ambient low in summer and closer to the ambient high in winter. Table 6.1 presents these temperature data in tabular form, together with the modelled monthly energy balance. Looking at these monthly energy balance figures, it is worth noting that conductive heat transfer and infiltration are positive numbers during the summer (they result in a net heat gain to the building) and negative numbers in the winter (indicating a net heat loss). This suggests the significance of design strategies in these two areas which, unlike those in a number of other areas, will be of benefit in both winter and summer. It is also of particular interest that the solar gains predicted are only slightly greater in winter than in summer (and of similar magnitude to the monthly conductive transfers and internal gains), suggesting that the solar heating of the building is not a particularly dominant energy transfer. Despite the limited effectiveness of the ventilation system (as discussed earlier), ventilation removes very large quantities of heat from the building in mid-summer. In winter, on the other hand, no ventilation to remove excess heat is required at all for the months of July, August and September.

At a more detailed level, the predicted day-by-day temperatures in the building during January are presented in Figure 6.4. It can be seen that the indoor low and high temperatures track each other very closely, almost always maintaining a 3.9-degree temperature swing from day to night. This can be contrasted with the more erratic ambient temperature pattern, which goes through an average diurnal swing of 12.8 degrees. In looking at this graph, it is worth noting that the days which result in the hottest indoor temperatures are those which follow the nights with the warmest ambient temperatures. It should also be noted that while the predicted indoor temperatures are well within the comfort zone most of the time in January, they rise above 25 degrees at least once every day, above 26 degrees on 24 days, and above 27 degrees on 7 days. There has been significant discussion on the upper bound of the comfort zone which should be used in Botswana in the summer. The Department of Electrical Engineering suggests designing to a maximum of 24 degrees for "fully air-conditioned buildings." The BRET passive solar design

FIGURE 6.3 – SIMULATION RESULTS

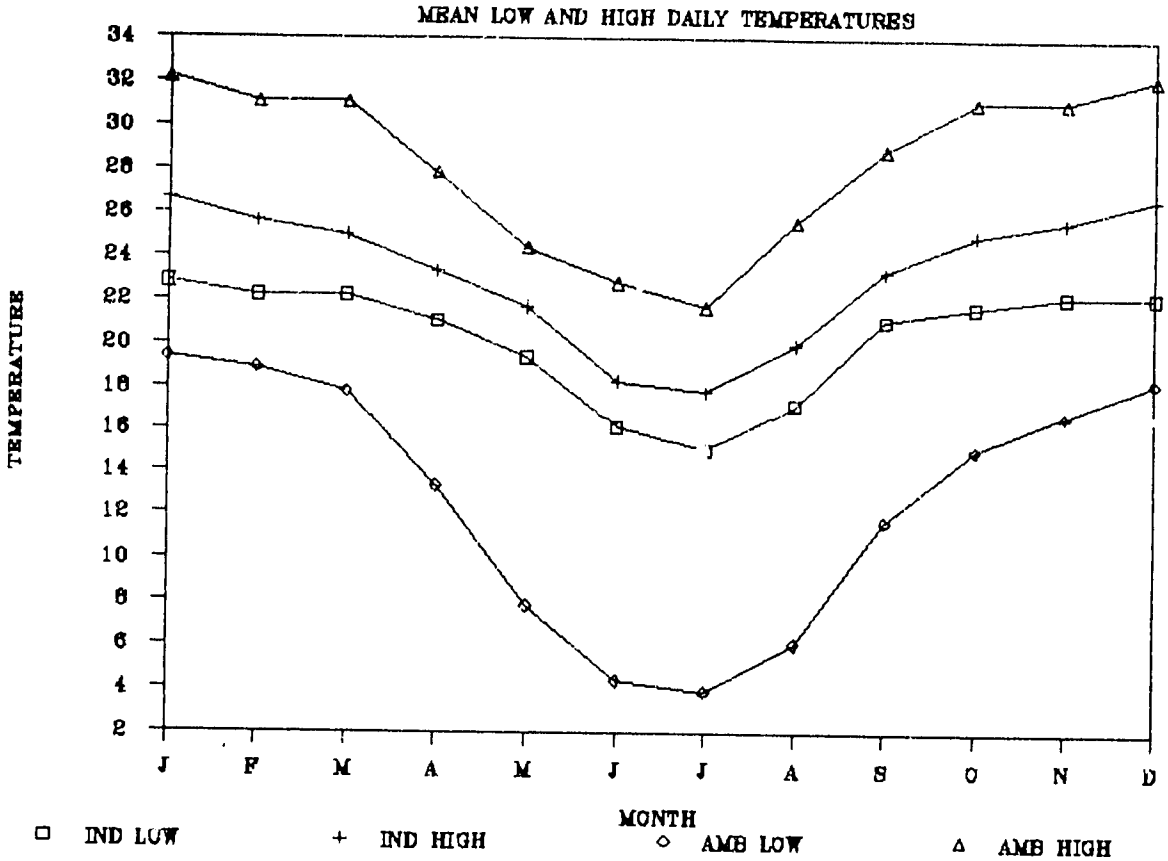


FIGURE 6.4 – SIMULATION RESULTS

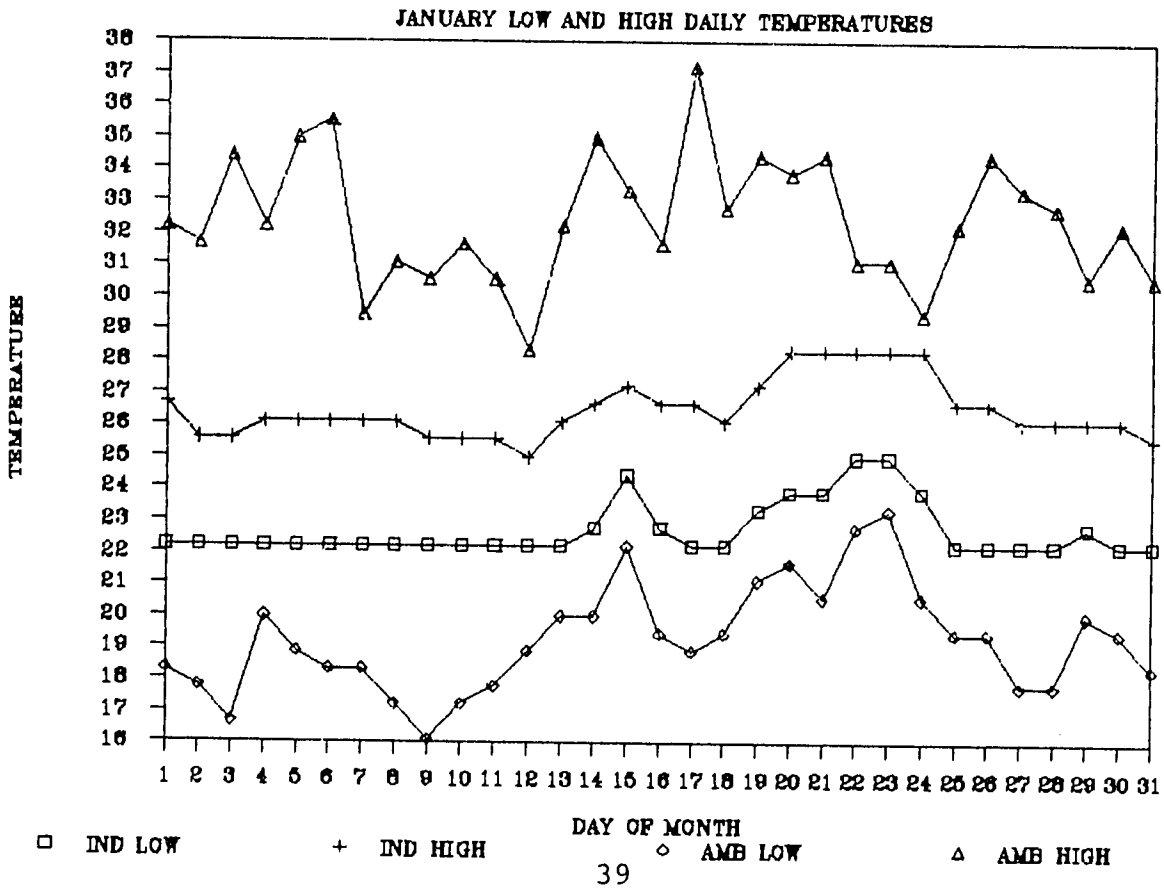


TABLE 6.1 BTC OFFICE SIMULATION RESULTS

MONTHLY CONDITIONS

MONTH	INDOOR AVG. TEMPERATURE LOW	HIGH	MEAN	AMBIENT TEMPERATURE LOW	HIGH	MEAN	SOLAR RADIATION
J	22.8	26.7	25.0	19.4	32.2	25.6	6852.4
F	22.2	25.6	23.9	18.9	31.1	24.4	6757.9
M	22.2	25.0	23.3	17.8	31.1	23.9	6269.3
A	21.1	23.3	22.2	13.3	27.8	19.4	5304.8
M	19.4	21.7	20.6	7.8	24.4	15.6	4485.3
J	16.1	18.3	17.2	4.4	22.8	12.2	3590.1
J	15.0	17.8	16.7	3.9	21.7	11.7	4728.0
A	17.2	20.0	18.9	6.1	25.6	14.4	5140.9
S	21.1	23.3	22.2	11.7	28.9	18.9	5774.5
O	21.7	25.0	23.3	15.0	31.1	22.2	7281.1
N	22.2	25.6	23.9	16.7	31.1	23.3	7627.8
D	22.2	26.7	24.4	18.3	32.2	25.0	7527.0
AVG	20.3	23.2	21.8	12.8	28.3	19.7	5944.9

MONTHLY BUILDING ENERGY BALANCE
GAINS AND LOSSES (MJ)

MONTH	COND.	INFIL.	SOLAR	INTERNAL	STORAGE	VENT
JAN	2848.5	1023.8	3462.9	3230.9	23.2	-10592.1
FEB	2041.8	855.0	2904.9	2918.3	202.2	-8934.7
APR	2011.7	671.6	2887.5	3230.9	88.0	-8893.7
MAY	-1663.4	-1325.3	2623.3	3126.7	706.6	-3509.0
JUN	-4381.0	-3861.0	4487.7	3230.9	1001.4	-541.3
JUL	-4114.3	-4045.1	3820.8	3126.7	1139.3	0.0
AUG	-3769.8	-4208.7	4848.5	3230.9	-94.3	0.0
SEP	-3008.6	-2990.6	4632.1	3230.9	-1753.2	0.0
OCT	-2280.2	-1546.1	2855.4	3126.7	-379.1	-1754.9
OCT	1028.1	105.9	3348.8	3230.9	-602.3	-7084.0
NOV	1820.3	652.7	3471.7	3126.7	-18.2	-9052.0
DEC	2878.0	1322.3	3686.0	3230.9	-160.1	-10941.7
YEAR	-6589.1	-13345.7	43029.8	38041.4	153.4	-61303.5

workbook suggests an upper design limit to the comfort zone in summer of 28 degrees. The response of occupants in the BTC office, as reported earlier in this report, suggests that the building is found to be uncomfortably hot only some of the day, and on most, but not all, of the days in mid-summer (January). This suggests that occupants are finding it too hot when the temperature rises above about 26 degrees. The graph, then, suggests that the building is not uncomfortably hot most of the time, but could use some additional measures to make it more comfortable during the peak heat hours on many summer days. The ceiling fans which were installed in the building are a reflection of this situation and appear to have a significant effect.

Further understanding of how the building works in summer can be gained by examining an hour-by-hour energy balance for the building for a typical January day, as presented in Table 6.2. Among those things which can be noted are:

- Conductive and infiltration exchanges are negative at night (heat loss from the building) and positive in the day (heat gain to the building).

- The dominant heat gain to the building during the day is conductive gain. This is heat conducted into the building through the walls, ceiling and windows. With the walls and ceiling already insulated to a high degree, the windows appear to account for a substantial conductive gain and are the only area which could be further insulated (i.e., increased to double glazing) to effectively reduce this gain.

- A substantial amount of heat is stored in the slab and interior walls of the structure from day to night, which keeps the building from cooling off as much as might be desirable. On the other hand, this thermal mass is a benefit in the day, preventing the building from getting as hot as it would with less mass.

Similar simulations were run for winter, examining the month of July. Figure 6.5 presents the daily low and high temperatures for both the inside of the building and outdoors. Like summer, the indoor temperatures show a highly consistent pattern of day-night temperature difference, averaging 2.8 degrees for the month. At the same time, the outdoor swing is much more variable and averages 17.8 degrees. Clearly, without auxiliary heating being supplied in the building, the temperatures are below the comfort zone a good deal of the time. While the lowest temperatures tend to occur at night, the daytime highs are above 20 degrees on only five days, above 19 degrees on eight days, and above 18 degrees on 16 days.

An hour-by-hour building energy balance for a typical day in July is presented in Table 6.3. The following observations can be made:

TABLE 6.2 BTC OFFICE SIMULATION RESULTS
HOURLY BUILDING ENERGY BALANCE - JANUARY 25

HOUR	GAINS AND LOSSES (MJ)				STORAGE (MJ)			
	COND.	INFIL.	SOLAR	INTERNAL	AIR	SLAB	INTWALL	EXWALL
1	-7.0	-2.1	0.0	0.4	1.0	11.5	21.9	10.5
2	-6.7	-0.8	0.0	0.4	0.5	10.1	19.8	10.0
3	-7.3	-0.2	0.0	0.4	2.6	10.5	20.8	10.6
4	-6.9	-1.7	0.0	0.4	2.1	10.1	20.5	10.7
5	-7.8	-3.3	0.6	0.4	6.2	12.6	25.4	12.6
6	-5.8	-1.6	4.3	0.4	1.5	10.7	21.9	10.5
7	-1.3	-1.1	8.0	0.4	-5.3	4.6	11.9	5.5
8	8.4	1.0	10.1	0.8	-9.6	-4.4	-0.6	-1.3
9	14.0	3.6	9.8	7.9	-6.9	-9.8	-8.8	-5.4
10	17.0	3.9	11.2	7.9	-4.8	-12.1	-12.5	-6.7
11	17.6	4.4	12.0	8.4	-3.7	-13.0	-15.2	-7.1
12	17.9	6.6	12.3	8.4	-3.6	-13.5	-17.2	-7.5
13	17.9	5.7	11.8	7.1	-2.6	-13.0	-17.2	-7.1
14	19.1	7.8	10.6	7.1	-2.8	-13.1	-17.9	-7.6
15	16.6	5.8	8.9	7.9	-1.5	-11.5	-17.0	-7.0
16	13.9	5.0	6.7	7.9	-0.9	-9.6	-15.3	-6.0
17	10.0	3.6	3.3	8.4	-0.1	-7.3	-12.7	-4.1
18	2.3	0.8	0.1	7.9	1.3	-3.2	-8.7	-0.7
19	-0.8	-0.2	0.0	6.1	1.8	-0.5	-5.5	0.7
20	-2.5	-0.6	0.0	5.3	3.3	2.2	-1.0	2.4
21	-5.7	-1.2	0.0	3.5	8.5	8.2	9.2	6.4
22	-7.0	-0.2	0.0	2.6	6.7	11.4	14.8	8.4
23	-7.3	-0.2	0.0	1.9	4.5	12.5	17.7	9.3
24	-6.0	-1.3	0.0	1.9	0.5	10.5	15.4	8.2

FIGURE 6.5 – SIMULATION RESULTS

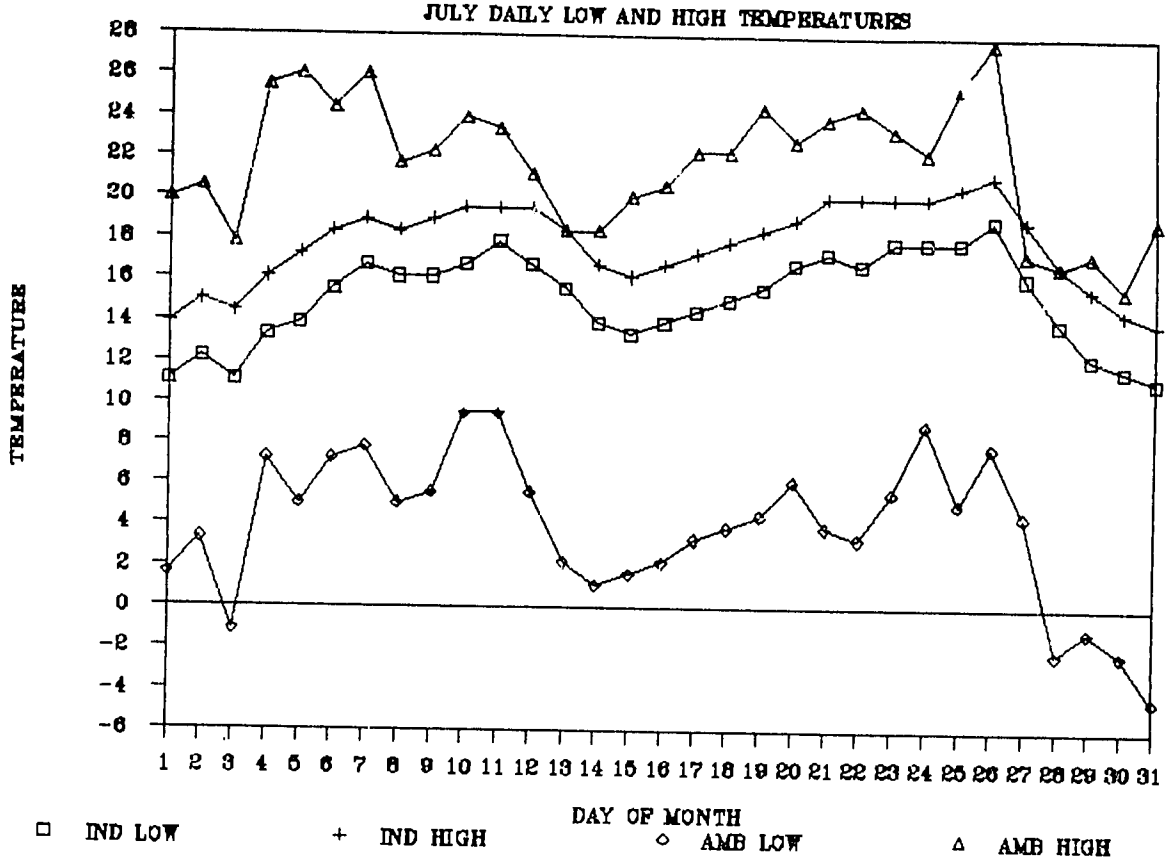


FIGURE 6.6 – SIMULATION RESULTS

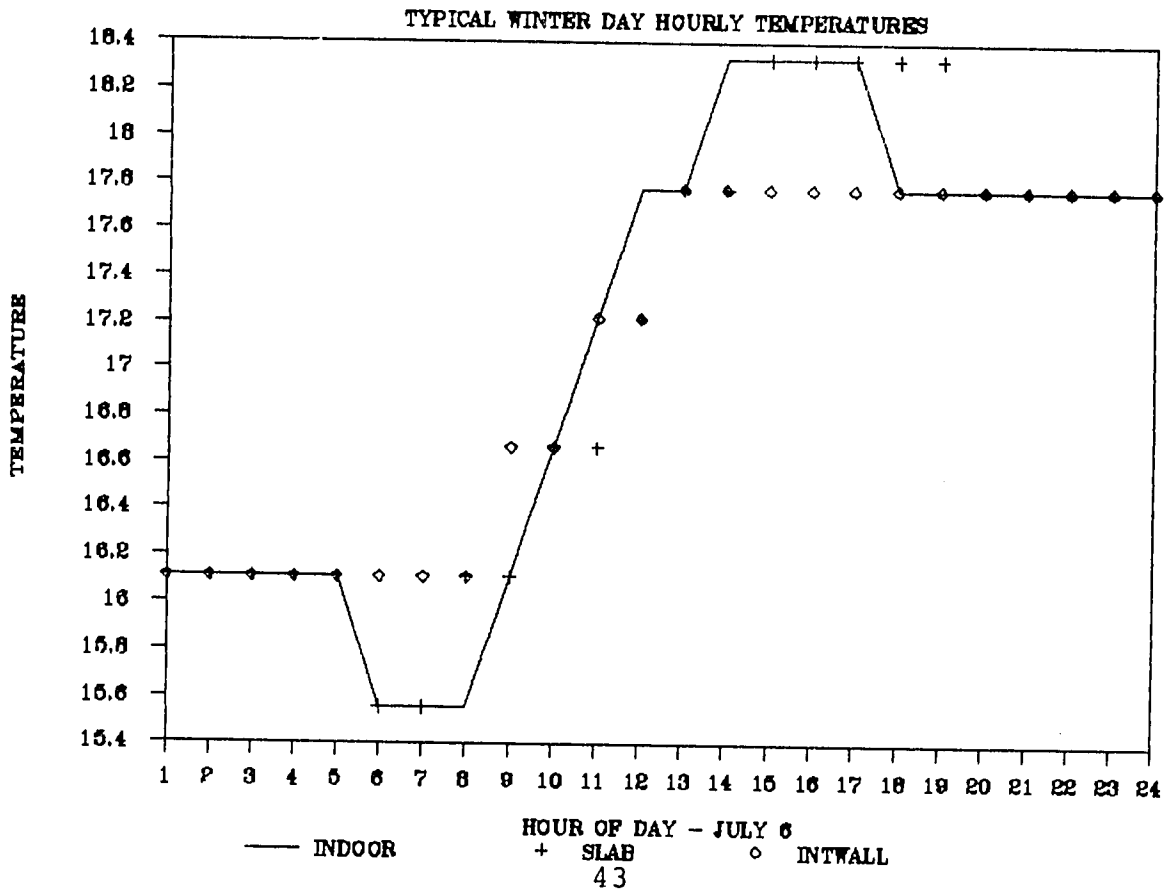


TABLE 6.3 TYPICAL JULY HOURLY ENERGY BALANCE

HOURLY BUILDING ENERGY BALANCE - JULY 18

HOUR	GAINS AND LOSSES (MJ)					STORAGE (MJ)		
	COND	INFIL	SOLAR	INTERNAL	AIR	SLAB	INTWALL	EXTWALL
1	-20.8	-8.4	0.0	0.4	2.1	8.0	9.7	6.6
2	-22.5	-3.6	0.0	0.4	0.8	7.9	9.1	6.7
3	-25.2	-4.5	0.0	0.4	1.4	8.7	9.8	7.4
4	-23.8	-10.1	0.0	0.4	2.8	8.6	11.8	7.9
5	-19.7	-8.8	0.0	0.4	1.2	6.6	11.5	6.9
6	-19.4	-8.6	0.1	0.4	1.2	6.3	11.5	6.9
7	-18.1	-8.5	2.1	0.4	1.0	5.5	10.5	5.9
8	-8.3	-1.7	17.2	0.8	-19.8	-12.2	-19.6	-10.1
9	6.6	-0.2	21.1	7.9	0.0	-15.4	-16.3	-12.3
10	12.1	-0.0	22.7	7.9	0.0	-15.0	-15.4	-13.2
11	16.3	0.8	23.7	8.4	-1.8	-15.2	-15.9	-14.3
12	15.8	0.7	23.0	8.4	-1.7	-13.7	-15.8	-13.9
13	15.6	0.9	21.5	7.1	-2.0	-12.5	-15.2	-13.3
14	14.4	0.7	19.0	7.1	-1.3	-11.1	-14.1	-12.6
15	12.0	1.1	14.4	7.9	-1.1	-9.4	-12.4	-11.1
16	3.8	-0.1	6.1	7.9	0.5	-5.4	-7.5	-5.6
17	-7.5	-3.1	0.0	8.4	2.5	0.4	-2.3	0.4
18	-11.1	-4.3	0.0	7.9	2.1	2.9	-0.1	1.8
19	-18.3	-5.2	0.0	6.1	2.2	6.7	2.7	4.2
20	-18.1	-2.3	0.0	5.3	0.8	6.3	3.0	4.2
21	-16.1	-1.9	0.0	3.5	0.4	5.3	3.6	4.0
22	-17.8	-2.3	0.0	2.6	1.1	5.9	4.6	4.6
23	-19.4	-4.7	0.0	1.9	1.8	6.9	6.3	5.5
24	-19.1	-5.5	0.0	1.9	1.6	6.8	7.2	5.7

- Like summer, the conduction heat gains to the building are substantial during the day. However, these are more than offset by conductive heat losses at night.

