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FENESTRATION DESIGN FOR DAYLIGHTING OF VOCATIONAL TRAINING CENTER CLASSROOMS

Prepared by:

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TABLE OF CONTENTS

Section	Page
Preface	i
I. Summary	1
A. Introduction	1
B. Design Goals	1
C. Recommendation Concerning Thermal Performance and Fenestration	1
II. Fenestration Design Options	2
A. Assumptions	2
B. Original Design	2
C. Design Variations	4
1. Reduced Glazing	4
2. Corner Windows	6
3. Increased Corner Glazing	6
D. Ventilation	9

PREFACE

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

I. SUMMARY

A. Introduction

This report summarizes the BRET project's analysis and recommendations concerning the size and location of windows for Vocational Training Center (VTC) classrooms and workrooms with dimensions similar to the "B-1" and "B-2" rooms shown in the sketch plan of August 24, 1984 from Mr. David Oldham of the Ministry of Works' Buildings Department. Areas that have other uses and/or different dimensions will require special consideration.

B. Design Goals

The BRET project understands that VTCs will provide adult vocational education throughout the year, and classrooms can be expected to be in use from 7:30 a.m. until seven or eight in the evening. The classes will utilize a traditional lecture format, with the instructor facing 16 students, seated at three rows of desks. The visual focus of the classrooms will be the instructor and blackboard, located in the center of the wall adjacent to the door. Horizontal visual tasks will include reading, note-taking and writing, while the vertical ones are reading information on the blackboard as well as seeing the instructor and other students without distraction. Modest access to a long view is also desirable. The classrooms should be reasonably comfortable on summer afternoons, presuming effective cross-ventilation and perhaps the use of ceiling fans. The rooms should also have enough thermal carryover from the previous day to be warm enough for the start of classes on winter mornings.

C. Recommendation Concerning Thermal Performance and Fenestration

Mr. Philip Niles, an ARD engineering consultant, made the primary recommendation regarding the thermal impact of classroom fenestration--overall, less glass was preferable in terms of providing a balance between summer and winter comfort. North-facing windows do help heat the classrooms on winter mornings, but adding glass (beyond the amount needed for daylight, view and ventilation) for the sole purpose of increasing solar heat gains is not warranted. VTC classrooms have a high rate of heat loss due to infiltration, uninsulated walls and the metal-frame, single-glazed windows. If enough windows were added to materially raise the indoor air temperature in winter for the beginning of classes the next morning, students would be subjected to glare from direct sunlight striking their desks.

II. FENESTRATION DESIGN OPTIONS

A. Assumptions

The analysis of fenestration design options proceeded on the general assumption that VTC classrooms should have as little glass as possible within the following limitations. First, on sunny days, the classrooms need to be fully daylit until an hour or so before sunset. "Fully daylit" means CIE illuminance level D, a minimum of 200 lux for noncritical visual tasks. Until recently, American school design standards called for uniform lighting to level E (500 to 1,000 lux), but current design practice varies illumination levels according to task difficulty and age. Given the fact that in this case, daylight levels will far exceed the minimum for most of the class sessions, it is reasonable to set a lower minimum than would be required for electric lights, where the output cannot be varied. For this reason, the minimum illumination level was based on the noncritical visual task for a classroom, taking notes while listening to a lecture.

Second, the windows should be operable and designed to direct air movement at the level of seated students. Third, direct sunlight on desks must be minimized to reduce glare from both sky and ground reflection in the field of view for students looking toward the blackboard. Fourth, the door should be located at the front of the classroom.

B. Original Design

The starting point for this investigation was the fenestration design of the sketch plan, which provided for continuous glazing 1.3 meters high on the north facade, 1.76 meters on the south side and a glazed door 2.8 meters tall with glass side panels. Thus, the glazing in the original design can be summarized as follows:

- 48 percent glazed area on the north wall,
- 75 percent glazed area on the south wall, and
- glazed area equal to 71 percent of the floor area.