- The hourly solar gains to the building are substantially greater than they were in summer, but are still not very high, being of similar magnitude to the conductive gains during the daytime hours.

- While the summer storage of heat was largely in the slab and interior walls, in winter all three mass locations (interior walls, exterior walls and slab) store significant amounts of heat from the day and release it slowly over the night.

Figure 6.6 shows the predicted air temperature for a single winter day, together with the concurrent average surface temperatures of the slab and interior masonry walls. This shows a very close thermal "coupling" between the interior temperature and the mass, with almost no time lag between the two. It can also be seen that the slab surface temperature experiences the same temperature swing as the indoor temperature, while the interior walls have a diurnal swing of about one degree less.

6.4 Performance of the BTC Office Building Compared to a Conventional Office

The comparison made uses the model described above with the inputs modified to describe an "equivalent" conventional office building. The operational and occupany assumptions for this building are the same as for the "as-built" BTC office building, so that performance truly indicates how a most-likely alternative building would perform under the same conditions of weather and occupancy. The inputs changed to reflect the equivalent conventional building are:

1. The walls are assumed to be 230mm brick with no insulation.

2. Ceiling insulation is assumed to be 38mm instead of 150mm.

3. A flat roof of unpainted galvanized steel sheeting is assumed, with no glazing openings and 600mm eaves on all sides.

4. No weatherstripping, and air bricks above each window (or perma-vents) are assumed, resulting in an infiltration rate of .0675 air changes per hour per degree of inside-outside temperature difference plus .504 air changes per hour per metre/second wind speed. This results in an average infiltration rate in summer of .72 air changes per hour and in winter of .81 air changes per hour.

5. Electric lighting energy use is assumed to be twice as

much, on an average daily basis. This results in an increase in internal gains of 6.6 kWh/day (and a corresponding increase in electrical consumption of 6.6 kWh/day).

6. Orientation of the building is assumed to be random. A 45-degree-clockwise rotation of the building was selected, relative to the as-built BTC office. This is neither the most favorable or unfavorable orientation of the building with respect to the sun, and is assumed to reasonably reflect "average" orientation of conventional buildings.

All other inputs for the conventional building are the same as for the as-built BTC office building.

Floating Temperature Comparison

A "floating-temperature" comparison of the two buildings compares the temperatures which would occur in each of the two buildings under the same weather conditions and without any auxiliary mechanical heating or cooling. Figure 6.7 presents a month-by-month comparison of the average indoor temperatures for both the "as-built" BTC office building and the "reference" conventional building. As expected, the temperatures in the reference building are colder in winter and warmer in summer. This is elaborated on in Figure 6.8, where the average low and high indoor temperatures for each month are compared.

In Figure 6.9 a floating-temperature comparison for each day of the summer month of January is presented. As can be seen, the as-built building is significantly cooler than the reference building at almost all times. The daily maximum temperature of the as-built office averages over two degrees cooler than the reference building, and the nightly low averages 1.7 degrees cooler. On the hottest day inside either design, when the ambient temperature is over 34 degrees, the reference building maximum indoor temperature is 31.1 while the as-built design was 2.8 degress cooler at 28.3 degrees.

Figure 6.10 compares the temperatures of the two designs on a typical summer day. It can be seen that the as-built design is substantially cooler than the reference design at all times and particularly during the late afternoon when the hottest conditions occur.

A different pattern is found when the winter floating-temperature comparison is made. Figure 6.11 presents this comparison for the month of July, as expressed through daily minimum and maximum temperatures. Here, the differences in performance between the two designs are not nearly so clear as they are for summer. On many days, the temperatures between the two designs are quite similar. While the as-built design never has a daily low temperature lower than the reference design, it does not always have a daily high which is greater than the reference. This is

FIGURE 6.7 – SIMULATION RESULTS

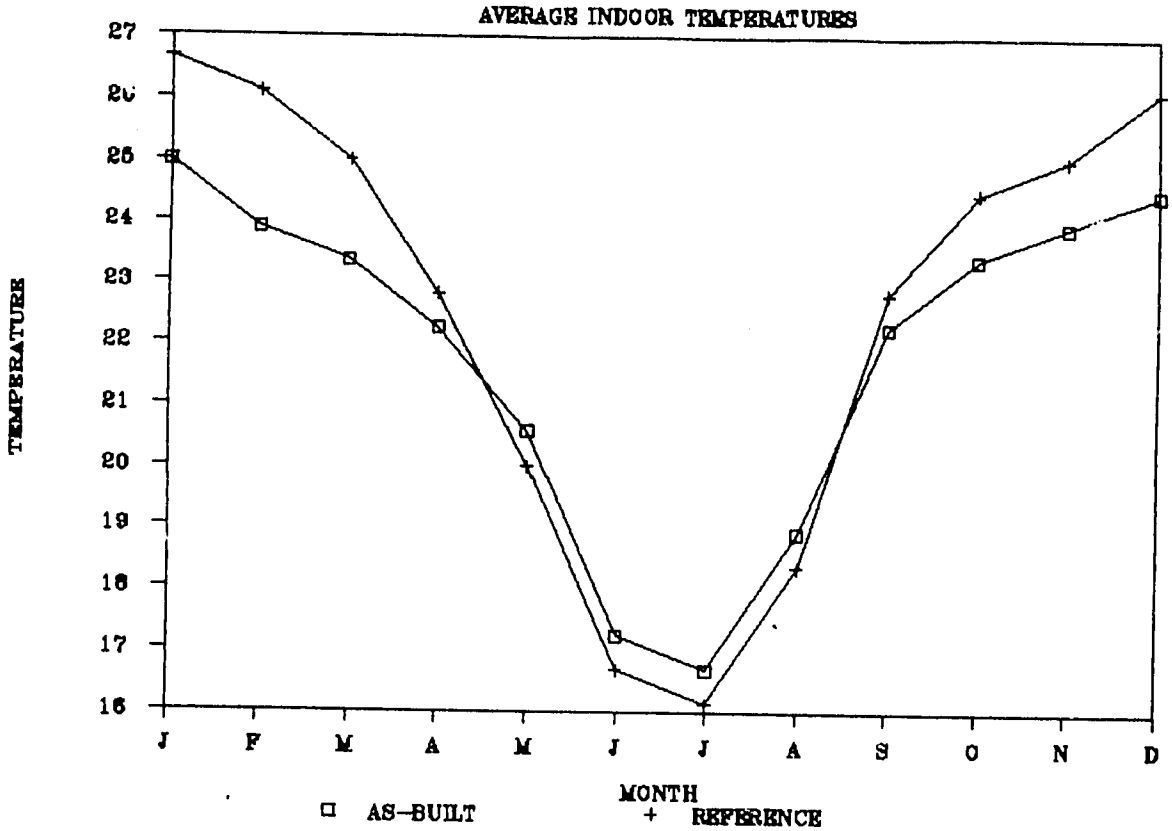


FIGURE 6.8 – SIMULATION RESULTS

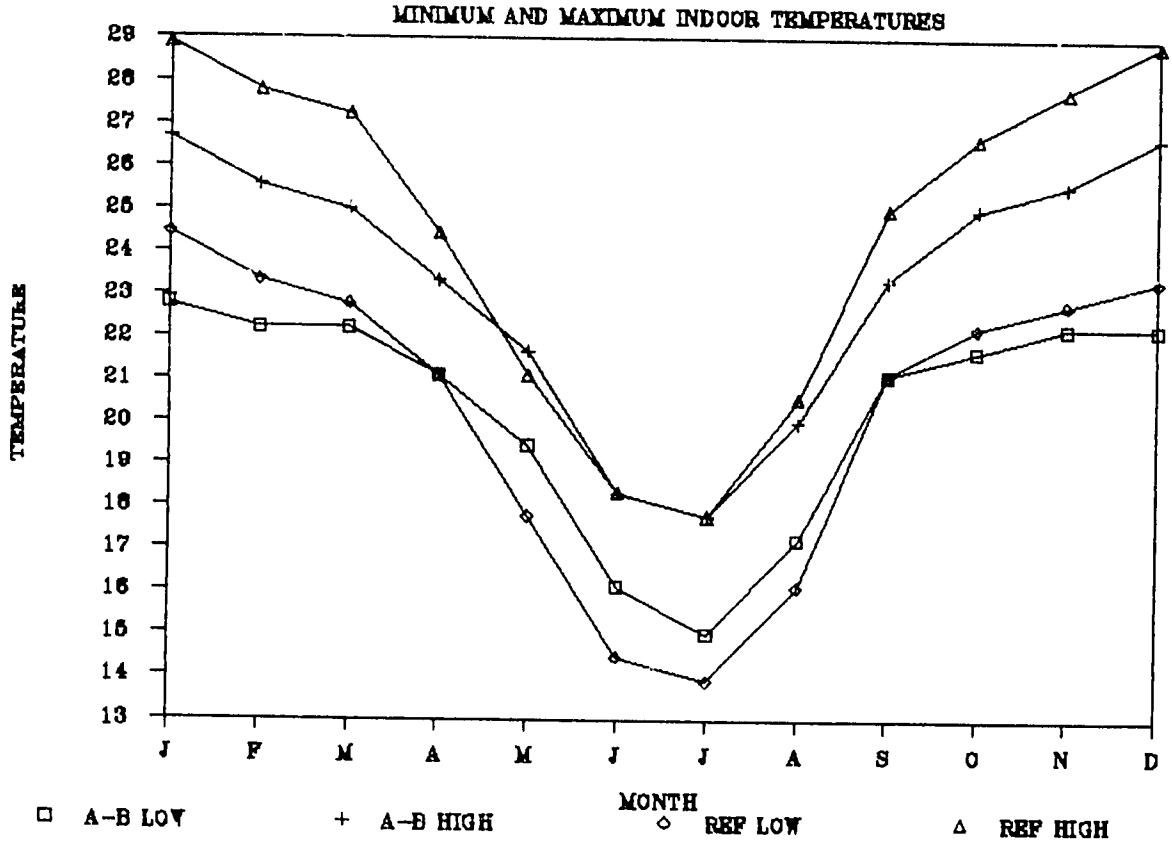


FIGURE 6.9 – SIMULATION RESULTS

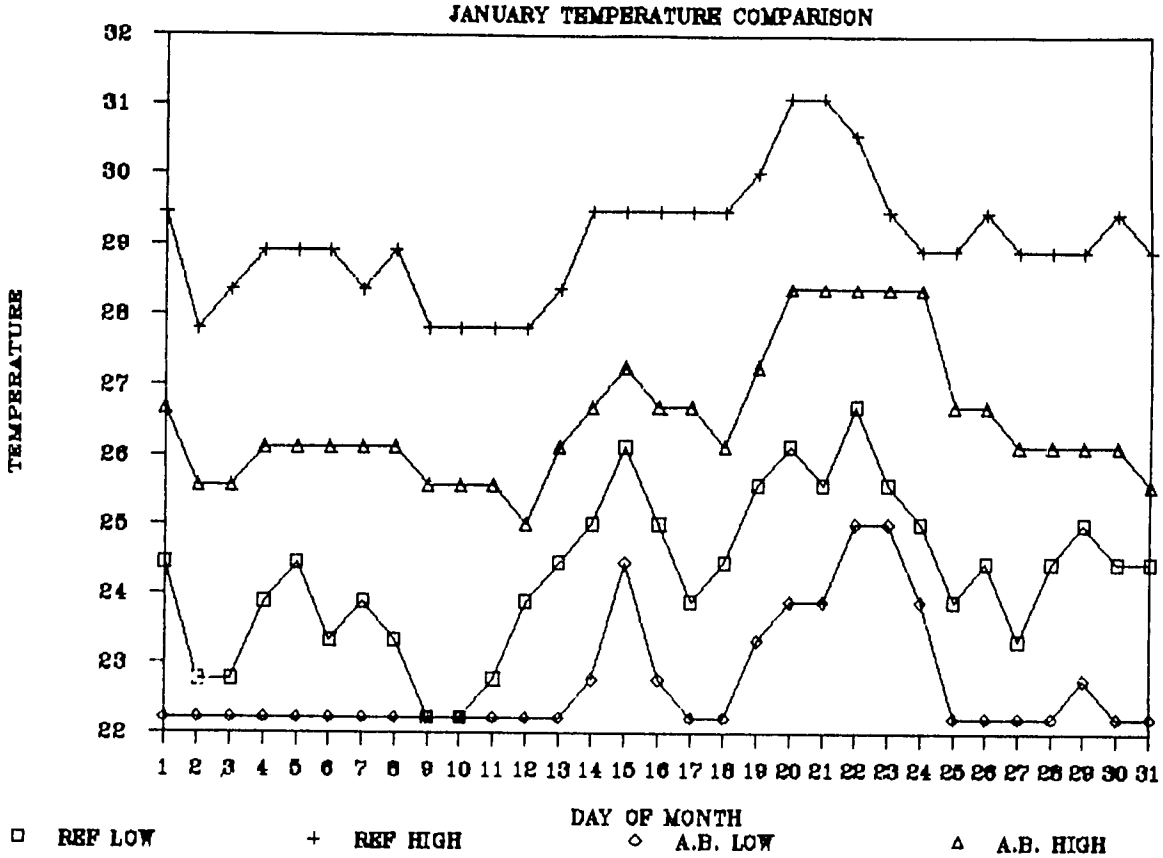


FIGURE 6.10 – SIMULATION RESULTS

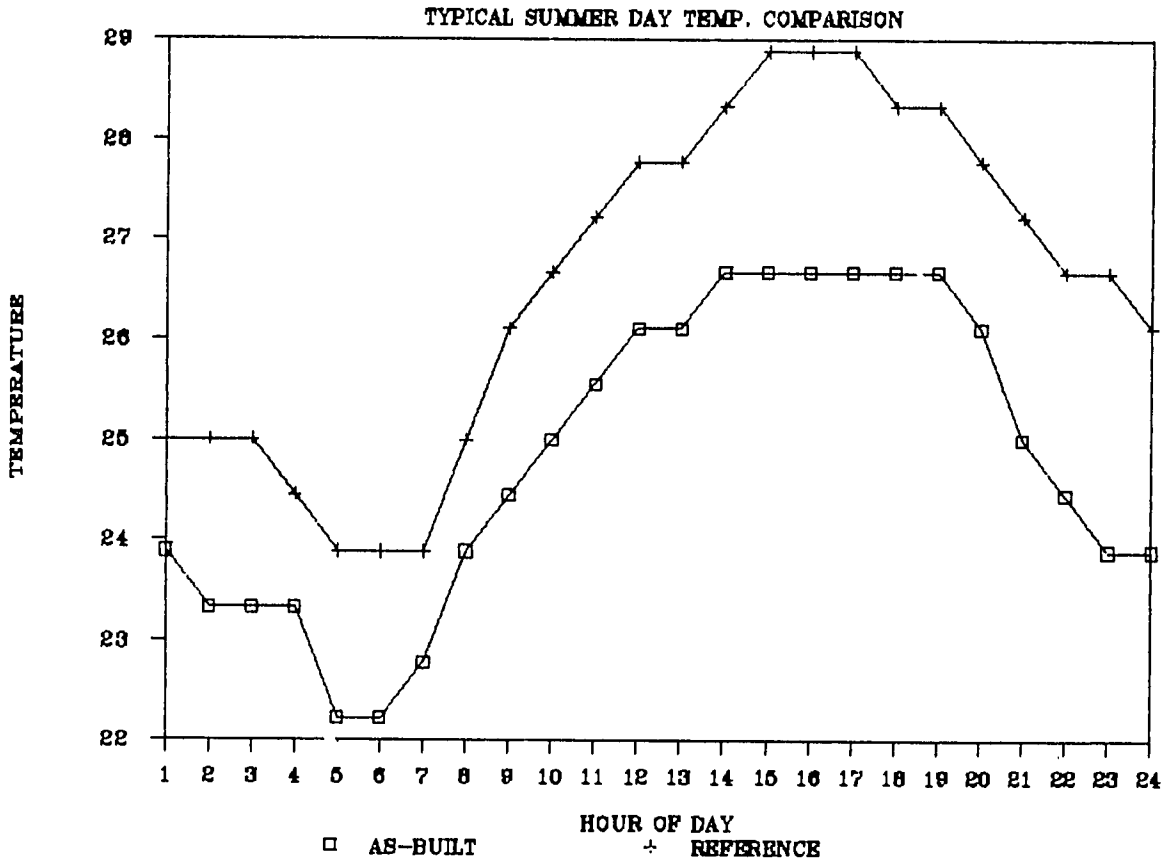


FIGURE 6.11 – SIMULATION RESULTS

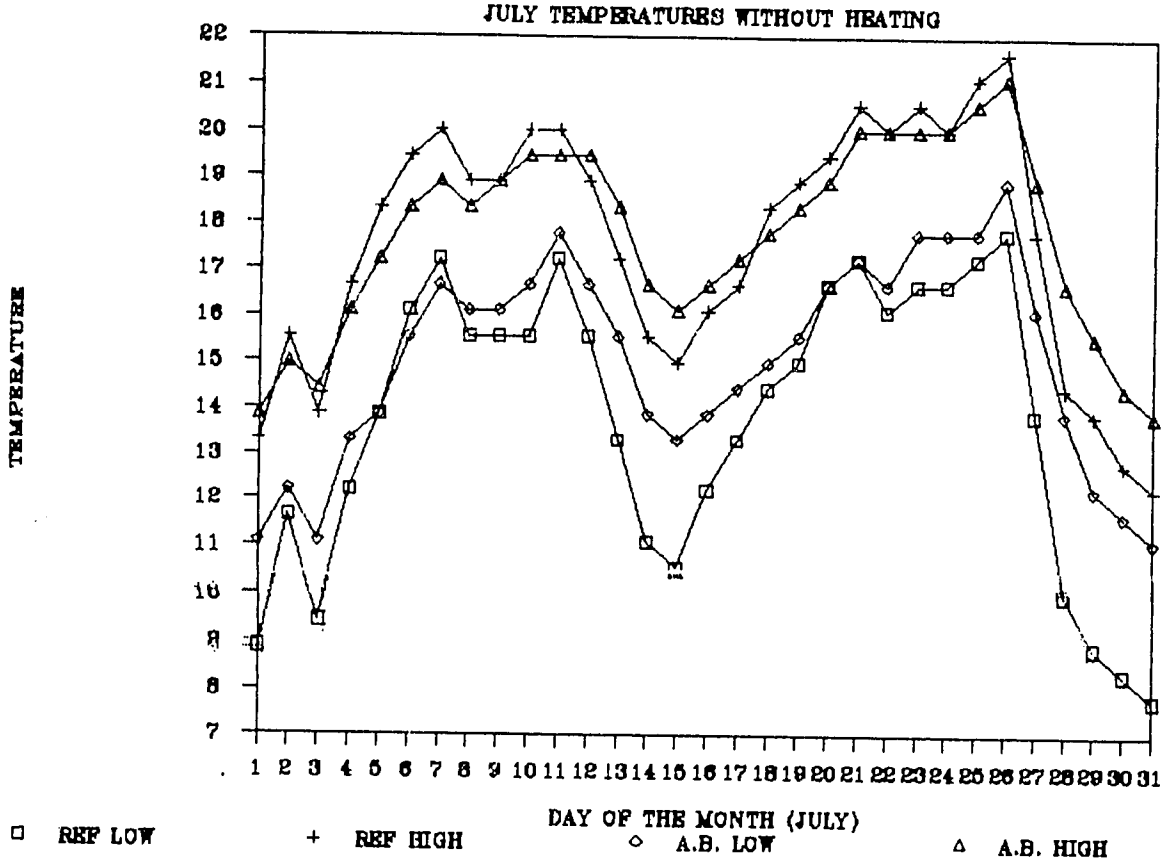
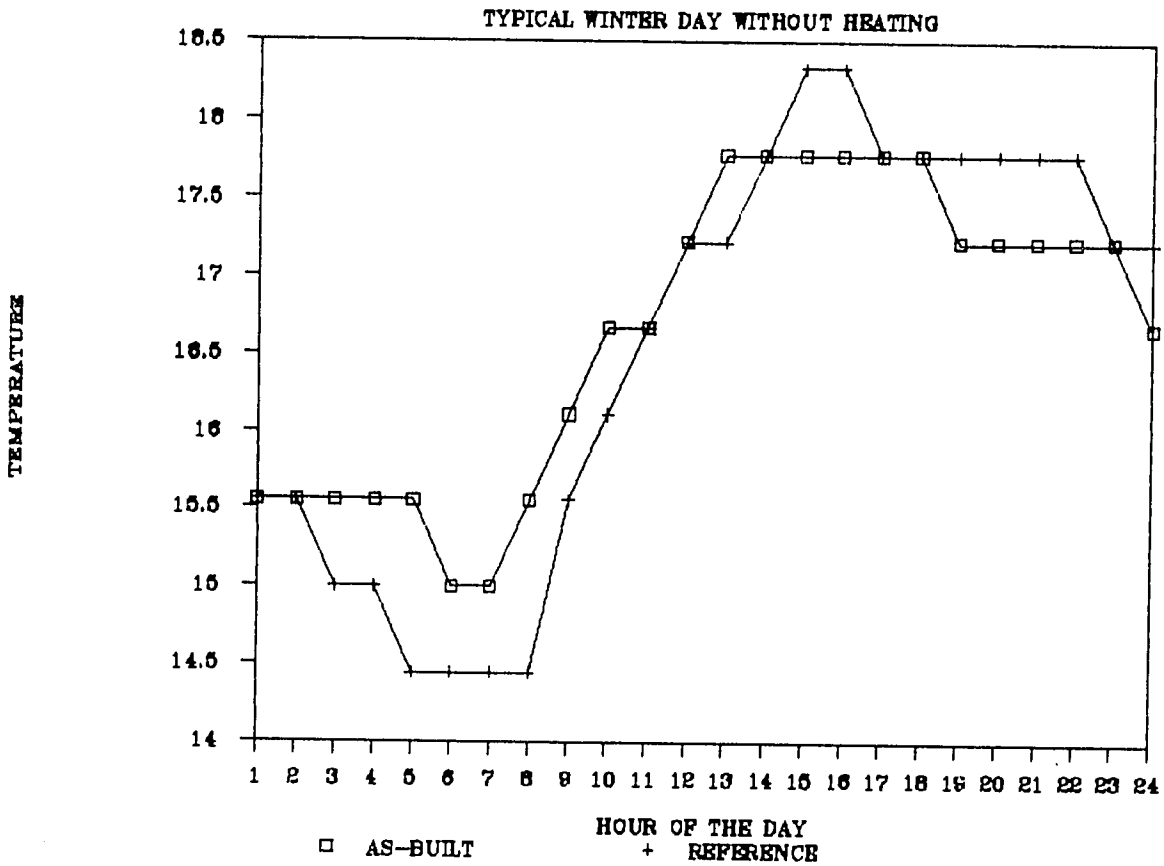


FIGURE 6.12 – SIMULATION RESULTS



illustrated further by examining a graph of hour-by-hour temperatures for a typical July day, presented in Figure 6.12. On such a day, it is clear that there is not too much difference between the two designs in terms of indoor temperatures. What is seen here is probably explained by the fact that the reference design receives substantial heat gains from solar radiation. Because it has a solid brick north wall of moderately high solar absorptivity, it actually gets more conductive heat gain through the wall than the insulated wall of the as-built design. Similarly, as heat builds up in the attic space during the day, from the sun striking the roof, the reference design gains more heat than the as-built design because it has less ceiling insulation. On an average winter day, these increased daytime gains into the reference building tend to compensate for its greater night heat losses.

On the other hand, on the half of the days in winter which are colder than average, the as-built design is clearly superior. This is illustrated in Figure 6.13 which presents simulation results on an hour-by-hour basis for the coldest day of July. On this day, when the ambient temperature falls to two degrees below zero just before sunrise, the reference design would be at 12.7 degrees when people come in for work, while the as-built design would be 2.3 degrees warmer at 15 degrees.

Obviously, some of these cold temperatures are unacceptable for an office, under either design. To obtain warmer temperatures on most winter mornings, some amount of heating is required for any building design in Botswana. For some buildings, it is also desired to maintain slightly cooler summer temperatures than can be achieved naturally through the use of mechanical air conditioning. In such cases, the advantages of one thermal design over another can be examined by determining their relative energy requirements to maintain selected temperature set points. An analysis which compares the relative requirements of these two building designs from this perspective follows below.

Heating and Cooling Load Comparison

Following the simulation of the as-built and reference building designs with floating indoor temperatures, further simulations were conducted with heating and/or cooling set points to maintain comfort conditions within certain limits. In this case, the relative performance of the two designs is not indicated by temperatures (they will be about the same), but rather by the magnitude of the predicted heating and cooling loads.

A heating set point of 20 degrees was selected for these simulations. This is the value both suggested by the building occupants as a minimum desired winter temperature and the value suggested by the Department of Electrical Engineering as a minimum for heated office space. Figure 6.14 presents the resultant monthly heating loads of both the as-built BTC office building and the conventional reference design. As can be seen,

FIGURE 6.13 – SIMULATION RESULTS

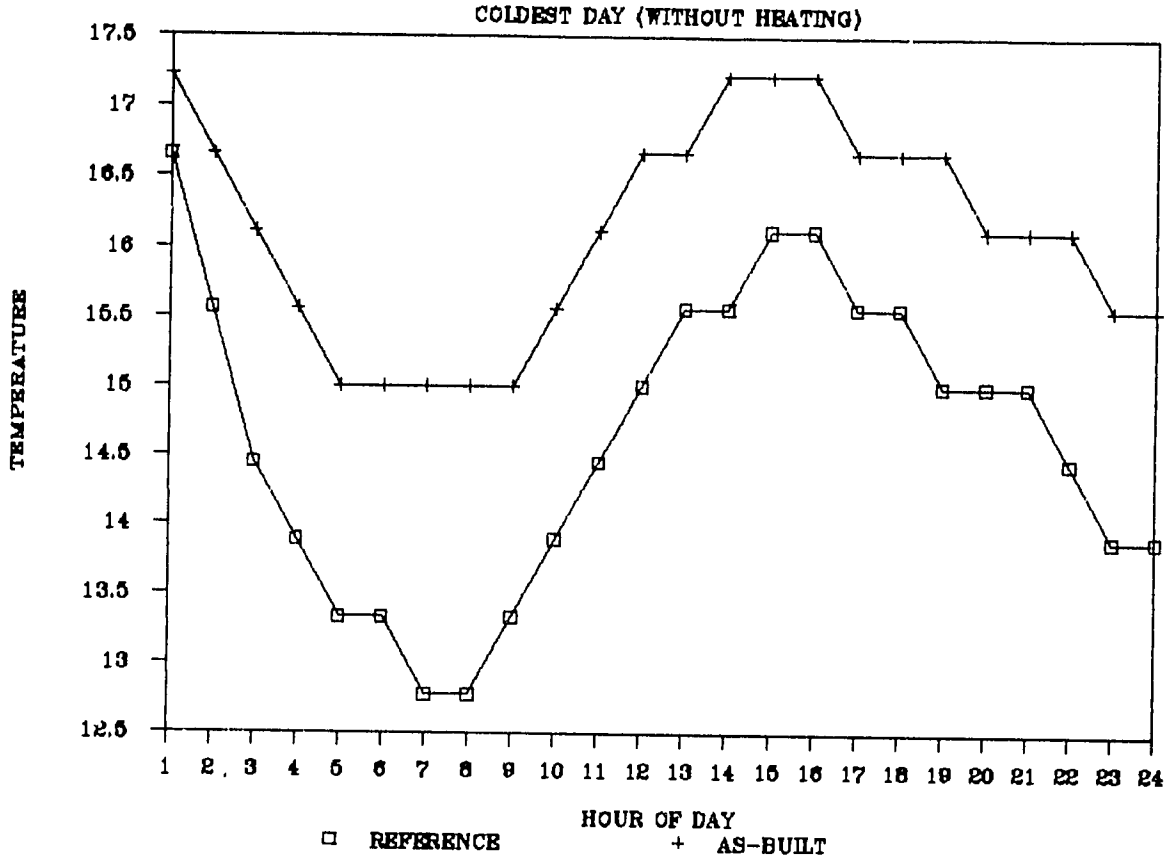
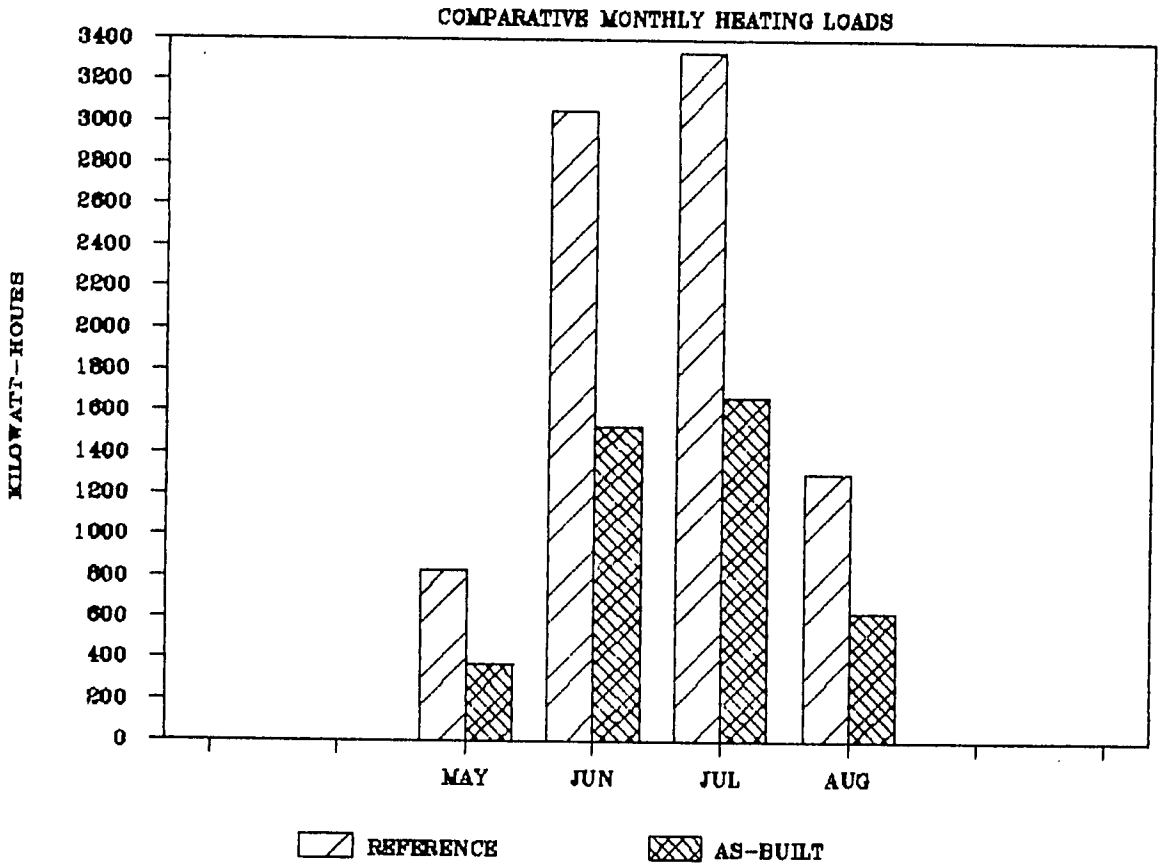


FIGURE 6.14 – SIMULATION RESULTS



the as-built design has a heating load of about half the load of the reference design for all four months of the winter.

The determination of a cooling set point is much more difficult. While the Department of Electrical Engineering recommends an upper design limit of 24 degrees for fully air-conditioned buildings in Botswana, they have also noted that temperatures above this value are, in general, more accepted by institutional staff than temperatures below 20 degrees in the winter. This is confirmed by the occupant evaluation of the BTC facility described earlier in this report. It is also reflected in the substantial number of existing institutional buildings in Botswana which are provided with mechanical heating, but not cooling. Still, there is no question that there is a value attached to being able to keep the temperature cool in summer, and that a calculated cooling "load" is a reasonable index of the magnitude and duration of discomfort that would occur in a building even if it were not air conditioned. For this reason, the building designs were simulated with a cooling set point, but to somewhat adjust for the perceived greater value of heating than cooling, the set point of 25 degrees was selected.

Figure 6.15 presents the comparative cooling loads by month, for the as-built and reference building designs, to maintain indoor temperatures below 25 degrees. It can be seen that the as-built design compares even more favorably to the reference design in summer than in winter, with cooling loads of the as-built never as high as one-third those of the reference.

Figure 6.16 summarizes the previous load calculations with an annual comparison of heating and cooling loads. It should be noted that these values are heating and cooling thermal loads, not energy requirements (i.e., air conditioning with a coefficient of performance of 2.0 would have an input electrical requirement of only half the values given in the chart). In tabular form these values are presented in Table 6.4.

Table 6.4. Comparison of Annual Heating and Cooling Loads for As-Built BTC Office Building and Equivalent Conventional Building.

	Conventional Reference Building	BTC Office Building As-Built	Savings
Cooling Load (kWh)	18355	4211	14144 (77%)
Heating Load (kWh)	8523	4210	4313 (51%)
Total (kWh)	26878	8421	18457 (69%)

FIGURE 6.15 – SIMULATION RESULTS

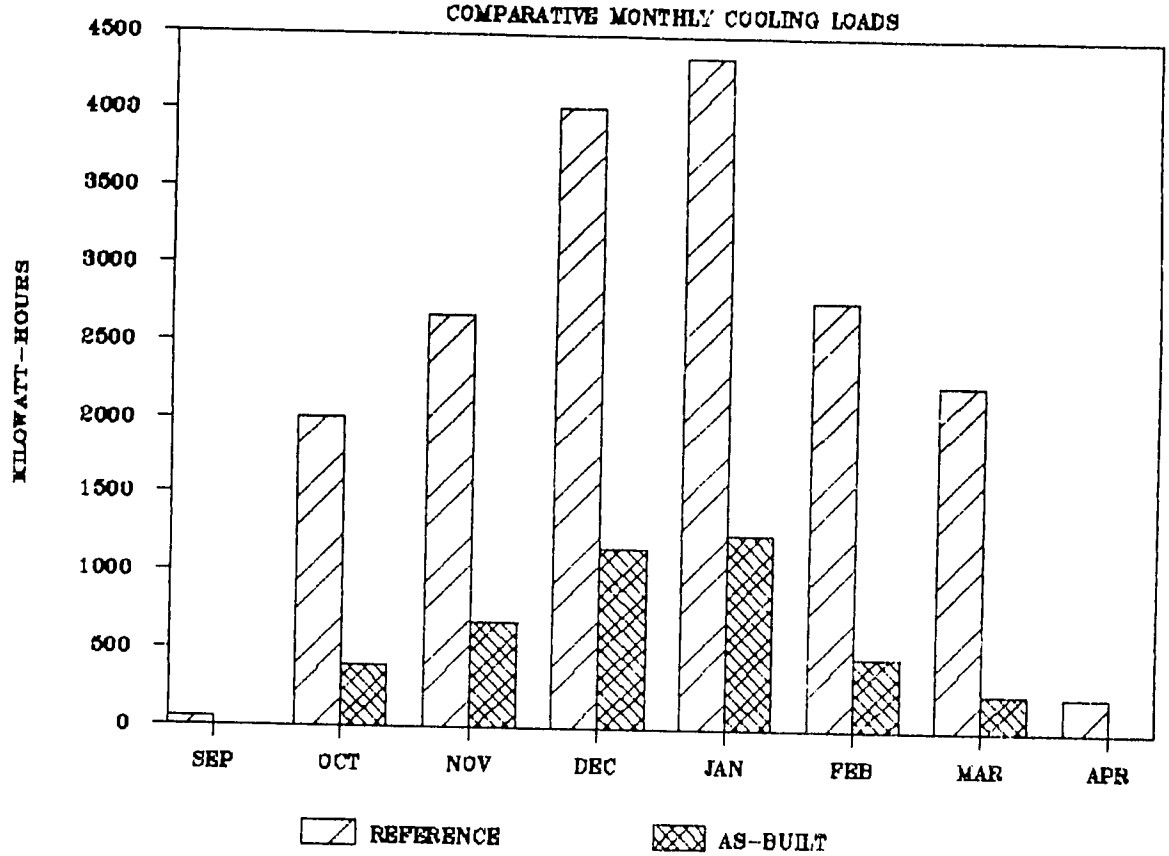
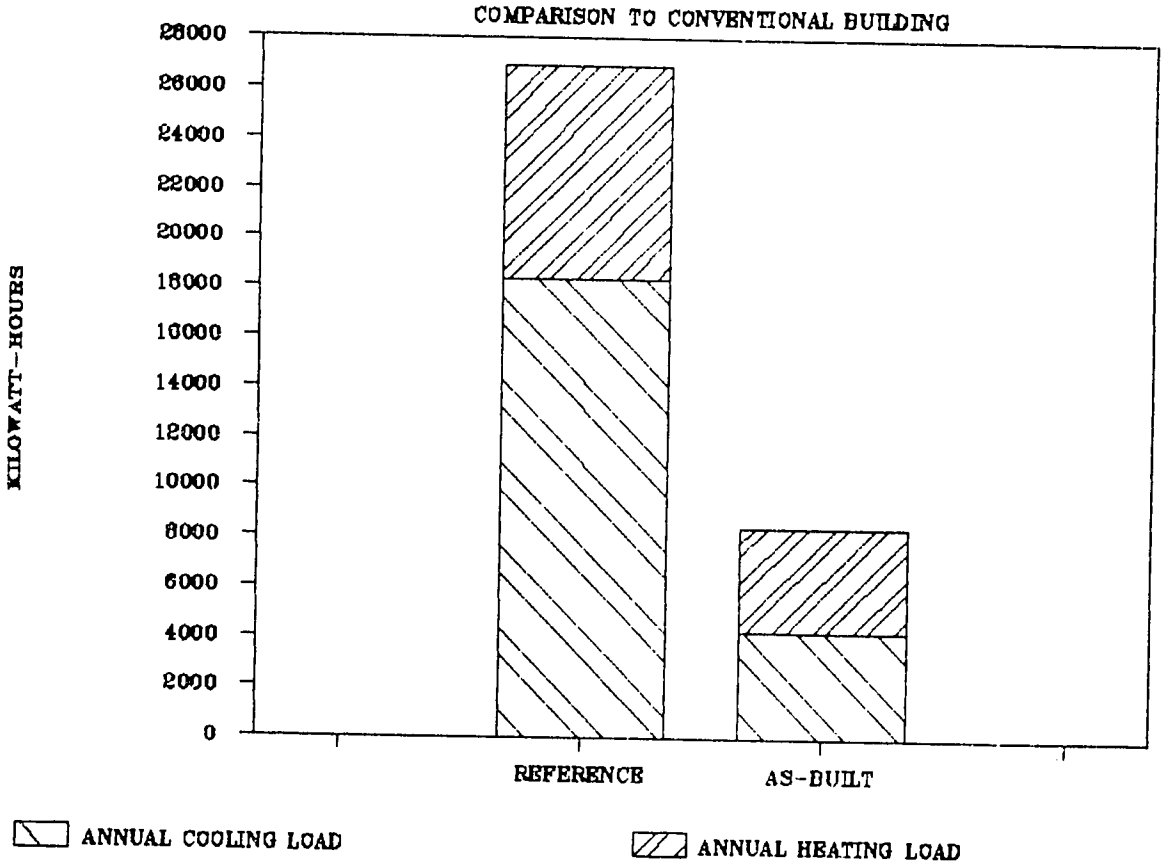


FIGURE 6.16 – SIMULATION RESULTS



6.5 Component Evaluation

In order to recommend energy design strategies for future buildings, based on this experience, it is useful to evaluate individual components of the BTC office building energy design. The key elements of this energy design, taken from the documentation of the building designers, are:

1. Choice of building form and orientation so that the largest areas of wall and roof are oriented directly toward the north and south.

2. Reduction of uncontrolled air infiltration by not using the usual air bricks or any other permanent ventilation devices, as well as installation of weatherstripping on all operable windows.

3. Installation of more than the usual amount of ceiling insulation.

4. Installation of insulation on the exterior of the walls.

5. Use of a system of louvre shades for the low windows in the north, west and east walls.

6. Use of a high-pitch ventilated roof to keep the space between the roof and ceiling cool.

7. Use of a glazed "monitor" along the ridge of the roof for daylighting and ventilation.

8. Use of glazed office doors, operable vents over these doors, and an open-plan central office area for improved daylight and ventilation distribution.

As with the comparative evaluation of the as-built structure to a conventional reference building, the easiest (and only practical) way to isolate the performance of these individual components is through thermal modelling. Accordingly, additional CALPAS3 simulations of the conventional reference building were conducted with individual components added to the building, one at a time. The last three of the above options were not modelled in this manner, for the following reasons:

- The ventilated roof (#6 above) was not modelled because of limitations in the model and the high uncertainty in the ventilation effectiveness values which should be used. This was not seen to be critical, however, since the analysis which was conducted indicates that the roof colour and roof space ventilation (1) have little effect given the high level of ceiling insulation, and (2) these design elements have an adverse effect on building heating in the winter which generally offsets the cooling benefit in summer in terms of net annual benefit.

- The glazed roof "monitor" (#7 above) was not modelled as an isolated thermal component due to both limitations in the model and the fact (discussed previously) that it appears to have had a very limited impact on heating and cooling of the overall building (most of the summer solar heat gain to this space is not transferred down to the rest of the building and the heat exchanges between this space and the main area below in winter are very small). It was not modelled from a daylighting perspective due to a lack of time and resources in this evaluation. It is assumed that the roof monitor clearly provides substantial daylighting into the core of the building, and that this reduces electrical lighting requirements appreciably.

- The open interior design of the building (#8 above) was modelled in terms of increased ventilation "effectiveness," but not from a daylighting perspective, again due to the limited time and resources for this effort which necessitated limiting quantitative evaluation to the thermal performance of the building design.

Table 6.5 presents the resultant annual heating and cooling loads from these simulations indicating the relative thermal impact on the reference building that would result from each of these improvements. The specific cases modelled are as follows:

REF — The conventional reference office building described earlier.

ORIENT — The reference building, but rotated so that it has the favorable orientation of the as-built BTC office.

SHADE — The reference building with the addition of the louvre shading system as built into the BTC office building.

CINSUL — The reference building, but with the ceiling insulation thickness increased from 38mm to the 150mm found in the as-built BTC office.

WINSUL — The reference building, but with the insulated wall construction found in the as-built BTC office instead of 230mm solid brick walls.

WSTRP — The reference building, but with weatherstripping added to doors and windows as in the as-built BTC office.

INFILT — The reference building, but without air bricks or other intentional, uncontrolled infiltration.

VENT — The reference building, but with the ventilation cooling openings and ventilation effectiveness of the as-built BTC office.