Interior daylight levels for the original design were calculated using the "Daylite" calculation program. The results, along with a sketch of the fenestration configuration that was modeled, are reproduced in Figure 1 on the following page. (It should be noted that the glazed orientations are reversed on this calculation plot, but this error does not affect the results' validity because the sun is perpendicular to both glazed facades.) The calculation was made for a sun position which corresponds to a

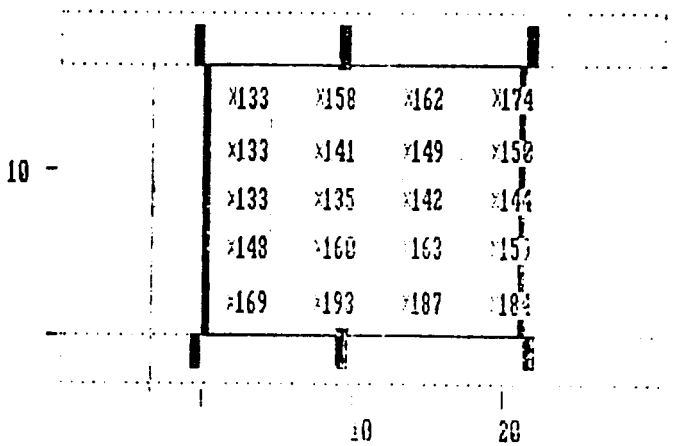
BUILDING NAME: Original
MONTH: 8 HOUR: 8

SKY CONDITION	ILLUMINATION (FootCandles) AVERAGE	MINIMUM	AT POINT	MAXIMUM	AT POINT
CLEAR	155.8	132.6	13	193.0	2
OVERCAST	117.0	99.4	9	157.9	20

STATION POINTS IN THE SUN

	SOLAR HEAT GAINS CLEAR (Btus)	OVERCAST
TOTAL:	927.2	427.6

FLOOR PLAN: Original
FEB at 16:00 Hours on a Clear Day
S Work Plane Height: 2.5



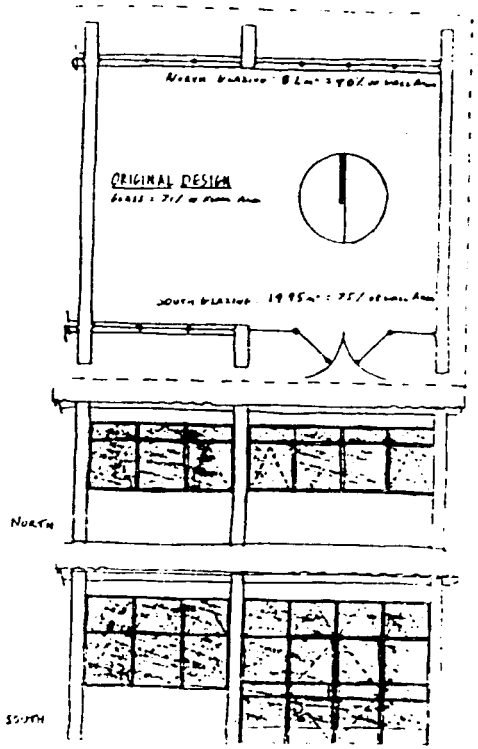


Figure 1. Original Design

February afternoon at four o'clock in Botswana. This time was chosen because the sun is relatively low in the sky (an altitude of 33°) and perpendicular to the classroom windows (a sun-window azimuth of 90°). Hence, interior daylighting is solely due to skylight and ground-reflected light.

The original design has a very large glazed area, relative to the room's size. Accordingly, the daylight levels are very high, exceeding 1,400 lux at all desk locations. As the sky condition tested represents the design minimum, the classroom is substantially over-lit, and occupants would experience uncomfortable solar gain and glare during much of the year. However, the lighting distribution is excellent, varying by less than 50 percent across the room. In general, observers only begin to notice variation in lighting distribution when it exceeds twice the minimum, unless their attention is called to the difference.

C. Design Variations

1. Reduced Glazing

The second configuration reduced the glazing in the original design by almost half, to a one-meter strip on the north wall and a 0.7-meter clerestory high on the south wall. In addition, the glazed door was reduced to a single panel at the edge of the wall. Figure 2 (on the next page) shows this configuration, and the glazing for this design can be summarized as follows:

- 37 percent glazed area on the north wall,
- 31 percent glazed area on the south wall, and
- a glazed area equivalent to 39 percent of the floor area.