PAINT — The reference building with the north wall painted dark (absorptivity = .88) and the other walls painted white (absorptivity = .3). While this was not a measure

Table 6.5

Load Impacts of Individual Component Improvements to Reference Building

	ANNUAL CONSUMPTION (kWh)				SAVINGS (kWh)			
	Cooling	Heating	Lighting	Total	Cooling	Heating	Lighting	Total
Ref	18356	8524	4818	31698	0	0	0	0
Shade	17013	8997	4818	30828	1343	-473	0	870
Paint	16988	8787	4818	30593	1367	-263	0	1104
Orient	16592	8258	4818	29668	1764	266	0	2030
CInsul	16490	8179	4818	29488	1865	345	0	2210
Vent	15650	8541	4818	29009	2706	-17	0	2689
Rapert	18924	7520	2408	28852	-568	1004	2410	2846
Wstrp	16895	6448	4818	28161	1461	2076	0	3537
Infilt	16164	5409	4818	26391	2192	3115	0	5307
WInsul	13335	8205	4818	26358	5021	319	0	5340

implemented in the BTC office, as built, it has been used in many other BRET-associated designs and is therefore included in this analysis to extend the usefulness of the results.

RAPERT The reference building, but with a roof aperture in the form of a north-facing clerestory at the ridge of a low-pitched roof. This also does not reflect the design of the as-built BTC office, but instead substitutes a somewhat more conventional roof and clerestory with a glazing area equal to the sum of the north- and south-facing glazing of the as-built roof. In this case, all the solar heat gains are assumed to be directly into the office area and utilizabile for meeting the heating requirements of the building.

In looking at Table 6.5 it is not immediately clear which of the components presented has the most value. Very often, a savings in heating load is offset by an increase in cooling load, or vice-versa. A closer examination is useful, and is more easily performed by looking only at the energy "savings" which result from each of these measures, both in cooling and heating.

Figure 6.17 presents the cooling load savings which were predicted for each of the design improvements, in decreasing order of magnitude. Obviously the single measure which makes the biggest difference on the cooling load of the reference building is the addition of wall insulation. While this affects the substantial conductive heat gain through all the walls which occurs on summer days, it is particularly associated with the gain through the northeast wall of the reference building, which receives a great deal of solar heat gain in the early morning due to the unfavorable orientation of the building. The high savings here are also related to the medium colour of the outside of the building, again leading to solar heat gain. If the building were better oriented and/or painted a lighter colour, the savings would not be as great.

The measure which makes the next largest difference in cooling load is improvement of the ventilation design of the building. This results in being able to cool down the building more at night, so that the cooling load on the following day is reduced. This is followed by the elimination of permanent ventilation openings, which allow hot air to enter the building during summer days when it is cooler inside than outside.

Each of the other measures yields an improvement in the cooling performance of the building except for the addition of the roof aperture, which actually increases the cooling load by a small amount, due to increased solar gains, and is accordingly displayed as a negative value in the graph of savings.

Figure 6.18 displays a similar breakdown of savings by individual design improvement but, in this case, for the heating season. The two measures which make the biggest difference here are the

FIGURE 6.17 – SIMULATION RESULTS

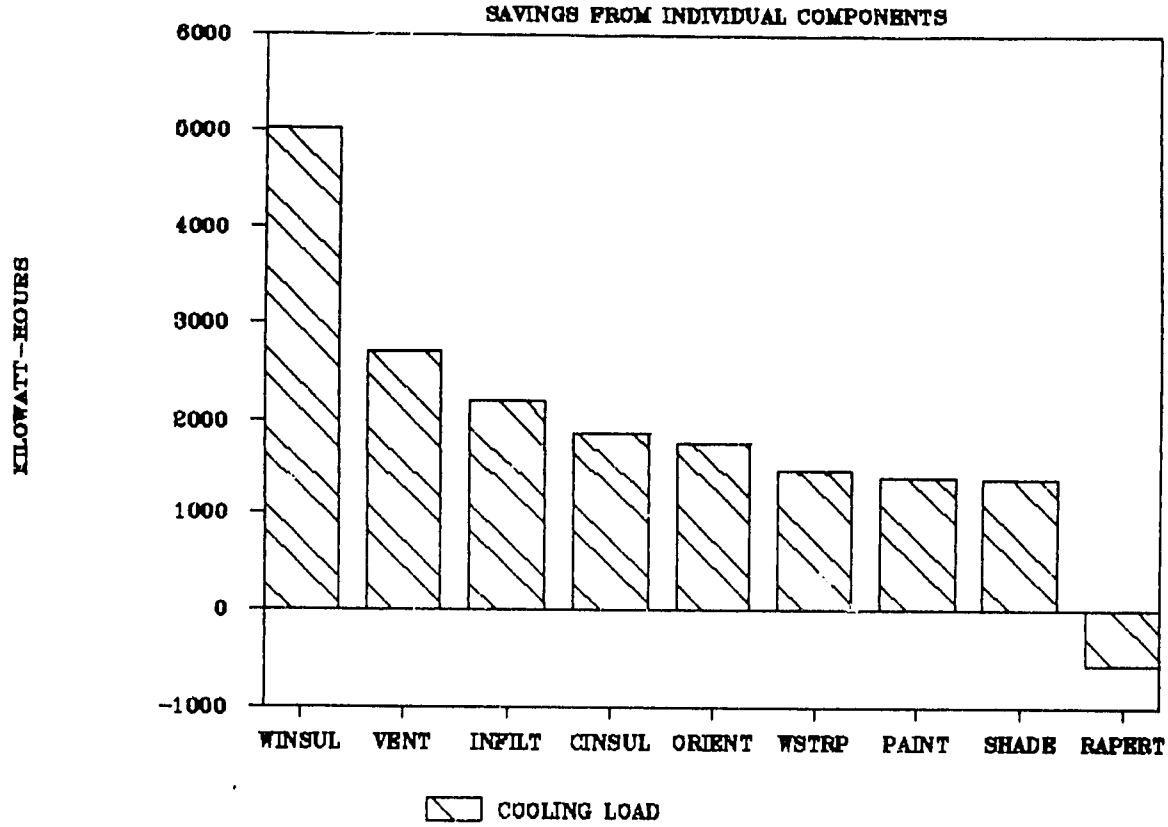
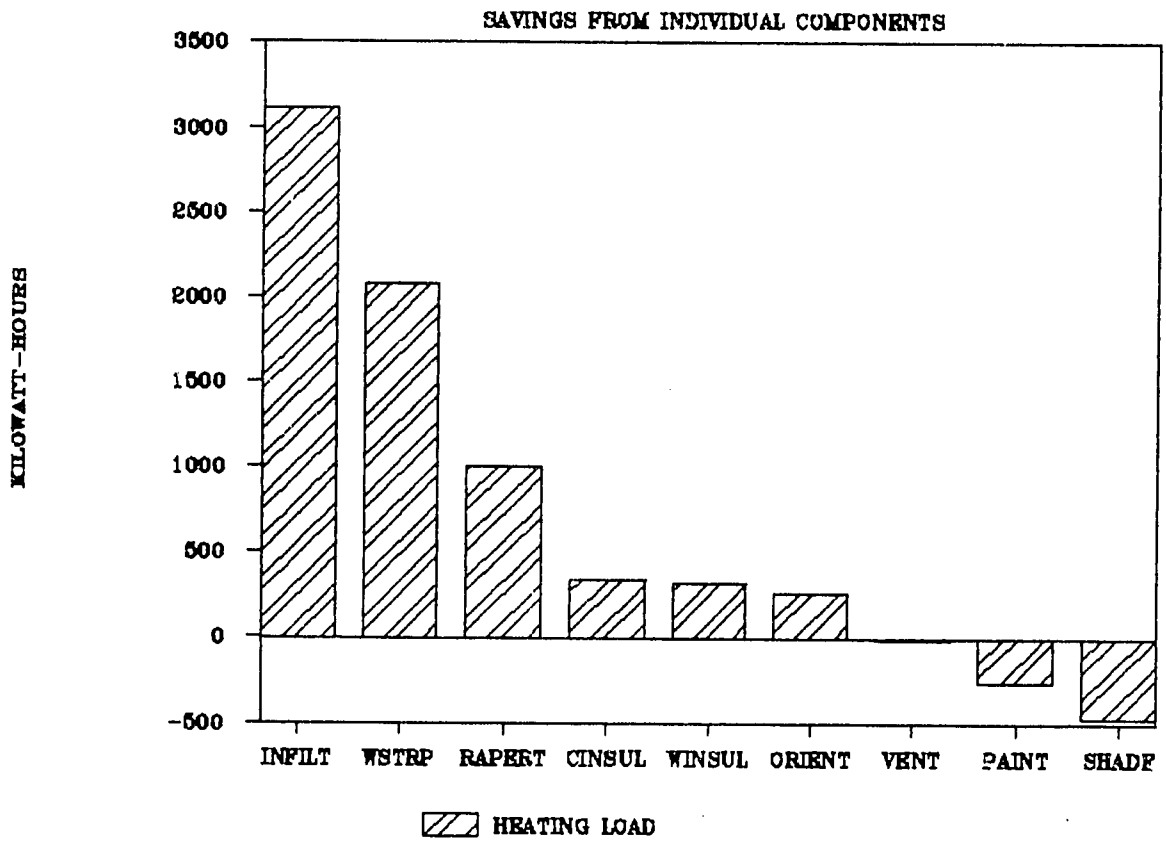


FIGURE 6.18 – SIMULATION RESULTS



two associated with reducing uncontrolled air leakage in and out of the building. While many other measures are important only during the day or night, reducing air leakage has a direct effect on heating loads whenever it is cooler outside than inside.

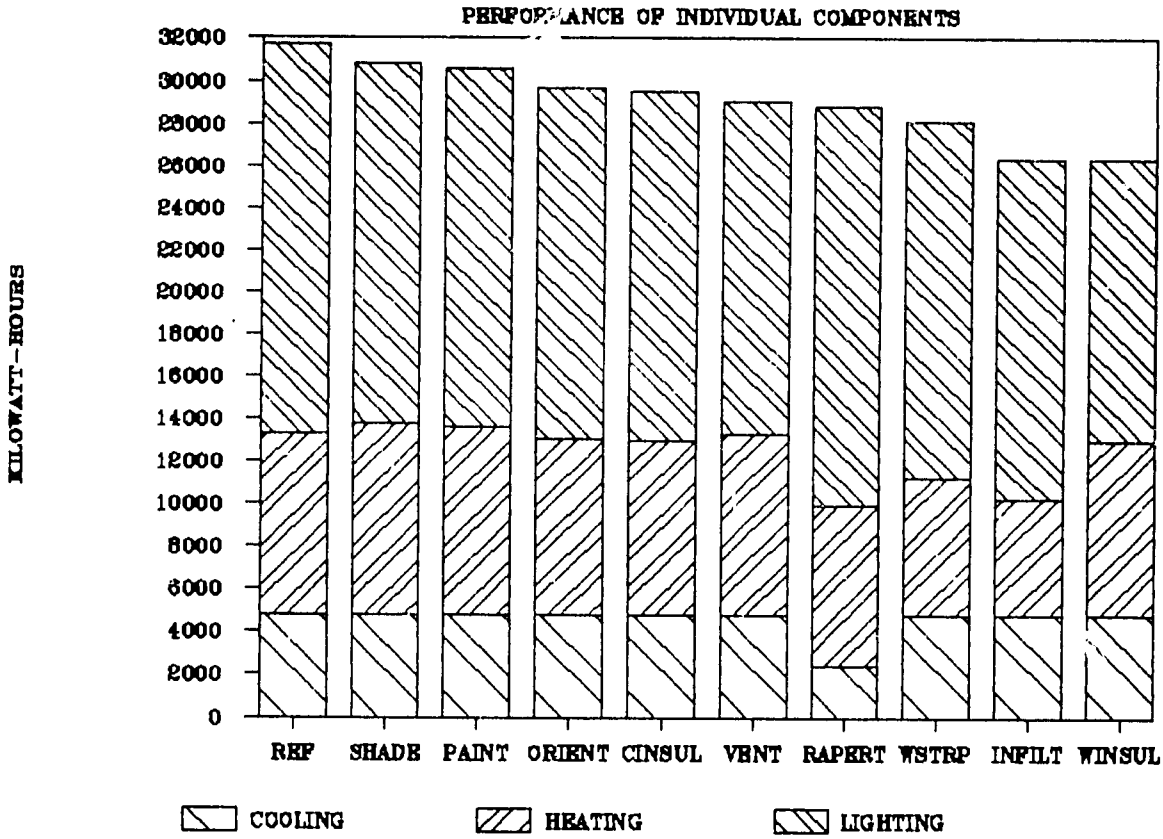
The next most effective single measure to reduce heating loads is the addition of the roof aperture. This increases substantially the winter day solar heat gain to the building.

The remaining measures have a small impact on heating loads, either positive or negative. It is worth noting that both of the insulation measures have a negligible impact on heating loads. This is due to the fact that, on the average, the building experiences a conductive heat gain during the daytime hours and loses heat primarily at night. Accordingly, while the insulation helps to keep the building warmer at night, it actually increases the heating load during the day. While the net effect is slightly positive, the night benefits of the insulation are mostly cancelled out by the daytime performance in winter, particularly for a building like this which is occupied only during the day.

Because the ranking of these measures is different for heating and cooling, the overall value of each measure will depend on the importance attached to heating impacts relative to cooling impacts. If heating improvement is the primary goal, then air leakage reduction and increased solar aperture will be the most important. If cooling is more important, then wall insulation and ventilation improvement would take priority. To the extent that both heating and cooling improvements are desired, the trade-offs between the two must be considered. For example, the roof aperture is a benefit in winter and a detriment in summer. The use of the heating and cooling set points used in this analysis means that if the load predictions for heating and cooling are added together, it is attributing the same value to keeping the temperature below 25 degrees as to keeping it above 20 degrees. While this is only one possible allocation of importance between cooling and heating, it is a reasonable one and provides a total annual performance value for each measure and an overall ranking of them.

Figure 6.19 presents the annual loads of all the design improvements compared to the reference building. Wall insulation yields the greatest savings, despite the fact that it achieves little heating savings. The measures to reduce air leakage are the next most important, because they reduce both heating and cooling loads. The roof aperture follows, then the improvement of ventilation effectiveness. The other measures follow, but their precise ranking must not be taken as the order in which design improvements should be added to a building. Once a particular improvement is made, the ranking of the remainder to be added to it may change. While this graph shows each of these individual measures having a minor effect on the energy loads of the reference building, it should be remembered that when many of them are combined together the savings can be substantial, as

FIGURE 6.19 – SIMULATION RESULTS



demonstrated by the 69% savings of the as-built BTC office compared to the referenece design.

The ranking of measures will also be affected by other factors barely touched on here. For instance, even if a building is to be heated and cooled by electricity, an air conditioner typically has a coefficient of performance of about 2.0, making an equivalent heating load twice as costly to meet in terms of kWh consumption.

Another aspect of comparative performance is reflected in the peak heating and cooling loads associated with the different design improvements discussed above. Table 6.6 presents the peak heating and cooling demands for each of the design improvements being evaluated as compared to the peak demands of the reference building. This is the peak hourly heating or cooling requirement for the year. It is significant in that if the building were actually heated or cooled mechanically, this is the capacity of the equipment which must be provided. The increased or decreased cost of providing this capacity can be just as important as the savings in energy consumption associated with a particular improvement.

While it would obviously be interesting to pursue each of the measures mentioned above, there was not time in the course of this study to do that. The ideal approach would be to choose, based on simulation performance the measure which achieved the greatest savings for the least cost on a reference building. Each of the remaining improvements would then be modelled on this new base-case building and the next options added, and so on. This would allow all combined effects to be taken into account and allow building-specific costing of options and savings. With just the options shown here, this would take a great deal of time, but the primary intent of this report was to focus on the as-built BTC buildings, not on development of a prioritized list of options for any new building. Instead of pursuing the reference building any longer, it is more useful to the main purpose of this report to now go back to the as-built design and investigate how sensitive its performance is to various design modifications.

6.6 Improvements to the As-Built BTC Design

As has been documented in Section 6.4 of this report, the BTC office building works well from an energy standpoint compared to a conventional office building. In exploring how the building works, a number of clear directions have also emerged as to how such a building design could be improved upon even further. These will be explored further in this section, not so much with the goal of suggesting remodelling of the existing structure, but rather to further suggest the combinations of design elements which should be considered in future buildings.

Again, the procedure used is the modelling with CALPAS3, but beginning in this case with the model of the as-built BTC office

TABLE 6.6 EFFECTS OF POTENTIAL DESIGN IMPROVEMENTS

	ANNUAL LOADS (kWh)			LOAD NET CHANGE		PEAK LOADS (kW)	
	COOLING	HEATING	TOTAL	COOLING	HEATING	COOLING	HEATING
AS-BUILT	4210	4211	8421	0	0	13.2	57.5
BV	3546	4319	7757	-664	108	12.8	57.5
DG	3841	3930	7771	-369	-281	12.6	54.8
NWI	4469	4316	8784	259	105	13.4	63.6
RR/IG&BV	5822	2634	8456	1612	-1577	15.2	57.5
RR/IG	6405	2634	9039	2195	-1577	15.4	57.5
RR/IG&BV&	7960	2879	10838	3750	-1332	16.9	65.0
RR&BV	4478	3246	7724	268	-965	13.9	57.4
RR	5217	3246	8463	1007	-965	14.7	57.4
RR&BV&NWI	6578	3495	10073	2368	-716	15.6	64.5
CARPET	5234	3646	8880	1024	-565	13.7	53.6

and modifying the inputs to describe slightly redesigned buildings. The resultant heating and cooling load changes are presented graphically in Figures 6.20 and 6.21. Figure 6.20 presents the options which result in the greatest reduction of cooling load, graphed together with their impact on heating load. Figure 6.21 presents the options that have the greatest benefit in reducing heating load, graphed together with their impact on cooling load. Both of these are presented due to the uncertainty of whether heating or cooling improvement may be of a higher priority in particular future buildings. The bars below the line indicate the reduction in heating load (benefit) achieved by each combination of measures, while the bar above the line indicates the corresponding increase in cooling load (penalty) due to the use of the option. Table 6.6 presents the annual load, savings and peak load results for each of these options. The variations modelled are as follows:

AS-BUILT - The as-built BTC office building.

BV - The as-built BTC office building, but with better ventilation effectiveness (modelled wind-driven ventilation effectiveness increased from 0.2 to 0.8).

DG - The as-built BTC office building, but with double glazing throughout.

NWI - The as-built BTC office building with no wall insulation.

RR - The as-built BTC office building but with a revised roof. This roof is a low-pitch, insulated roof with a north-facing clerestory such as was previously described and as illustrated in Figure 6.22.

RR/IG - The same as the revised roof option above, but with the total north-facing glazed area doubled.

RR/IG&BV - The same as the RR/IG option above, but with the addition of better ventilation effectiveness.

RR&BV - The combination of options RR and BV above.

RR&BV&NWI - The combination of options RR,BV and NWI above.

CARPET - The as-built BTC office building, but with carpeted floors.

With reference to Figures 6.20 and 6.21, the following observations can be made:

- The improvement that would most significantly decrease the cooling load is increasing the ventilation effectiveness of the building. This would save 16% (664 kWh) of the cooling load based on a 25-degree set-point temperature. Even this is a small amount and corresponds to a decrease in the

FIGURE 6.20 - SIMULATION RESULTS

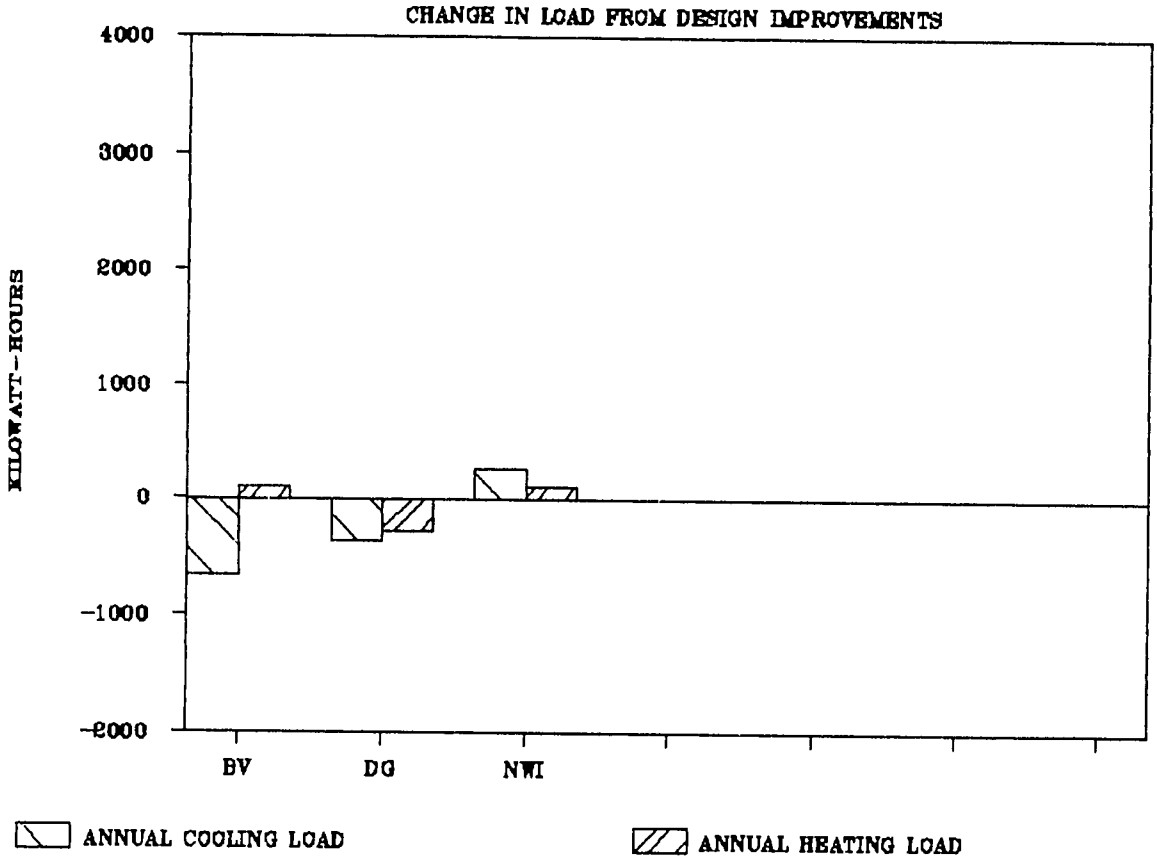


FIGURE 6.21 - SIMULATION RESULTS

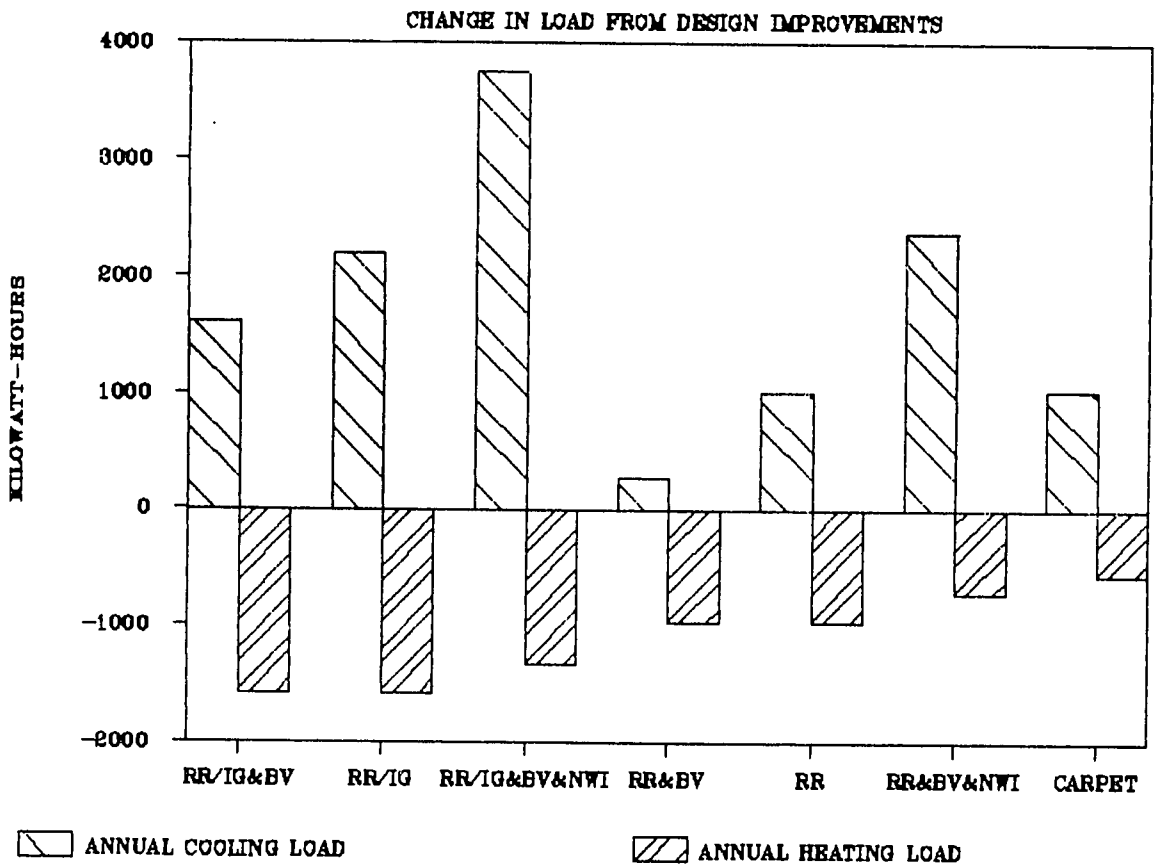
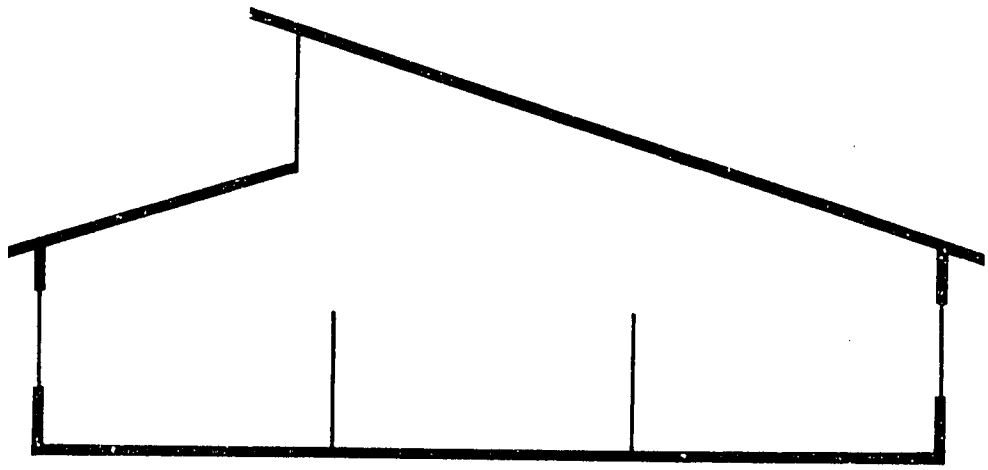
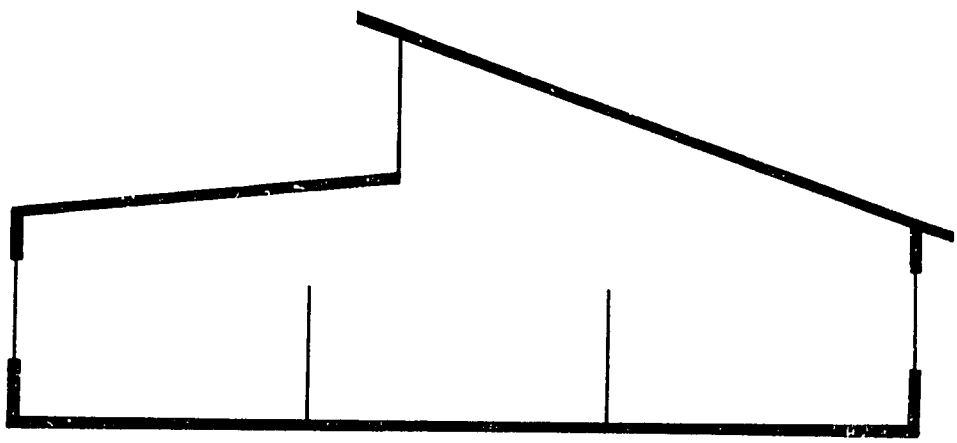


Figure 6.22

Possible Revised Roof Designs





average summer daytime temperature of less than one degree. It could be accomplished, however, at no increase in construction cost. It is merely a design improvement having to do with the manner in which windows open and the lack of obstruction between ventilation inlet and outlet. This option has no impact on heating load.

- The only other improvement examined which would result in a decreased cooling load is the use of double-glazed windows. This occurs because the inside is cooler than the outside most of the time in the summer, and an increased thermal resistance for the windows would reduce conductive heat gain. Interestingly, this is the only improvement examined which benefits both heating and cooling, as the increased thermal resistance in winter would also reduce conductive heat loss from the building. In both cases, however, the net impacts are small, with combined load reduction of only 650 kWh/year (8% of the combined loads). A floating temperature simulation of this option showed a negligible impact on average daytime temperatures in the building.

- The third option shown in Figure 6.20 is elimination of the wall insulation in the as-built office. This was examined not because it would necessarily improve thermal performance of the building (the insulation is clearly a benefit), but because it is a relatively expensive option. As might be expected, removing wall insulation from the design increases both the heating and cooling loads of the building. What is surprising is that the impacts are so small, considering that wall insulation had the greatest impact on reducing the cooling load of the reference building discussed earlier in this section. The cooling load is increased by 6% (259 kWh) and the heating load is increased by 2% (105 kWh). The apparent reason for this is that the reference building was poorly oriented, leading to high solar heat gain through the large sunlit walls. Once the building is properly oriented and the walls are shaded by the louvre system, the wall insulation does not make nearly so much difference.

- The greatest reduction in heating load (37%) is achieved with the two options that use the combination of the revised roof and increased north-facing glazing. The first option (RR/IG&BV) yields an increase in cooling load (38%) of similar magnitude to its decreased heating load, while without better ventilation (RR/IG) the cooling penalty is 52% greater than the heating load benefit.

- Taking away the wall insulation of the RR/IG&BV option reduces the savings on the heating only a little, but increases the cooling load substantially (to 3750 kWh over the as-built design).

- The revised roof design, combined with improved ventilation effectiveness, is the option which provides the greatest heating season benefit (23% decrease) for its corresponding adverse effect (6% increase) on the cooling load. While

both these values are still small, the improvements suggested would probably result in a lower building cost than the as-built structure.

- The revised roof design alone produces a heating season benefit (23% load decrease) and cooling season penalty (24% load increase) of approximately equal magnitude, again for a design change which should be less expensive than the as-built structure.

- Removing the wall insulation from the RR&BV option only reduces the winter benefit a small amount, but results in a major increase in summer cooling load. The resultant heating load savings are 17% (716 kWh) while the cooling load increase is 56% (2368 kWh).

- Adding carpet to the building (R value=.32), which might be desirable to increase sound absorption, actually reduces the heating load by 13% (565 kWh). This suggests that the storage value of the slab mass is less critical than the heat loss through the slab from the inside of the building. In summer, the mass is more important, and the addition of carpet causes an increase in the cooling load of 24% (1024 kWh). It should be noted, however, that the CALPAS3 ground heat loss model is weak and that the benefits of carpet in reducing heat flows may be overestimated. No firm conclusions should be drawn on this option without a more detailed analysis.

- None of the options examined has a high impact on peak load for heating. The options without wall insulation result in increases in peak heating load of 11 to 13%. All other options change the peak heating requirement by less than six percent. The options without wall insulation also result in the highest increases in peak cooling demand, ranging up to a 28% increase. The greatest decrease in peak cooling load is achieved by double glazing and is only 5%.

Even without a detailed economic analysis of these options, it is clear that the most promising is the revised roof design (RR) combined together with design for better ventilation effectiveness (BV). The combination of these two measures would decrease the combined heating and cooling loads of the as-built structure by eight percent (697 kWh). The increased ventilation effectiveness should not have any incremental cost, as it could largely be achieved through interior design for free air flow and the choice of window opening details. The revised roof design should cost substantially less than the as-built structure due to its smaller size and much simpler design. So, while these are not the measures which will have the greatest impact on heating and cooling loads, they are the measures which could lower the cost of building construction the most without significant adverse effects on heating and cooling loads.

Any further selection of measures from this list depends on whether either heating or cooling performance is valued more than

the other. If heating is the main issue, to be addressed even at some expense to cooling, the options with increased north glazing become very interesting. If cooling is the primary concern, the better ventilation measure alone may be preferable compared to combining it with the revised roof design. Even then, further selection eventually depends on economic as well as thermal evaluation. Such analysis is addressed at a preliminary level in the next section of this report.

7.0 ECONOMIC ANALYSIS

In economic analysis, the usual intent is to contribute to the evaluation of investment decisions by determining and analyzing both the costs and benefits of that set of decisions over a period of time. In the context of building energy performance evaluation, economic analysis is useful in determining whether incremental costs of a building for its passive solar and energy conservation features are "worthwhile" and should be considered for incorporation into future building designs. In buildings such as the BTC office and library, this is somewhat difficult because both costs and benefits are somewhat difficult to isolate and quantify. A limited effort in this area has been made, however, and the results should be none the less useful in guiding future building design for Botswana.

Because the buildings are similar, and because a detailed thermal analysis was carried out only on the office building, cost estimates and examination of costs vs. benefits will be limited to that building.

7.1 Costs

The construction costs of the entire BTC complex were closely monitored by the clients and the quantity surveyors on the job. The total cost of the office building was P91,491, the library cost P36,975 and the siteworks cost P44,815.

The cost of the siteworks is irrelevant in this analysis, as they would be required for any building and were no different in cost because of the energy design of the building. Starting with an as-built cost of P91,490 for the office building, the problem is then to determine what portion of this cost is associated with passive solar and energy-conserving design features both collectively and for each design feature. According to the quantity surveyors, Kille and Dannhauser, an "office building of standard government specification" would have cost P57,640, or P33,851 less than the as-built structure. They estimated the breakdown of this difference as follows:

- Sun louvres and low-level gutters	4,895
- Monitor roof and supporting structure	19,115
- Glazed internal doors	1,795
- Provision for monitoring system	1,329
- External wall insulation	2,947
- High-level cupboards	2,766
- Weatherstripping to doors and windows	319
- 150mm ceiling insulation instead of 75mm	686

	33,851

Obviously not all of these items are elements of the energy design of the building. The gutters (cost: P1000) were part of a water catchment system which did not have to do with the energy design of the buildings. The glazed internal doors and high-level

cupboards were amenities requested by the clients. The monitoring system was used to evaluate the energy design but is not a part of it.

The most difficult feature to deal with is also the one with the highest cost - the roof system. While the use of a roof aperture for daylighting and ventilation was seen as part of the energy design of the building, the overall roof design went far beyond this. The roof design was primarily a relection of the architectural expression that the building designers wished to make in these buildings. The high cost of the roof structure was due not so much to the roof aperture itself, but to the high pitch on the roof which both increased the surface area of the roof and required a complex timber support system. In order to evaluate, then, the cost and benefit of this element of the design, the cost of a simpler roof design yielding the same daylighting and ventilation performance as the one actually built was estimated. The incremental cost of such a roof was estimated to be approximately P4000.

It was also noted by several building designers reviewing this material that a conventional office building was more likely to have 38mm ceiling insulation instead of 75mm. Accordingly, a larger incremental cost of P1029 has been used, corresponding to increasing the insulation from 38mm to 150mm.

It is now useful to list the apparent cost of each of the energy features of the building design that were described earlier in this report.

	Incremental Cost (P)
- Choice of building orientation	0
- Sun louvres	3,895
- Choice of wall paint colour	0
- Wall insulation	2,947
- Additional ceiling insulation	1,029
- No uncontrolled ventilation (air bricks)	0
- Weatherstripping	319
- Improved ventilation cooling design	0
- Addition of roof aperture	4,000
Total cost of energy features	12,190

This incremental cost of P12,190 represents a 21 percent increase in cost over the quantity surveyors' estimate for a "standard" government office building. Stated another way, it represents 13 percent of the actual, as-built cost of the BTC office building.

It should be noted that four of the elements of the building energy design have been assigned no cost. While it is true that there is no additional construction cost, it is important to note that there could be increased design costs associated with taking the time to learn about these design concepts and using them in a particular building design. However, it could also be argued that

there would be "opportunity costs" involved in not using state-of-the art energy design techniques. In this analysis, the cost of using or not using better design techniques will not be considered.

7.2 Cost-Benefit Analysis of As-Built Office Compared to Reference Building

As discussed in the previous sections of this report, the benefits of the energy design of the BTC office building are partly in reduced energy use, but even more in increased comfort and quality of the environment inside the building. These are difficult to quantify and use in a cost-benefit analysis. Even if examination is limited to the benefits strictly having to do with energy, the question remains complex because the BTC office did not use significant heating or cooling energy during the evaluation period used for this report. As was discussed in Section 6.4 of this report, the best basis for comparative evaluation of the as-built design against a conventional office is the combined heating and cooling loads associated with maintaining conditions which have been determined to be desirable for office buildings in Botswana. In that section it was determined that the as-built design had a cooling load 14,144 kWh less than a similar conventional building, and that the heating load was 4313 kWh less. While the savings attributable to less need for electrical lighting were not analyzed, the monitored electrical lighting usage in the building was approximately 2500 kWh/year, which is about 2000 kWh less than would be expected without the efforts to utilize more natural daylighting. This totals an annual consumption savings of 20,457 kWh.

In such an analysis, it is also important to quantify the savings associated with heating and cooling equipment capacity for the two designs. The as-built design has a peak heating requirement of 57.5 kW, where the reference design has a peak requirement of 103 kW. At an estimated cost of P45/kW, this is an increase in cost for the two buildings of P2588 and P4635 respectively. Similarly, for cooling, the as-built building has a peak load of 13.2 kW and the reference building 26.9 kW, for capacity costs at P165/kW of P2178 and P4439 respectively. Assuming both building designs must be usable at night, there is no capacity savings associated with electrical lighting. Thus, the combined capacity cost savings of the as-built office over the reference design are P4308. Crediting these against the P12,190 incremental construction cost developed above results in a net incremental cost for the energy-efficient design of P7882. This would represent a 12 percent increase in the cost of a heated and cooled building of conventional design.

In summary, then, for the net additional construction cost of P8643 spent to improve the energy design of the building, a savings of 20,457 kWh/year would be achieved. The value of these savings are estimated for the next 30 years (in present day

pula) in Table 7.1 on the following page. The assumptions used are:

- energy price inflation at three percent above general inflation rate;
- financing of present construction at six percent above general inflation rate; and
- no difference in maintenance costs, except that weatherstripping would have to be replaced every four years.

In the first year, the savings easily offset the increased cost of the building design, and in subsequent years the accumulated benefits are enormous. At a discount rate of six percent, the net present value of the savings over 30 years is P59,058. Looked at another way, for a building heated and cooled to within the desired comfort range, the operational cost savings over the life of the building are of a comparable magnitude to the initial construction cost of the building. While the assumptions made in this example are only estimates, it is difficult to imagine any reasonable alternative assumptions which would not show this to be an extremely attractive investment for a heated and cooled office building.

7.3 Cost-Benefit Analysis of Individual Design Elements

The above approach can also be used to examine the value of each of the major elements of the building energy design. Tables 7.2 to 7.10 present 30-year analyses of marginal costs and benefits for each of the nine energy design elements present in the BTC office building. Both consumption and capacity impacts are considered, and the same assumptions about interest rates, etc., applied in Table 7.1 are used.

The first four of these elements are the design improvements noted earlier as having no additional construction cost. In fact, because they have net effects of reducing required capacity, their net effect is to reduce building cost. Thus the net cost for these four measures is shown as a negative number, as are the numbers in the amortized cost column.

The results of this analysis can be summarized as follows:

TABLE 7.1 ESTIMATED 30-YEAR COSTS AND BENEFITS OF COMBINED ENERGY DESIGN IMPROVEMENTS IN AS-BUILT OFFICE BUILDING

- Net cost of improvement (P): 10876
- Annual heating consumption impact: -4313 kWh
- Annual cooling consumption impact: -14144 kWh
- Annual lighting consumption impact: -2000 kWh
- Heating capacity impact: -13.7 kW
- Cooling capacity impact: -45.5 kW

Year	Energy Consumption Costs (P) Ref.	As-Built	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	1638	3069	790	2278
2	4848	1687	3161	790	4649
3	4993	1738	3255	790	7114
4	5143	1790	3353	790	9678
5	5297	1844	3454	790	12341
6	5456	1899	3557	790	15109
7	5620	1956	3664	790	17983
8	5789	2015	3774	790	20966
9	5962	2075	3887	790	24064
10	6141	2137	4004	790	27277
11	6325	2202	4124	790	30611
12	6515	2268	4248	790	34069
13	6711	2336	4375	790	37654
14	6912	2406	4506	790	41370
15	7119	2478	4641	790	45222
16	7333	2552	4781	790	49212
17	7553	2629	4924	790	53346
18	7779	2708	5072	790	57628
19	8013	2789	5224	790	62062
20	8253	2873	5381	790	66653
21	8501	2959	5542	790	71405
22	8756	3047	5708	790	76324
23	9019	3139	5880	790	81413
24	9289	3233	6056	790	86679
25	9568	3330	6238	790	92127
26	9855	3430	6425	790	97762
27	10150	3533	6618	790	103589
28	10455	3639	6816	790	109616
29	10769	3748	7021	790	115846
30	11092	3860	7231	790	122287

TABLE 7.2 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: IMPROVED ORIENTATION

- Net cost of improvement (P): -448.5 (savings)
- Annual heating consumption impact: -426 kWh
- Annual cooling consumption impact: -918 kWh
- Heating capacity impact: -5.2 kW
- Cooling capacity impact: -1.3 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4505	202	-33 (savings)	234
2	4848	4640	208	-33	475
3	4993	4779	214	-33	722
4	5143	4923	220	-33	975
5	5297	5071	227	-33	1235
6	5456	5223	234	-33	1502
7	5620	5379	241	-33	1775
8	5789	5541	248	-33	2056
9	5962	5707	255	-33	2345
10	6141	5878	263	-33	2641
11	6325	6054	271	-33	2945
12	6515	6236	279	-33	3257
13	6711	6423	287	-33	3577
14	6912	6616	296	-33	3906
15	7119	6814	305	-33	4244
16	7333	7019	314	-33	4591
17	7553	7229	324	-33	4948
18	7779	7446	333	-33	5314
19	8013	7670	343	-33	5690
20	8253	7900	354	-33	6077
21	8501	8137	364	-33	6474
22	8756	8381	375	-33	6882
23	9019	8632	386	-33	7301
24	9289	8891	398	-33	7732
25	9568	9158	410	-33	8175
26	9855	9433	422	-33	8630
27	10150	9716	435	-33	9098
28	10455	10007	448	-33	9578
29	10769	10307	461	-33	10073
30	11092	10617	475	-33	10581

TABLE 7.3 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: CHOICE OF WALL PAINT COLOUR

- Net cost of improvement (P): -64.5 (savings)
- Annual heating consumption impact: 263 kWh
- Annual cooling consumption impact: -1367 kWh
- Heating capacity impact: 0.4 kW
- Cooling capacity impact: -0.5 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4541	166	-5 (savings)	170
2	4848	4677	171	-5	346
3	4993	4818	176	-5	527
4	5143	4962	181	-5	712
5	5297	5111	186	-5	904
6	5456	5264	192	-5	1101
7	5620	5422	198	-5	1304
8	5789	5585	204	-5	1512
9	5962	5753	210	-5	1727
10	6141	5925	216	-5	1948
11	6325	6103	223	-5	2176
12	6515	6286	229	-5	2410
13	6711	6475	236	-5	2651
14	6912	6669	243	-5	2899
15	7119	6869	250	-5	3155
16	7333	7075	258	-5	3418
17	7553	7287	266	-5	3688
18	7779	7506	274	-5	3967
19	8013	7731	282	-5	4254
20	8253	7963	290	-5	4549
21	8501	8202	299	-5	4854
22	8756	8448	308	-5	5167
23	9019	8701	317	-5	5489
24	9289	8962	327	-5	5821
25	9568	9231	337	-5	6162
26	9855	9508	347	-5	6514
27	10150	9793	357	-5	6876
28	10455	10087	368	-5	7249
29	10769	10390	379	-5	7633
30	11092	10701	390	-5	8028