The logic of this configuration is that the north glazing would provide daylight, view and some solar heating, while the south clerestory would illuminate the ceiling with ground-reflected light to provide acceptable daylighting. The resulting plot indicates that the quantity of daylight is sufficient (400 lux minimum), but variation in its distribution is excessive, exceeding four to one from south to north across the middle of the room. As a result, students seated near the south side of the classroom would likely perceive their area to be gloomy in comparison with the other side of the room, even though there is sufficient illumination for their tasks. Furthermore, the brightest part of the room, and thus its visual focus, would be the north side. Because the blackboard wall would be less bright, visual distraction toward the view would be inevitable.

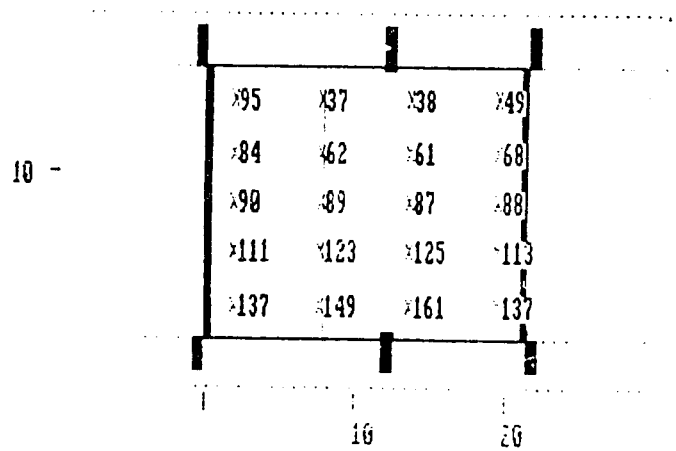
BUILDING NAME: S1m N.7m 1 Door
MONTH: 8 HOUR: 9

SKY CONDITION	AVERAGE	ILLUMINATION (Foot Candles) MINIMUM	AT POINT	MAXIMUM	AT POINT
CLEAR	95.2	37.3	19	161.4	3
OVERCAST	59.2	20.8	10	87.9	3

STATION POINTS IN THE SUN

	SOLAR HEAT GAINS CLEAR (Btus)	OVERCAST
TOTAL:	795.2	391.8

FLOOR PLAN: S1m N.7m 1 Door
FEB at 16:00 Hours on a Clear Day
S Work Plane Height: 2.5



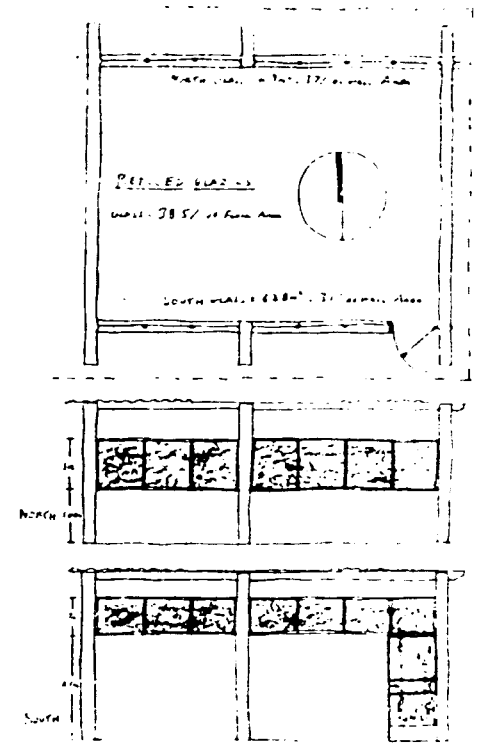


Figure 2. Reduced Glazing Option

2. Corner Windows

To improve lighting distribution in the classroom and further reduce glazing area, a minimum glass configuration with 0.9 meters of vertical glazing at the four corners of the room was tested (see Figure 3). The glazing for this design can be summarized as follows:

- 21 percent glazed area on the north wall,
- 24 percent glazed area on the south wall, and
- glazed area equal to 25 percent of the floor area.