TABLE 7.4 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: NO UNCONTROLLED VENT OPENINGS

- Net cost of improvement (P): -2257.5 (savings)
- Annual heating consumption impact: -3115 kWh
- Annual cooling consumption impact: -2192 kWh
- Heating capacity impact: -28.9 kW
- Cooling capacity impact: -5.8 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	3911	796	-164 (savings)	960
2	4848	4028	820	-164	1944
3	4993	4149	845	-164	2953
4	5143	4273	870	-164	3986
5	5297	4401	896	-164	5046
6	5456	4534	923	-164	6133
7	5620	4670	951	-164	7248
8	5789	4810	979	-164	8391
9	5962	4954	1008	-164	9563
10	6141	5103	1039	-164	10766
11	6325	5256	1070	-164	12000
12	6515	5413	1102	-164	13266
13	6711	5576	1135	-164	14565
14	6912	5743	1169	-164	15898
15	7119	5915	1204	-164	17266
16	7333	6093	1240	-164	18670
17	7553	6275	1277	-164	20111
18	7779	6464	1316	-164	21591
19	8013	6658	1355	-164	23110
20	8253	6857	1396	-164	24670
21	8501	7063	1438	-164	26272
22	8756	7275	1481	-164	27917
23	9019	7493	1525	-164	29606
24	9289	7718	1571	-164	31341
25	9568	7950	1618	-164	33123
26	9855	8188	1667	-164	34954
27	10150	8434	1717	-164	36835
28	10455	8687	1768	-164	38767
29	10769	8947	1821	-164	40752
30	11092	9216	1876	-164	42792

TABLE 7.5 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: IMPROVED VENTILATION DESIGN

- Net cost of improvement (P): -39 (savings)
- Annual heating consumption impact: 17 kWh
- Annual cooling consumption impact: -2706 kWh
- Heating capacity impact: 0.6 kW
- Cooling capacity impact: -0.4 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4303	403	-3 (savings)	406
2	4848	4432	415	-3	825
3	4993	4565	428	-3	1256
4	5143	4702	441	-3	1699
5	5297	4843	454	-3	2156
6	5456	4989	468	-3	2627
7	5620	5138	482	-3	3111
8	5789	5293	496	-3	3611
9	5962	5451	511	-3	4125
10	6141	5615	526	-3	4654
11	6325	5783	542	-3	5199
12	6515	5957	558	-3	5760
13	6711	6136	575	-3	6338
14	6912	6320	592	-3	6934
15	7119	6509	610	-3	7547
16	7333	6704	628	-3	8178
17	7553	6906	647	-3	8828
18	7779	7113	667	-3	9498
19	8013	7326	687	-3	10188
20	8253	7546	707	-3	10898
21	8501	7772	728	-3	11629
22	8756	8005	750	-3	12383
23	9019	8246	773	-3	13159
24	9289	8493	796	-3	13958
25	9568	8748	820	-3	14781
26	9855	9010	845	-3	15628
27	10150	9281	870	-3	16501
28	10455	9559	896	-3	17400
29	10769	9846	923	-3	18326
30	11092	10141	951	-3	19279

TABLE 7.6 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: SHADING LOUVRE SYSTEM

- Net cost of improvement (P): 3814
- Annual heating consumption impact: 473 kWh
- Annual cooling consumption impact: -1343 kWh
- Heating capacity impact: 0.4 kW
- Cooling capacity impact: -0.6 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4576	131	277	-147
2	4848	4713	134	277	-289
3	4993	4855	138	277	-428
4	5143	5001	143	277	-562
5	5297	5151	147	277	-692
6	5456	5305	151	277	-818
7	5620	5464	156	277	-939
8	5789	5628	160	277	-1056
9	5962	5797	165	277	-1167
10	6141	5971	170	277	-1274
11	6325	6150	175	277	-1376
12	6515	6335	181	277	-1472
13	6711	6525	186	277	-1563
14	6912	6720	192	277	-1648
15	7119	6922	197	277	-1728
16	7333	7130	203	277	-1802
17	7553	7343	209	277	-1869
18	7779	7564	216	277	-1930
19	8013	7791	222	277	-1985
20	8253	8024	229	277	-2033
21	8501	8265	236	277	-2075
22	8756	8513	243	277	-2109
23	9019	8768	250	277	-2136
24	9289	9032	258	277	-2155
25	9568	9302	265	277	-2167
26	9855	9582	273	277	-2171
27	10150	9869	281	277	-2166
28	10455	10165	290	277	-2154
29	10769	10470	299	277	-2132
30	11092	10784	308	277	-2101

TABLE 7.7 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: WALL INSULATION

- Net cost of improvement (P): 2443
- Annual heating consumption impact: -319 kWh
- Annual cooling consumption impact: -5021 kWh
- Heating capacity impact: -5.7 kW
- Cooling capacity impact: -1.5 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	3906	801	177	624
2	4848	4023	825	177	1272
3	4993	4144	850	177	1944
4	5143	4268	875	177	2643
5	5297	4396	902	177	3367
6	5456	4528	929	177	4119
7	5620	4664	956	177	4898
8	5789	4804	985	177	5706
9	5962	4948	1015	177	6544
10	6141	5096	1045	177	7412
11	6325	5249	1076	177	8312
12	6515	5406	1109	177	9243
13	6711	5569	1142	177	10208
14	6912	5736	1176	177	11208
15	7119	5908	1212	177	12242
16	7333	6085	1248	177	13313
17	7553	6268	1285	177	14422
18	7779	6456	1324	177	15568
19	8013	6649	1364	177	16755
20	8253	6849	1405	177	17983
21	8501	7054	1447	177	19252
22	8756	7266	1490	177	20565
23	9019	7484	1535	177	21923
24	9289	7708	1581	177	23327
25	9568	7939	1628	177	24778
26	9855	8178	1677	177	26279
27	10150	8423	1727	177	27829
28	10455	8676	1779	177	29431
29	10769	8936	1833	177	31087
30	11092	9204	1888	177	32797

TABLE 7.8 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: ADDITIONAL CEILING INSULATION

- Net cost of improvement (P): 555
- Annual heating consumption impact: -345 kWh
- Annual cooling consumption impact: -1865 kWh
- Heating capacity impact: -3.2 kW
- Cooling capacity impact: -2 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4375	332	40	291
2	4848	4506	341	40	593
3	4993	4642	352	40	904
4	5143	4781	362	40	1227
5	5297	4924	373	40	1560
6	5456	5072	384	40	1904
7	5620	5224	396	40	2260
8	5789	5381	408	40	2627
9	5962	5542	420	40	3007
10	6141	5709	433	40	3400
11	6325	5880	446	40	3805
12	6515	6056	459	40	4224
13	6711	6238	473	40	4657
14	6912	6425	487	40	5104
15	7119	6618	501	40	5565
16	7333	6816	516	40	6042
17	7553	7021	532	40	6534
18	7779	7232	548	40	7042
19	8013	7448	564	40	7566
20	8253	7672	581	40	8107
21	8501	7902	599	40	8666
22	8756	8139	617	40	9243
23	9019	8383	635	40	9838
24	9289	8635	654	40	10452
25	9568	8894	674	40	11086
26	9855	9161	694	40	11740
27	10150	9436	715	40	12415
28	10455	9719	736	40	13111
29	10769	10010	758	40	13830
30	11092	10310	781	40	14571

TABLE 7.9 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: WEATHERSTRIPPING

- Net 30-year cost of improvement (P): 1040
- Annual heating consumption impact: -2076 kWh
- Annual cooling consumption impact: -1461 kWh
- Heating capacity impact: -19.3 kW
- Cooling capacity impact: -3.9 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4176	531	76	455
2	4848	4301	546	76	925
3	4993	4430	563	76	1412
4	5143	4563	580	76	1916
5	5297	4700	597	76	2437
6	5456	4841	615	76	2976
7	5620	4987	634	76	3534
8	5789	5136	653	76	4110
9	5962	5290	672	76	4706
10	6141	5449	692	76	5323
11	6325	5612	713	76	5960
12	6515	5781	734	76	6618
13	6711	5954	756	76	7298
14	6912	6133	779	76	8002
15	7119	6317	803	76	8728
16	7333	6506	827	76	9479
17	7553	6701	851	76	10254
18	7779	6903	877	76	11055
19	8013	7110	903	76	11882
20	8253	7323	930	76	12737
21	8501	7543	958	76	13619
22	8756	7769	987	76	14530
23	9019	8002	1017	76	15470
24	9289	8242	1047	76	16441
25	9563	8489	1078	76	17444
26	9855	8744	1111	76	18479
27	10150	9006	1144	76	19547
28	10455	9276	1179	76	20649
29	10769	9555	1214	76	21787
30	11092	9841	1250	76	22962

TABLE 7.10 ESTIMATED 30-YEAR COSTS AND BENEFITS OF IMPROVED BUILDING DESIGN ELEMENT: ROOF APERTURE

- Net cost of improvement (P): 3903
- Annual heating consumption impact: -1004 kWh
- Annual cooling consumption impact: 568 kWh
- Annual lighting consumption impact: -2000 kWh
- Heating capacity impact: -9.5 kW
- Cooling capacity impact: 2 kW

Year	Energy Consumption Costs (P) Ref.	Improved	Savings (P)	Amortized Cost of Energy Improvements (P)	Cumulative Benefit (P)
1	4707	4341	365	284	82
2	4848	4472	376	284	174
3	4993	4606	388	284	278
4	5143	4744	399	284	393
5	5297	4886	411	284	520
6	5456	5033	424	284	660
7	5620	5184	436	284	812
8	5789	5339	449	284	978
9	5962	5499	463	284	1157
10	6141	5664	477	284	1349
11	6325	5834	491	284	1556
12	6515	6009	506	284	1778
13	6711	6190	521	284	2015
14	6912	6375	537	284	2268
15	7119	6567	553	284	2537
16	7333	6764	569	284	2822
17	7553	6967	586	284	3124
18	7779	7176	604	284	3444
19	8013	7391	622	284	3782
20	8253	7612	641	284	4139
21	8501	7841	660	284	4515
22	8756	8076	680	284	4911
23	9019	8318	700	284	5327
24	9289	8568	721	284	5764
25	9568	8825	743	284	6223
26	9855	9090	765	284	6704
27	10150	9362	788	284	7208
28	10455	9643	812	284	7735
29	10769	9933	836	284	8287
30	11092	10231	861	284	8865

INDIVIDUAL MEASURES RANKING	30-YEAR COST IMPACT (P)	30-YEAR BENEFITS (P)
1 VENTILATION CONTROL	-4,920	42,792
2 BETTER VENTILATION DESIGN	-90	19,279
3 ORIENTATION	-990	10,581
4 WALL PAINT COLOUR	-150	8,028
5 CEILING INSULATION	1,200	14,571
6 WEATHERSTRIPPING	2,280	22,962
7 WALL INSULATION	5,310	32,797
8 ROOF APERTURE	8,520	8,865
9 SHADING LOUVRES	8,310	-2,101
ALL COMBINED	23,700	122,287

The most economic improvements are the first four, which achieve substantial benefits while actually reducing the cost of the building. While the initial cost of weatherstripping is only P319, it is assumed that it will have to be replaced periodically, thus increasing its cost over the 30-year period. Wall insulation produces a greater total benefit over time than ceiling insulation, but the ceiling insulation is a much smaller investment, the cost of which is recovered more quickly than the wall insulation. A roof aperture which performs as the one in the as-built BTC office is a good investment, but not nearly so attractive as the others listed above it. A redesigned roof aperture, such as was discussed in Section 6.6, would probably be a much more attractive alternative from an economic perspective. The shading louvre system on the north and west walls is not a good investment from an energy standpoint (it may have unconsidered benefits with respect to glare, aesthetics, etc.). It does not yield net positive benefit after 30 years, and its annual benefits do not exceed annualized cost until after 26 years.

It also appears that a building design which incorporated only the first six of these features would cost approximately the same or less than a conventional building, and should achieve over 80% of the benefits achieved by the as-built combination.

7.4 Conclusions of Economic Analysis

Based on the limited analysis presented above, a number of conclusions can be made regarding both the BTC office building and future energy design of office buildings in Botswana.

Regarding the as-built BTC office building:

A. The incremental cost of the BTC office building design to incorporate passive solar and energy conservation features was an extremely good investment.

B. If the as-built BTC office were heated and cooled to within the desired office comfort range of 20-25 degrees, the operating cost savings would be five times greater than the annualized increase in construction cost in the first year alone. Over 30 years, the savings would be approximately seven times greater than the cost of the improvements. At a discount rate of six percent, the net present value of these savings is P59,058 compared to a P10,874 net present value of costs.

C. If the building had been built using only those energy design improvements with little or no incremental cost, the building energy performance could still have been almost as good as was achieved in the as-built BTC office building.

Regarding future building energy design:

A. Improved energy conservation and passive solar building design can achieve very high cost savings at very low cost in institutional buildings where it is desired to maintain high degrees of environmental control.

B. Those energy design improvements which involve no incremental construction cost and little or no increase in design cost should be incorporated into all future office and similar institutional buildings. These measures include:

- choice of building orientation with respect to building shape and window placement;

- maximum reduction of uncontrolled infiltration;

- design and placement of windows, and any other ventilation openings, to maximize ventilation cooling;

- design and placement of windows to achieve an economic balance between maximum daylighting/winter solar heat gain and minimal summer heat gain;

- choice of exterior building surface colours for heating and cooling benefits; and

- increased levels of ceiling insulation.

C. The economic benefits of passive solar and energy-conserving design improvements in any buildings which are to be heated and cooled are of enormous potential. Many of these improvements can actually have the effect of decreasing the initial cost of the building by reducing the peak load requirements for mechanical equipment. Beyond this, there will always be a number of improvements which will increase the initial cost of the building, but which will be very worthwhile because they will lower recurrent costs. It should be noted that while initial costs of new

institutional buildings are sometimes supported by international financial assistance to Botswana, recurrent costs are more likely to rely on scarce local financial resources. From this standpoint, it would appear that large savings in recurrent costs at low increases in initial cost of construction should be even more desirable than a simple cost-benefit analysis suggests.

8.0 SUMMARY OF SIGNIFICANT FINDINGS

A. THE BTC OFFICE AND LIBRARY BUILDINGS PERFORM AS PREDICTED BY THE BUILDING DESIGNERS.

- Building performance is essentially consistent with the original predictions of the building designers. They predicted a January average indoor temperature of 24.9 degrees and the measured average (normalized for long-term weather conditions) was 25.0 degrees. They predicted a July average indoor temperature of 18.4 degrees and the as-built, normalized average was 16.7 degrees. Most of the discrepancy in the winter prediction is associated with a lower than expected occupancy in the building and cost-saving modifications made to the original design at the time of construction. The fact that a building of this scale and complexity will perform as designed should give designers greater confidence in using passive heating and cooling designs for similar buildings in Botswana in the future.

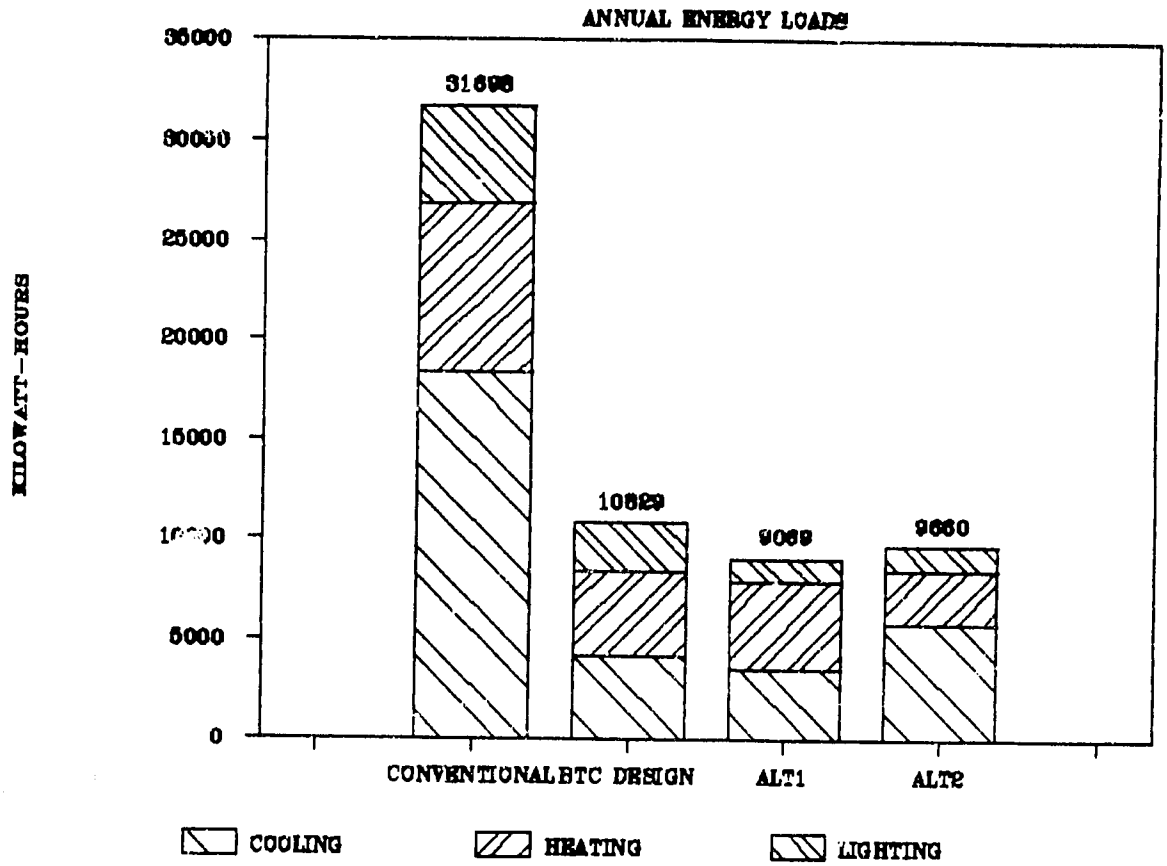
B. OCCUPANTS ARE PLEASED WITH THE BTC OFFICE AND LIBRARY AS WORK ENVIRONMENTS.

From an occupant perspective, there are some aspects of building performance which it would be desirable to improve, but the overall level of occupant satisfaction with the buildings is high. The things occupants like least about the building are that it is sometimes too hot in summer and too cold in winter, sometimes there is too much noise and sometimes it is felt there is not enough light. On the other hand, this seems to be far outweighed for most occupants by an overall attitude that the building has a pleasant general atmosphere and, on the whole, works well.

C. THE AS-BUILT BTC OFFICE BUILDING IS THERMALLY FAR SUPERIOR TO A CONVENTIONAL OFFICE BUILDING.

Computer thermal simulation of the BTC office building and a comparable conventional office show the as-built building to be significantly better than a high-cost conventional office design. Summer day temperatures will be two to three degress cooler in the passive design on almost all days. In winter, the passive design will not have temperatures much warmer than the conventional building on the warmer days, but on the coldest days, it will average about two degrees warmer. Using comfort zone limits of 20 - 25 degrees, the passive design reduces the cooling load of the conventional building by 77% (a savings of 14,144 kWh), the heating load by 51% (4313 kWh) and the total thermal load by 69% (18,457 kWh). This is displayed graphically in Figure 8.1 on the following page.

FIGURE 8.1 - Overall Energy Performance of BTC Office Building to a Similar Conventional Building and Two Hypothetical Improved Designs



CONVENTIONAL - is a building similar to the BTC office building but without its passive solar and energy conservation improvements.

BTC DESIGN - is the as-built BTC office building.

ALT1 - is the BTC design with several design modifications to optimally improve cooling performance.

ALT2 - is the BTC design with several design modifications optimally improve heating performance.

D. THE AS-BUILT BTC BUILDINGS WORK BETTER IN SUMMER THAN THEY DO IN WINTER.

Occupant response, monitored data and simulation results all suggest that the as-built BTC building design is more successful in attaining a desirable indoor environment in summer than in winter, both in absolute terms and compared to conventional building designs. Despite the fact that the cooling load is dominant in such buildings, future design efforts should investigate a more balanced impact on heating and cooling loads.

E. THERE ARE OPPORTUNITIES FOR THERMAL IMPROVEMENTS OVER THE AS-BUILT DESIGN OF THE BTC BUILDINGS, BUT THEY WOULD YIELD ONLY SMALL NET IMPACTS.

Of various options investigated, the only one which would significantly improve the cooling performance of the building would be to improve the natural ventilation "effectiveness" of the windows in the building. This would involve better choice of window hardware and window location to increase the wind-driven ventilation of the building at night. Even this, however, would only reduce the cooling load of the as-built building by 16% (664 kWh). This alternative design, which lowers cooling load the most, is shown in Figure 8.1 with the label "ALT1".

Of the options investigated for winter heating performance improvement, all had an adverse impact on summer performance. Given the present imbalance in summer and winter performance, this could be desirable, but would yield very limited net annual load improvement. Doubling the glazing area which faces north, with a revised roof design, would cut the as-built heating load by 37% (1577 kWh), corresponding to an average winter temperature increase of about one degree. For this, the summer penalty would be an increase of cooling load by an amount similar to the winter savings, even with improved ventilation effectiveness. The alternative design which lowers heating load the most is shown in Figure 8.1 with the label "ALT2" (see Section 6.6 for details).

F. THERE ARE SEVERAL CHANGES TO THE AS-BUILT BTC DESIGN WHICH COULD LOWER CONSTRUCTION COST WITHOUT SIGNIFICANTLY AFFECTING THERMAL PERFORMANCE.

The following changes are all recommended for consideration in future similar designs as cost-saving improvements:

- The elimination of wall insulation from the as-built design is predicted to increase the cooling load by only six percent and the heating load by two percent. With an estimated incremental cost of P 2947, wall insulation does

not appear to have been worthwhile in combination with the other components of the design.

- The roof design of the as-built BTC building was very expensive. While some of the rationale for the design was architectural expression and building appearance, some of it was also intended to impact building thermal and daylighting performance. The height of the roof, intended partially to promote stack-driven ventilation, was largely ineffective, as discussed in Section 4 of this report. Special efforts at providing ventilation of the attic space were useful, but probably again of excessive cost relative to their performance. Heat gain to the building from the roof is more sensitive to ceiling insulation and roof surface absorptivity than it is to roof space ventilation. The roof colour, while appearing visually to be a light colour, has a measured solar absorptivity which is relatively high (about 60%) and not much different from plain, galvanized steel, and costs quite a bit more. The daylighting performance of the roof aperture was less than could be achieved with a lower roof aperture due to absorption of light on the upper walls of the light well.

  A redesigned roof, such as that suggested in Section 6.6 of this report, could be built for much less cost and could slightly improve thermal and daylighting performance of the building. One possible redesign of this type would simply involve lowering the roof pitch and eliminating the glazed roof "monitor." Instead, the pitch on the north side would be lowered more than on the south side, creating a "clerestory" (a strip of northfacing windows) along the ridge line of the roof. This clerestory need have no more glazing than the combined area of the existing high north and south windows in the roof monitor. If the ceiling followed the roof line, this geometry would further improve daylighting and thermal performance of the building, particularly in winter.

- The sun-shading louvre system on the north and west walls of the as-built BTC office building had an incremental cost of P3895 but was of limited thermal value. This is largely due to the fact that there is, in fact, very little direct solar gain on the north face of the building in summer. Botswana's high sun elevation in summer leads to relatively small solar gains on this surface. On the west side, however, shading is more important, but even here a different type of shading would probably have been more effective. In any case, for any of the walls, the use of a more reflective paint colour would probably be almost as effective as trying to provide shade with this kind of louvre system. Overall, the building should perform similarly to the way it does now if the louvre system were replaced by individual window shades (or elimination of windows) on the west side, if the west wall were painted a very reflective colour, and if a typical roof overhang were used on the north side. It should also

be noted that some other shading mechanisms, such as vegetation or shade netting, should be less expensive than the louvre system and might therefore be more cost-effective.

G. THE PRIMARY DEFICIENCIES IN PRESENT PERFORMANCE OF THE BTC BUILDINGS HAVE PROMISING SOLUTIONS.

The primary problems of the present BTC building design can be summarized as follows:

- sometimes too hot in summer
- sometimes too cold in winter
- open-plan area has acoustic problems
- daylighting is often inadequate

The problem of being too hot in summer is a product of both high temperatures and the lack of air movement. As noted in this report, the only modelled strategy which lowered the air temperature of the building at all was improving the natural ventilation effectiveness of the building design. Even this did not have a great impact. The problem of air movement is an issue due to the requirement that the building windows be kept closed on summer days when it is cooler inside than outside. This problem was noted soon after occupancy of the building. The suggested solution was the use of electric fans. An increase of air flow past the body from none to 1 m/s gives an equivalent cooling effect of lowering the dry-bulb temperature by 2.8 degrees. Accordingly, some ceiling fans have been installed in the BTC office. This is a promising solution, but as yet there has been no mid-summer experience with it. However, given that the office and library only had indoor temperatures over 30 degrees on one occasion last summer, it would seem that using adequate fans on the hotter afternoons could keep conditions comfortable almost all of the time.

- The problem of being too cold some of the time in winter is somewhat more difficult. The modelled options suggest only solutions which increase solar gain, and these all have an adverse effect in summer. Even if solar gains were increased somewhat by using a different building design, they would not be adequate to eliminate the heating load. The problem is the early morning working hours. In winter, the work day begins just after sunrise, when the ambient temperature has just gone to its lowest and before the new day's sun can provide any significant solar heating, regardless of design. The only possibilities would be those of storing heat from the previous day, but such strategies all appear to be too expensive to be worth pursuing. The most realistic solution appears to be simply to provide a small amount of mechanical heating for the first hour or two of the day, until the solar heating and internal gains can take over. It might also significantly affect comfort if the floor were carpeted.

- The acoustic problems of the open-plan area are associated both with a perceived high noise level and concerns for privacy. While some of this is unavoidable in an open-plan area, there is no question that this area is very "live" acoustically, due to all the hard surfaces surrounding it. While acoustic dividers, common in many open-plan offices, are one solution, it has also been suggested that floor carpet might help. If this had been substituted for the existing floor finish, the cost might not have been much greater. A thermal simulation of the building with carpet installed indicated that it would reduce heat losses to the floor slab, resulting in a 13% decrease in heating load (565 kWh). In the summer however, the cooling function of the slab would also be reduced, resulting in a cooling load increase of 1024 kWh. While the thermal load effects may not be that attractive, the warmer winter floor and potential acoustic advantages of this option may make it worthwhile.

- The problem of daylighting inadequacy is not by comparison to conventional buildings, which are usually much worse, but rather with respect to the perceived potential of this type of building. On cloudy days, it is always necessary to use artificial lighting, and even on many other days the natural light levels are somewhat low for many tasks. As discussed above, a redesigned roof structure could probably eliminate the need for artificial lighting during the daytime. For the existing building, it has been noted that the colour of the walls extending down from the high windows appears to be quite a bit darker than normal white paint. ARD consultants recommended that these walls be repainted white and in July, 1985, such painting was done in the office building. While no detailed analysis was done for this report, it appears that repainting these surfaces a more reflective colour will improve the situation somewhat.

H. ECONOMIC ANALYSIS OF ENERGY PERFORMANCE OF THE BTC BUILDINGS HAS DEMONSTRATED THAT PASSIVE SOLAR, ENERGY-CONSERVING DESIGN CAN BE A VERY GOOD ECONOMIC INVESTMENT.

The incremental cost of the energy features of the BTC buildings was a very good investment. If the as-built office was heated and cooled to within the comfort range of 20-25 degrees, the operating cost savings would be five times greater than the annualized increase in construction cost in the first year alone. Over 30 years, the savings would be approximately seven times greater than the cost of improvements. At a discount rate of 6%, the net present value of these savings is P59,058 compared to a P10,874 net present value of costs. Looked at another way, the operational cost savings over the life of the building could approach the total initial construction cost of the building.

Certain individual components of the energy design were more cost-effective than others. The louvre shade system produces the least benefit for its cost. Ventilation control produces

the greatest benefit for its cost. If the BTC office had been built using only those energy design improvements with little or no incremental cost, the building energy performance could still have been almost as good as was achieved with the as-built BTC office building.

I. A NUMBER OF RECOMMENDATIONS FOR FUTURE DESIGN OF SIMILAR BUILDINGS CAN BE MADE BASED ON THE PERFORMANCE ANALYSIS OF THE BTC BUILDINGS.

The intent of this study was to report on the performance of the BTC buildings, not to evaluate all possible options for passive design of similar buildings in the future. However, a number of lessons have been learned which are transferable to other buildings. While future buildings should receive their own analysis, the following should provide guidance to initial design and direction for building-specific analysis.

The first recommendations are those which can be recommended confidently because they do not need to affect the cost of a building relative to a conventional design - they simply involve better design:

- Orientation of a building so that a long side faces north is important both for summer cooling and winter heating. The more of the building surface which faces true north, the less significant is wall insulation (assuming appropriate external wall colouring).

- Selecting a dark colour for painting a north wall will improve winter heating performance and only slightly aggravate summer cooling performance, making it appropriate for any building which has some heating requirement. Painting the other walls a very light colour is a choice which also has no cost and will always reduce summer cooling loads.

- Reduction of uncontrolled ventilation (infiltration) will be a thermal benefit in almost any building, both in winter and summer. It will probably have the greatest benefit of any single low-cost measure which can be applied to a building. The key to this is not using any uncontrolled ventilation openings, such as "air bricks" or "perma-vents." Additionally, the choice of windows and doors for air leakage characteristics and use of weatherstripping can have a major impact.

- The ventilation design of buildings like these is very important if the potential benefits of natural cooling are to be achieved. It should not be necessary to add ventilation openings beyond the normal amount of windows usually put in buildings, but the placement of the windows, the extent to which they open and the direction they open are all important design considerations. In general, ventilation design should concentrate on

wind-driven ventilation, as opposed to stack-driven ventilation, as it is likely to be, by far, the dominant ventilation mechanism. Again, this need not cost more than windows in a conventional building.

The remaining recommendations for other buildings are associated with passive design features that have some cost, and must therefore be evaluated in the context of a particular building design, the costs of the measures and the benefits which would result from it:

- In most cases, wall insulation will not be advisable in buildings similar to the BTC buildings, as long as they are properly oriented and have appropriate wall colours.

- In deep buildings, like the BTC building, a roof aperture can be particularly worthwhile, both for daylighting and winter solar heating.

- The desire to make maximum use of thermal mass and ground coupling in passive designs needs to be tempered by a concern for the adverse acoustic effects of extensive hard surfaces in a working environment.

- Because of the high solar intensity in Botswana, roof and ceiling design is of great importance for both summer and winter conditions. The solar effects are clearly dominant on this segment of the building envelope and, depending on the building's requirements, a roof/ceiling system should be designed to achieve an appropriate balance between winter solar gain and summer solar gain avoidance. If the roof is not highly reflective to solar radiation, it will probably be appropriate to use higher levels of insulation than usual (i.e., 150mm) to prevent excessive summer heat gain. As less ceiling insulation is used, the sensitivity of the roof/ceiling system to roof ventilation and roof surface absorptivity will increase.

- The BTC buildings have demonstrated that small institutional and commercial buildings can be built in Botswana which eliminate almost all cooling requirements. Small fans to create air movement on occupants during the hottest days are an effective part of this solution. It should be a goal of passive design in Botswana, for most buildings, to be able to maintain comfort conditions without air conditioning. As far as design for heating in the winter, the best solution for any building which requires winter morning temperatures to be above 20 degrees will probably be to minimize the heating requirement with good passive design and then provide some form of morning start-up auxiliary heating.

- The economic benefits of passive solar and energy-conserving design improvements in any buildings which are to be heated and cooled are of enormous potential.

Many of these improvements can actually have the effect of decreasing the intial cost of the building by reducing the peak load requirements for the mechanical system. Beyond this, there are a large number of improvements which will be very worthwhile because they will greatly lower recurrent costs. It should be noted that while first costs of new institutional buildings are sometimes supported by international financial assistance to Botswana, recurrent costs tend to rely on scarce local financial resources. From this standpoint, it appears that large savings in recurrent costs are even more desirable than suggested by simple cost-benefit analysis. This makes an investment in good energy design an imperative for any new construction which will have substantial recurrent energy costs.

REFERENCES

1. Design of Demonstration Passive Solar Buildings. Norris, D. and Temple, P., Associates in Rural Development, Burlington, Vermont, February, 1982.

2. Level B Monitoring Manual. Hamilton, B. and Alward, R., Solar Energy Project Report Passive-08, National Research Council, Ottawa, Canada, April, 1984.

3. Measured Performance Evaluation of the SHAKAWE-EC: A Prototype Passive Solar House for Botswana. Hamilton, B., Associates in Rural Development, Burlington, Vermont, October, 1984.

APPENDICES

APPENDIX A

Typical Monitored Data

The following page shows typical hourly data, which were acquired on the BTC buildings through use of the microprocessor data acquisition system. The format in which the data are presented is a spreadsheet used by the LOTUS-123 software program. Each row in the spreadsheet represents a channel of the data acquisition system. Each row covers the data recording interval of one hour. The data presented are an hourly total for solar radiation and electrical consumption channels. For temperature channels and wind velocity, the values presented are hourly averages of the 15-second scans.

MONTH	DATE	HOUR	WINDOW NORTH (%)	WINDOW SOUTH (%)	WINDOW OFFICE.W (%)	WINDOW LIB S (%)	WINDOW LIB.N (%)	SOLAR A	WIND B	AMBIENT C (DEG C)	OFC WLK D (DEG C)	PERSONEL E (DEG C)	CEN LOW F (DEG C)	CEN HI G (DEG C)	ATTIC H (DEG C)	LIBRARY I (DEG C)	OFC ARS J (DEG C)	VOLTAGE L (VOLTS)	CURRENT M (AMPS)
5	29	8	1.00	1.00	0.00	0.00	1.00	42.08	1862.72	12.91	20.29	19.41	19.64	19.25	13.07	18.92	20.05	216.34	2.02
5	29	9	1.00	1.00	0.00	0.00	1.00	122.71	1827.47	14.74	20.68	19.79	20.20	19.71	16.59	19.73	20.47	216.05	2.62
5	29	10	1.00	1.00	0.00	0.00	1.00	249.36	8383.22	16.94	21.13	20.05	20.63	20.11	20.15	20.42	20.90	217.72	2.69
5	29	11	1.00	1.00	0.00	0.00	1.00	325.73	11292.46	19.43	21.68	20.29	21.13	20.68	23.70	21.20	21.61	217.68	2.69
5	29	12	1.00	1.00	0.00	0.00	1.00	380.81	9297.91	20.91	22.23	20.50	21.63	21.31	25.81	21.75	22.40	214.50	2.64
5	29	13	1.00	1.00	0.00	0.00	1.00	399.85	6920.17	21.53	22.82	20.64	21.99	21.88	27.93	22.18	22.89	216.80	2.70
5	29	14	1.00	1.00	0.00	0.00	1.00	377.55	6993.74	22.35	23.03	21.28	22.20	22.28	28.97	22.40	23.08	218.19	2.38
5	29	15	1.00	1.00	0.00	0.00	1.00	322.10	5926.15	22.25	23.76	21.89	22.66	22.66	29.21	22.70	23.82	217.95	1.75
5	29	16	1.00	1.00	0.00	0.00	1.00	224.55	8549.14	22.40	23.71	22.44	23.28	22.84	28.05	22.88	23.86	217.28	2.02
5	29	17	1.00	1.00	0.00	0.00	1.00	118.33	5724.21	21.63	23.24	22.30	22.89	22.71	25.97	22.82	23.38	217.26	2.31
5	29	18	1.00	1.00	0.00	0.00	1.00	13.68	3202.38	20.00	22.45	21.79	22.27	22.37	21.83	22.53	22.67	217.65	1.67
5	29	19	1.00	1.00	0.00	0.00	1.00	0.00	59.78	16.91	22.21	21.53	22.02	22.10	17.91	22.38	22.30	220.34	1.65
5	29	20	1.00	1.00	0.00	0.00	1.00	0.02	0.00	14.95	21.98	21.35	21.84	21.86	15.22	21.81	22.08	219.38	1.75
5	29	21	1.00	1.00	0.00	0.00	1.00	0.02	267.47	14.41	21.79	21.15	21.57	21.51	14.31	21.36	21.70	219.77	1.48
5	29	22	1.00	1.00	0.00	0.00	1.00	0.04	5604.65	16.00	21.71	20.96	21.25	21.17	15.48	21.09	21.45	219.12	1.37
5	29	23	1.00	1.00	0.00	0.00	1.00	0.03	2114.49	15.77	21.59	20.87	21.06	21.00	15.33	20.91	21.36	220.07	1.40
5	30	0	1.00	1.00	0.00	0.00	1.00	0.00	340.28	13.15	21.43	20.74	20.93	20.84	12.85	20.65	21.19	220.70	1.41
5	30	1	1.00	1.00	0.00	0.00	1.00	0.00	0.00	11.46	21.22	20.57	20.69	20.54	11.03	20.37	20.96	221.12	1.40
5	30	2	1.00	1.00	0.00	0.00	1.00	0.02	0.00	10.64	21.00	20.39	20.45	20.29	10.02	20.10	20.74	221.05	1.38
5	30	3	1.00	1.00	0.00	0.00	1.00	0.04	37.94	10.81	20.85	20.25	20.24	20.06	10.14	19.87	20.60	221.07	1.42
5	30	4	1.00	1.00	0.00	0.00	1.00	0.03	4072.63	12.37	20.76	20.18	20.12	19.93	11.53	19.75	20.53	222.45	1.39
5	30	5	1.00	1.00	0.00	0.00	1.00	0.04	3402.80	12.72	20.69	20.13	20.07	19.86	12.41	19.70	20.48	221.97	1.40
5	30	6	1.00	1.00	0.00	0.00	1.00	0.04	254.06	11.77	20.60	20.04	19.99	19.76	11.42	19.53	20.41	220.42	1.39
5	30	7	1.00	1.00	0.00	0.00	1.00	1.23	5.75	11.00	20.45	19.91	19.83	19.58	10.11	19.36	20.29	217.19	1.37
5	30	8	1.00	1.00	0.00	0.00	1.00	44.34	784.02	11.80	20.59	19.94	19.94	19.66	11.21	19.34	20.25	217.85	1.86

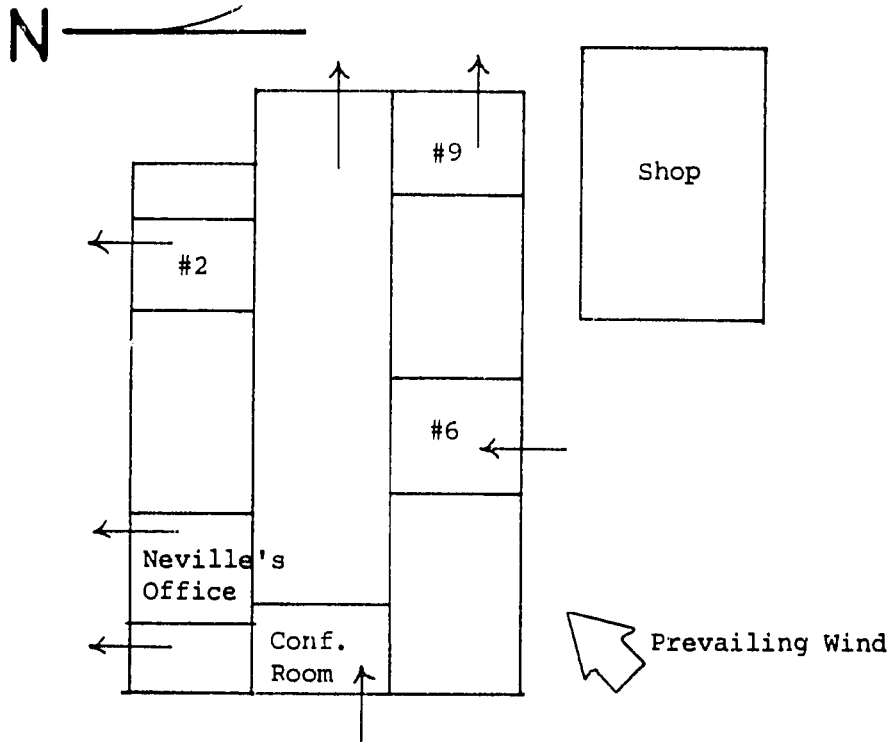
APPENDIX B

Notes from Testing of Natural Ventilation

The following notes are from the one-time tests of natural ventilation in the BTC building conducted by P. Niles and N. Wilkinson:

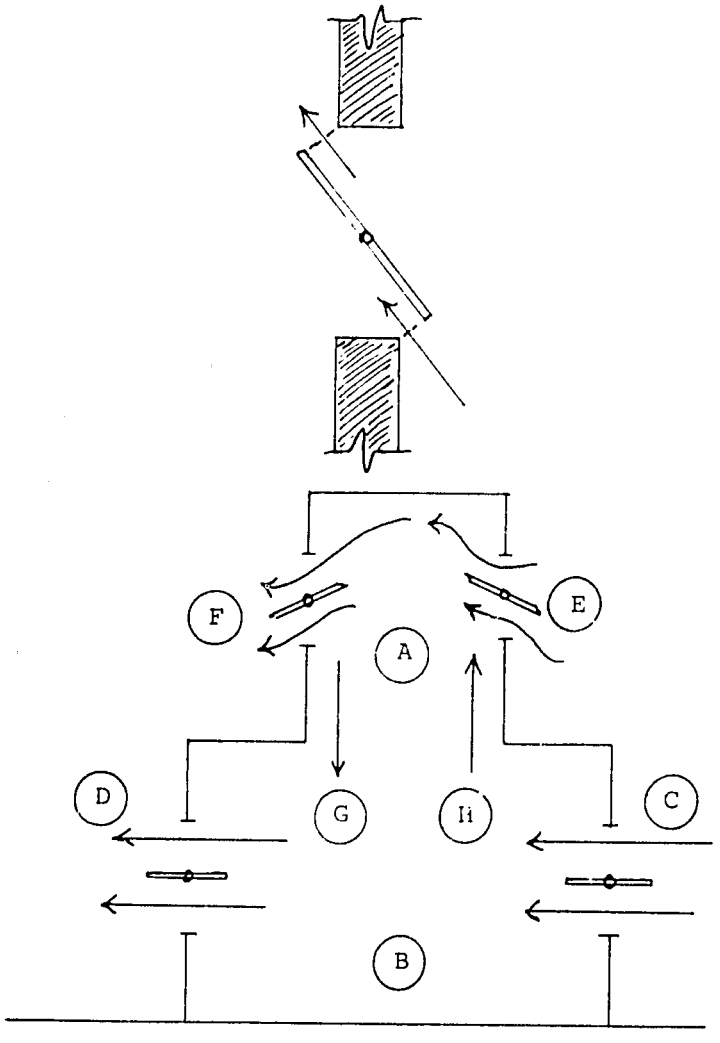
The measurements were made on March 9, 1985 beginning at about 5:30 a.m., a time near which the wind velocity is typically near a minimum. However, this morning was probably not typical. The previous evening the wind had been gusty, and some sand was blowing in Gabarone. By 6:30 a.m. it looked like rain was falling in the Tlokweng direction. The wind velocity measured at the cup anemometer varied during the test from about 2 m/s at 5:30 to 15 m/s at 6:30 a.m. It varied widely, with a minimum occasionally of zero. The wind direction was generally from the SW or WSW.

The flow pattern through the windows at the office level was typically as follows (not to scale):



Generally, the flow velocities through the windows were such that $V_6 > V_2 > V_{Conf.\ room} > V_g$

The flow velocities were measured through the high windows between ≈ 5:45 to 6:00 a.m., when the outside wind velocity was ≈ 3 m/s ± 3. The velocities at E and F were measured near the center of the smallest part of the openings, as shown by the dotted lines. The velocity was fluctuating so much that it appeared to be useless to try to make a velocity survey across the dotted area. Instead, ballpark velocities were estimated at the center of the opening. At F, the typical velocity was ≈ 110 fpm (ft/min) ± 100. At E, it seemed higher, on the order of ≈ 300 fpm ± 150. At this time, the flow at G was downward, and was upward at H. The velocities were typically on the order of 0 to 50 fpm. The flow velocities at C and D and were measured later than E and F, at a time when the wind velocity was nearer 11 m/s. The velocities were measured with the windows horizontal, as shown.



At C, the velocities were on the order of 400 fpm while at D they were nearer 200 fpm. At the conference room, they were $\approx$ 30% less than at C. In room #9, they were only $\approx \frac{1}{4}$ of the velocities at C.

No attempt has yet been made to use this data to estimate the total flow rate of ventilation air through the building. Considering the wind velocity and direction fluctuations, this flow rate would have a large uncertainty. Nevertheless, it may give some sense of the size of the opening effectiveness that should be used in simuating the performance of the building by CALPAS. Also, it may be useful in determining the open-building time-constant during this period.