Placing vertical glazing adjacent to a wall tends to help provide even illumination because the wall acts as a diffuse reflector. Other benefits of lighting the walls include making them the visual focus of the room and giving occupants the illusion of being in a larger, brighter room. For a school, one further advantage is the ability to control or restrict the view to the outside, thus reducing distractions while still maintaining some connection to the exterior environment. While the corner glazing option affords all these benefits, the amount of daylight it would provide is probably too low to meet the design minimum.

The Daylite calculation program has several limitations that make its results quite conservative for Botswana conditions. For instance, the program does not account for light entering the room by reflection from the sides of exterior fins or other buildings, and the important contribution of ground-reflected light may not be accurately modeled. For these reasons, the 140-lux minimum calculated for the corner glazing option is probably lower than actual illumination levels that would be found in a building of this type. On the other hand, classrooms may not be maintained well enough to keep their walls perfectly white. This design approach is quite sensitive to wall reflectance, which was assumed to be equivalent to clean white paint on the ceiling and walls above one meter (chair height) and a very dirty white (25 percent reflectance) below the one-meter level. The floor was assumed to be unpainted concrete. Since adequate daylight is important to the function of the classrooms, the use of somewhat larger windows would be prudent.

3. Increased Corner Glazing

This option is identical to the configuration just described, except that the width of the windows was increased 40 percent to 1.25 meters (see Figure 4). The glazed area is similar to that of the reduced glazing option, but the interior daylighting

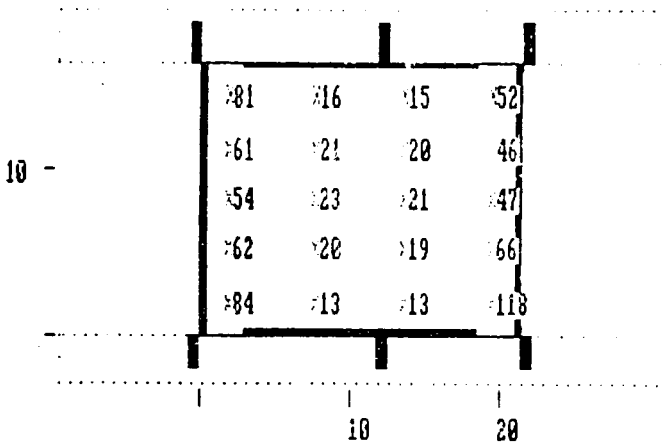
BUILDING NAME: .9 m V glz, 1 Door
MONTH: 8 HOUR: 8

SKY CONDITION	ILLUMINATION (Footcandles) AVERAGE	MINIMUM	AT POINT	MAXIMUM	AT POINT
CLEAR	42.5	12.7	3	118.3	4
OVERCAST	22.8	5.9	18	59.6	4

STATION POINTS IN THE SUN

	SOLAR HEAT GAINS CLEAR (Btus)	OVERCAST
TOTAL:	983.4	212.2

FLOOR PLAN: 9 V glz, 1 Door
F&B at 16:00 Hours on a Clear Day
S Work Plane Height: 2.5