APPENDIX C

Test Measurements on Ceiling Fans

As noted in this report, ceiling fans were installed in the office building in the Fall of 1984 in an effort to improve thermal comfort by increasing air movement past occupants. Preliminary tests of the resulting velocities were measured by BTC staff in July, 1985 for the fan in the conference room and are reported below.

All velocity measurements were made with a Sierra Instruments air flow measurement device of the "hot wire anemometer" type. The figure on the following page shows the position of each measurement on a floor plan of the room. These positions are further described as follows:

Position 1 - 1.0m directly below the fan;

Position 2 - 1.5m below fan (desk height) and 1.5m west from center of table;

Position 3 - 1.5m below fan (desk height) and 1.5m east from center of table;

Position 4 - 1.5m below fan (desk height) and 3.0m north-east from center of table;

Position 5 - 1.5m below fan (desk height) and 4.0m south-east from center of table;

Position 6 - 1.5m below fan (desk height) and 4.0m south-west from center of table;

Position 7 - 2.0m below fan (chair height) and 2.5m south from center of table.

Measurements were made at each of these locations for each of four different fan speeds available. Observed results were as follows:

Air Velocity (m/s)

	Speed 1	Speed 2	Speed 3	Speed 4
Position 1	3.0	2.5	2.0	0.5
Position 2	1.3	0.5	0.8	0.3
Position 3	1.8	0.5	0.6	0.4
Position 4	1.0	0.8	0.5	0.5
Position 5	1.3	1.0	0.8	0.5
Position 6	0.5	1.5	0.5	0.5
Position 7	1.5	1.5	0.5	1.5

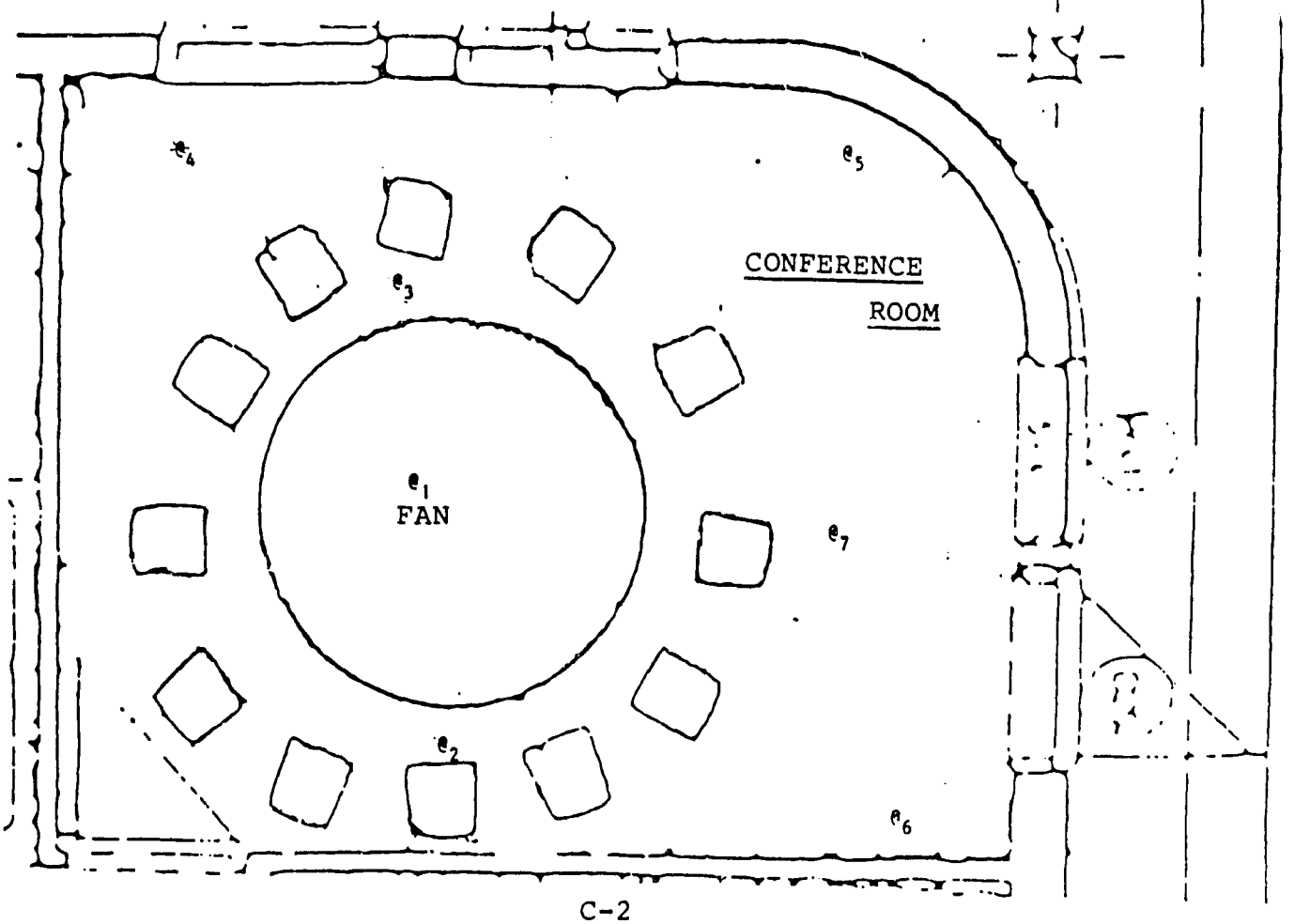
The importance of air movement for cooling in this building is primarily in summer, during the hot afternoons. Based on the likely indoor, dry-bulb temperature of 25° to 30° during such periods, the approximate cooling effect of this air movement would be as follows:

Cooling Effect (Deg C)

	Speed 1	Speed 2	Speed 3	Speed 4
Position 1	5.7	4.8	4.0	1.4
Position 2	2.7	1.4	1.8	0.9
Position 3	3.5	1.4	1.4	1.1
Position 4	2.2	1.8	1.4	1.4
Position 5	2.7	2.2	1.8	1.4
Position 6	1.4	3.1	1.4	1.4
Position 7	3.1	3.1	1.4	3.1

At high speed, there is no question of a significant cooling effect being accomplished. At the lower speeds, while the effect is less, it still appears to be adequate to provide noticeable improvement in comfort conditions.

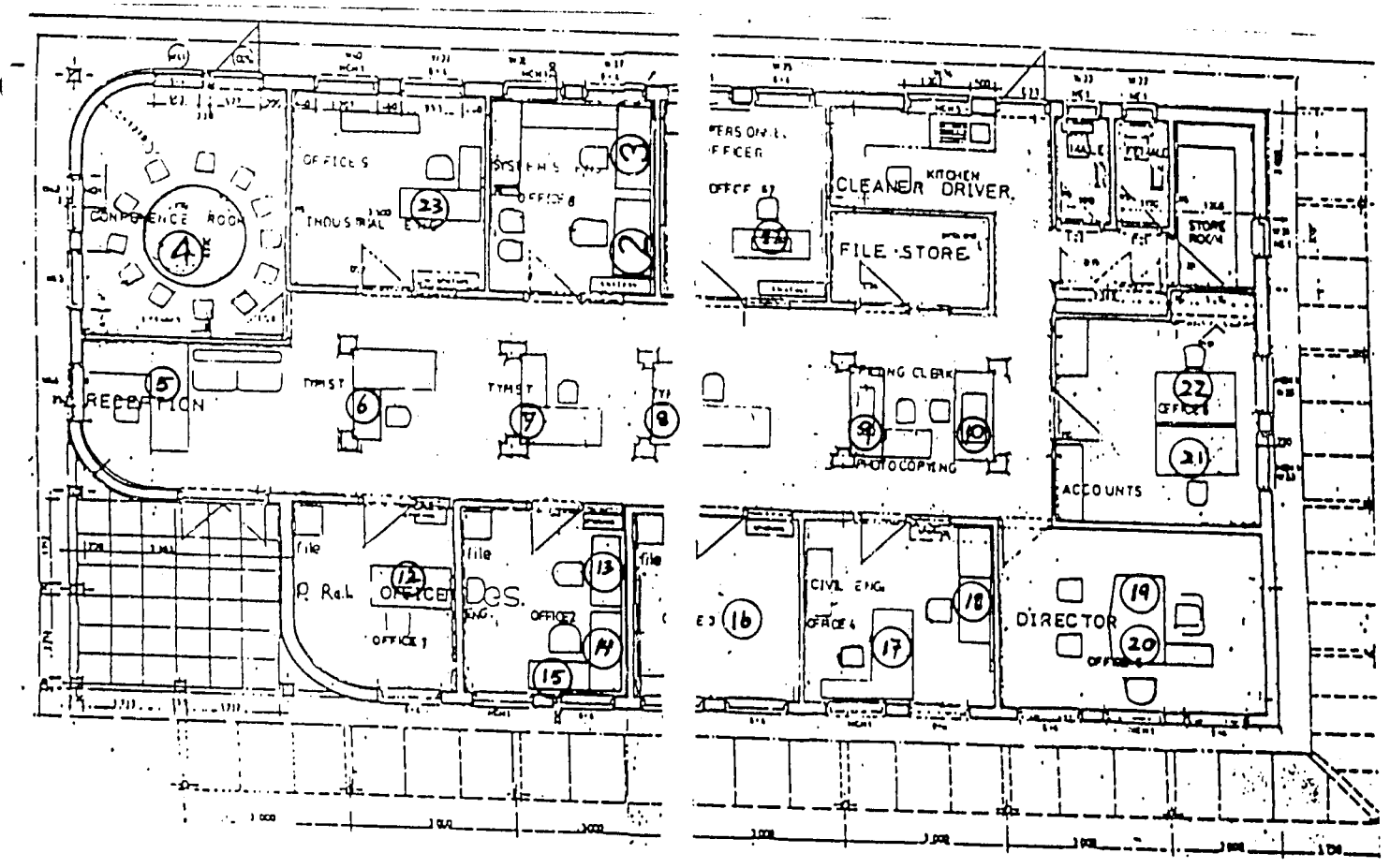
Position of electric fan with reference to furniture in room.



APPENDIX D

Test Measurements on Lighting Levels

In July of 1985, BTC staff conducted preliminary measurements of illumination levels at various locations inside the BTC office building. Measurements were made both with the electrical lighting on and off, at different times of day, on three different days. The locations of each measurement are shown on the floor plan of the office, below, followed by a table presenting the observed illumination levels.



MEASUREMENTS OF ILLUMINATION IN BTC BUILDING

USING LUX-HI TESTER 3421

TIME (HRS)	AVERAGE IRRADIANCE (W m^{-2})	DATE:		ILLUMINATION (LUX) AT POSITION																					
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10:10	580	25/07/85	Lights ON	520	520	[illegible]	[illegible]	[illegible]	900	900	920	900	700	550	720	620	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1100	1100	[illegible]	[illegible]
			Lights OFF	930	920	520	[illegible]	[illegible]	540	540	520	460	400	310	520	900	[illegible]	[illegible]	770	820	660	[illegible]	900	100	100
14:45	497	25/07/85	Lights ON	280	260	520	[illegible]	420	500	500	680	460	500	400	820	[illegible]	[illegible]	[illegible]	1100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			Lights OFF	155	195	360	195	360	200	470	420	280	300	[illegible]	750	[illegible]	[illegible]	[illegible]	280	[illegible]	660	[illegible]	1150	520	260
8:00	145	26/07/85	Lights ON	260	590	270	540	210	390	300	300	295	208	230	420	560	590	900	390	480	380	500	650	300	320
			Lights OFF	90	70	230	135	160	90	120	110	105	80	115	190	185	500	820	190	320	300	320	360	415	50
10:30	564	26/07/85	Lights ON	900	380	520	600	600	540	540	500	490	380	300	680	800	[illegible]	[illegible]	510	800	840	950	920	[illegible]	37[illegible]
			Lights OFF	185	160	350	340	540	230	360	350	320	240	185	410	620	[illegible]	[illegible]	460	640	740	700	[illegible]	700	1[illegible]
9:30	434	29/07/85	Lights ON	380	340	520	680	620	500	460	[illegible]	320	390	340	680	740	[illegible]	[illegible]	530	910	820	700	[illegible]	360	420
			Lights OFF	165	[illegible]	320	[illegible]	[illegible]	220	300	255	260	190	210	400	[illegible]	[illegible]	[illegible]	400	600	660	600	670	50	80
15:10	442	29/07/85	Lights ON	220 166	420	[illegible]	420	340	500	580	440	400	480	460	760	860	[illegible]	[illegible]	720	1200	990	[illegible]	950	460	680
			Lights OFF	160	180	340	410	300	340	280	420	420	380	270	460	660	[illegible]	[illegible]	450	910	660	[illegible]	820	[illegible]	500

Remarks: All measurements done at desk level at positions stated or shown in the plan.

APPENDIX E

CALPAS3 Model Inputs for the As-Built BTC Office

The following pages contain a listing of the program inputs for one of the many CALPAS3 simulation model runs of the BTC office building. This particular set of inputs is for the case of the as-built structure under winter operation.

```
Line
----    ---------------------------------------------------------------------
  1     *TITLE BTC   AS-BUILT (WINTER)
  2     SITE LAT=-24 LONG=-26 TZN=22 LOCATION=GABORONE
  3
  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     HOUT 2
  7
  8     *HOUSE *FLRAREA=2582.79 VOL=27357.14
  9     ROOF AREA=3706.45 AZM=0 TILT=0 UVAL=.045 ABSRP=.2
 10
 11     WALL NAME=N1 *AREA=380.64 *AZM=180 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 12     WALL NAME=N2 *AREA=72 *AZM=180 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 13     WALL NAME=N3 *AREA=44.1 *AZM=180 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 14     WALL NAME=E1 *AREA=197.8 *AZM=270 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 15     WALL NAME=E2 *AREA=108.6 *AZM=270 UVAL=.105 ABSRP=.55 INSIDE=EXWALL
 16     WALL NAME=W1 *AREA=322.6 *AZM=90 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 17     WALL NAME=S1 *AREA=498.9 *AZM=0 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 18     WALL NAME=S2 *AREA=44.1 *AZM=0 UVAL=.105 ABSRP=.65 INSIDE=EXWALL
 19
 20     SLAB *AREA=2582.79 *THKNS=4 *MATERIAL=CONC120 UDB=0.13
 21     INTWALL *AREA=5115.05 *THKNS=4.52 *MATERIAL=BRICKCMN
 22     EXWALL *THKNS=9.44 *MATERIAL=BRICKCMN
 23
 24     GLASS NAME=NL(HCH1) *AREA=18.27 *AZM=180 NGLZ=1 GLSTYP=3
 25      SGDISTWNTR SLB=.2 IW=.5 XW=.1
 26      SGDISTSMR SLB=.2 IW=.5 XW=.2
 27      SGFACTORS JANSGF=.95 FEBSGF=.95 MARSGF=.95 APRSGF=.95 MAYSGF=.8 &
 28       JUNSGF=.8 JULSGF=.8 AUGSGF=.8 SEPSGF=.95 OCTSGF=.95 NOVSGF=.95 DECSGF=
     C .95
 29      SHADING *WHEIGHT=1.7 *WWIDTH=10.72 OHDEPTH=1.63 OHWD=1.96 &
 30       OHLX=9.83 OHRX=9.83
 31     GLASS NAME=NL(6+4) *AREA=62.36 *AZM=180 NGLZ=1 GLSTYP=3
 32      SGDISTWNTR SLB=.2 IW=.5 XW=.1
 33      SGDISTSMR SLB=.2 IW=.5 XW=.2
 34      SGFACTORS JANSGF=.95 FEBSGF=.95 MARSGF=.95 APRSGF=.95 MAYSGF=.8 &
 35       JUNSGF=.8 JULSGF=.8 AUGSGF=.8 SEPSGF=.95 OCTSGF=.95 NOVSGF=.95 DECSGF=
     C .95
 36      SHADING *WHEIGHT=6.75 *WWIDTH=9.24 OHDEPTH=1.63 OHWD=1.96 &
 37       OHLX=9.83 OHRX=9.83
 38     GLASS NAME=NL(DOOR) *AREA=25.8 *AZM=180 NGLZ=1 GLSTYP=3
 39      SGDISTWNTR SLB=.5 IW=.2 XW=.1
 40      SGDISTSMR SLB=.5 IW=.2 XW=.1
 41      SHADING *WHEIGHT=5 *WWIDTH=5.16 OHDEPTH=9.83 OHLX=5.57 OHRX=16.39
 42     GLASS NAME=NH(HCH6) *AREA=54.83 *AZM=180 NGLZ=1 UVAL=.25 GLSTYP=5
 43      SGDISTWNTR XW=.8
 44      SGDISTSMR XW=.8
 45      SGFACTORS JANSGF=.1 FEBSGF=.1 MARSGF=.1 APRSGF=.1 MAYSGF=.1 &
 46       JUNSGF=.1 JULSGF=.1 AUGSGF=.1 SEPSGF=.1 OCTSGF=.1 NOVSGF=.1 DECSGF=.1
 47      SHADING *WHEIGHT=2.62 *WWIDTH=20.9 OHDEPTH=1.63 OHWD=.26 OHLX=9.83 &
 48       OHRX=9.83
 49     GLASS NAME=E(HCH1) *AREA=4.3 *AZM=270 NGLZ=1 GLSTYP=3
 50      SGDISTWNTR SLB=.4 IW=.4
 51      SGDISTSMR SLB=.4 IW=.4
 52      SGFACTORS JANSGF=.95 FEBSGF=.95 MARSGF=.95 APRSGF=.95 MAYSGF=1 &
 53       JUNSGF=1 JULSGF=1 AUGSGF=1 SEPSGF=.95 OCTSGF=.95 NOVSGF=.95 DECSGF=.95
```

```
BTC   AS-BUILT (WINTER)                                CALPAS3 V3.13  License: PC0215

GABORONE                                  Weather: GABARONE.BA3 (Gabarone BA MOD Shifted)

Line
----    ---------------------------------------------------------------------
  54     GLASS NAME=E(6+4) *AREA=20.43 *AZM=270 NGLZ=1 GLSTYP=3
  55      SGDISTWNTR SLB=.4 IW=.4
  56      SGDISTSMR SLB=.4 IW=.4
  57      SGFACTORS JANSGF=.95 FEBSGF=.95 MARSGF=.95 APRSGF=.95 MAYSGF=1 &
  58       JUNSGF=1 JULSGF=1 AUGSGF=1 SEPSGF=.95 OCTSGF=.95 NOVSGF=.95 DECSGF=.95
  59     GLASS NAME=W *AREA=12.9 *AZM=90 NGLZ=1 GLSTYP=3
  60      SGDISTWNTR SLB=.4 IW=.4
  61      SGDISTSMR SLB=.4 IW=.4
  62      SGFACTORS JANSGF=.95 FEBSGF=.95 MARSGF=.95 APRSGF=.95 MAYSGF=.8 &
  63       JUNSGF=.8 JULSGF=.8 AUGSGF=.8 SEPSGF=.95 OCTSGF=.95 NOVSGF=.95 DECSGF=
     C .95
  64      SHADING *WHEIGHT=1.7 *WWIDTH=7.54 OHDEPTH=1.63 OHLX=1.96 OHRX=9.83
  65     GLASS NAME=SL(HCH1) *AREA=1.3 *AZM=0 NGLZ=1 GLSTYP=3
  66      SGDISTWNTR SLB=.15 IW=.55
  67      SGDISTSMR SLB=.15 IW=.55
  68      SHADING *WHEIGHT=1.7 *WWIDTH=8.19 OHDEPTH=1.63 OHWD=1.96 OHLX=9.83 &
  69       OHRX=9.83
  70     GLASS NAME=SL(6+4) *AREA=41.93 *AZM=0 NGLZ=1 GLSTYP=3
  71      SGDISTWNTR SLB=.15 IW=.55
  72      SGDISTSMR SLB=.15 IW=.55
  73      SHADING *WHEIGHT=6.75 *WWIDTH=1.89 OHDEPTH=1.63 OHWD=1.96 OHLX=9.83 &
  74       OHRX=9.83
  75     GLASS NAME=SL(OTHR) *AREA=15.05 *AZM=0 NGLZ=1 GLSTYP=3
  76      SGDISTWNTR SLB=.1 IW=.6
  77      SGDISTSMR SLB=.1 IW=.6
  78      SHADING *WHEIGHT=2.62 *WWIDTH=5.73 OHDEPTH=1.63 OHWD=1.96 OHLX=9.83 &
  79       OHRX=9.83
  80     GLASS NAME=SH(HCH6) *AREA=54.83 *AZM=0 NGLZ=1 UVAL=.25 GLSTYP=5
  81      SGDISTWNTR XW=.8
  82      SGDISTSMR XW=.8
  83      SGFACTORS JANSGF=.1 FEBSGF=.1 MARSGF=.1 APRSGF=.1 MAYSGF=.1 &
  84       JUNSGF=.1 JULSGF=.1 AUGSGF=.1 SEPSGF=.1 OCTSGF=.1 NOVSGF=.1 DECSGF=.1
  85      SHADING *WHEIGHT=2.62 *WWIDTH=20.9 OHDEPTH=1.63 OHWD=.26 OHLX=9.83 &
  86       OHRX=9.83 FLDEPTH=.81 FRDEPTH=.81
  87
  88     INFIL ACBASE=0 ACTD=.0125 ACWIND=.375
  89     INTGAIN INTGAIN=29 SCHED=COM SLB=.2 IW=.4 XW=.1
  90     VENT *TYPE=NATURAL AINLET=160.21 AOUTLET=138.7 HDIFF=16.39 STACKEFF=.6 &
  91      AZMINLET=180 DIEFF=.2
  92     TSTATSWNTR THEAT=0 TDSRD=75.2 TCOOL=150
  93     TSTATSSMR THEAT=0 TDSRD=71.6 TCOOL=150
  94     PRINTDAILY JUL-01 JUL-31
  95     PRINTHOURLY JUL-18
  96     *END

    *** No input errors.

    *** Beginning simulation    22-JUN-85    14:49:09
House energy imbalance for MAY Net=-59.94 kBtu (0.0036)
House energy imbalance for JUN Net=-69.034 kBtu (0.0045)
House energy imbalance for AUG Net=105.365 kBtu (0.0071)

    *** Run complete.


Run: B:WINTER    001                                  22-JUN-85 14:47:35
```