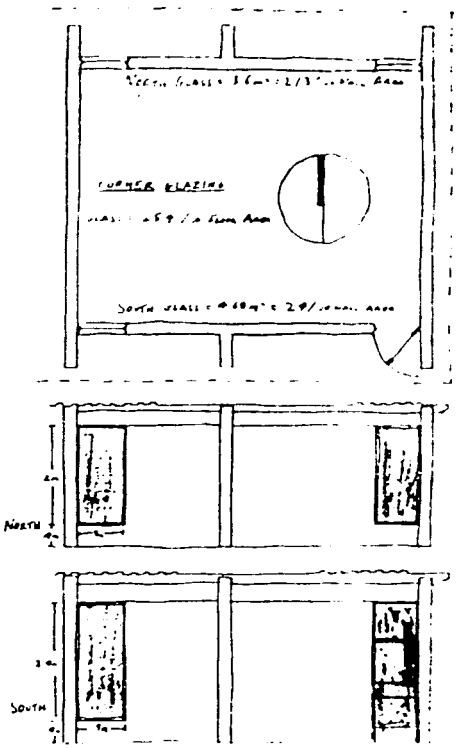


Figure 3. Corner Glazing

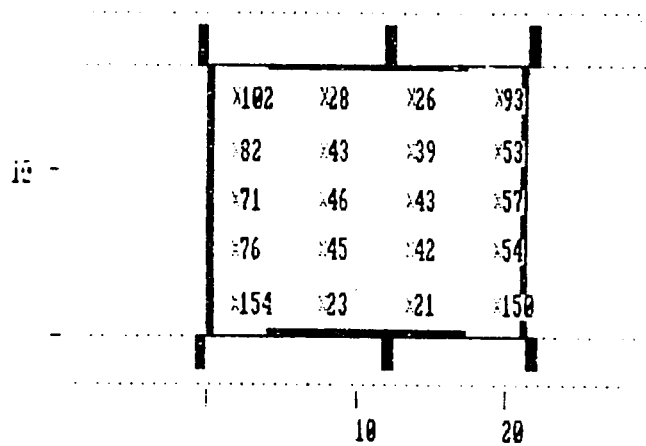
BUILDING NAME: 1.5m V glz 1 door
MONTH: 8 HOUR: 8

SKY CONDITION	ILLUMINATION (Foot-Candles) AVERAGE	MINIMUM	AT POINT	MAXIMUM	AT POINT
CLEAR	62.3	20.9	3	154.5	1
OVERCAST	36.8	12.5	18	84.0	20

STATION POINTS IN THE SUN

	SOLAR HEAT GAINS CLEAR (Btus)	OVERCAST (Btus)
TOTAL:	1292.9	279.7

FLOOR PLAN: 1.5m V glz 1 door
FEB at 1600 Hours on a Clear Day
Work Plane Height: 2.5



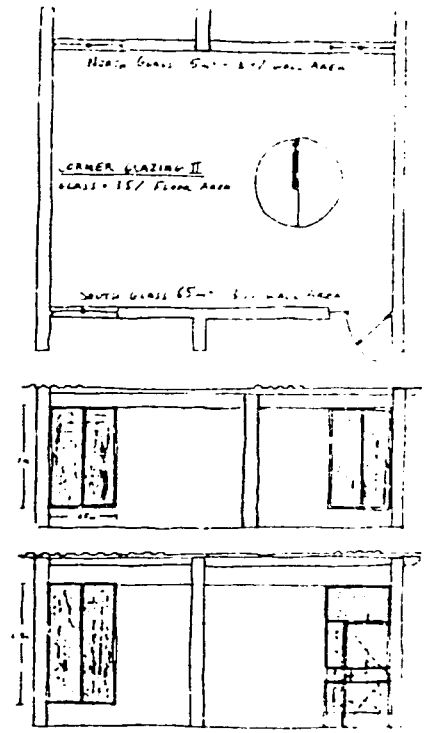


Figure 4. Increased Corner Glazing

performance shows substantial improvement. The glass in this design can be summarized as follows:

- 24 percent glazed area on the north wall,
- 33 percent glazed area on the south wall, and
- glazed area equal to 35 percent of the floor area.

This configuration or a similar one would meet the following design criteria:

- interior daylight levels that exceed 200 lux;
- an acceptable amount of variation in daylight levels across the middle of the room--two to one from north to center;
- the variation of light distribution from front to back in the middle of the room is also acceptable--1.95 to one; and
- the front and back walls are brighter than the desks and side walls.

D. Ventilation

For ventilation, the best type of window to use would be horizontal glass louvers. These windows allow the ventilating breeze to be directed either straight into the room for summer cooling or toward the ceiling on winter days when ventilation, but not cooling, is desired. Larger, horizontal, center-pivot windows would provide the same flexibility, but are somewhat more cumbersome.

For a substantial portion of school hours, there will be insufficient air movement in the classroom to provide any cooling. Two fans, one meter or larger in diameter, would provide sufficient air movement at all desk locations to maintain comfortable working conditions during the summer.